

THE EFFECTS OF DELAYED REINFORCEMENT AND A
RESPONSE-PRODUCED AUDITORY STIMULUS
ON THE ACQUISITION OF OPERANT BEHAVIOR IN RATS

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The present experiment examined the effects of different delays of food delivery with and without a response-produced auditory stimulus on the acquisition of a spatially defined operant in rats. The operant was breaking a photoelectric beam located near the ceiling at the rear of the experimental chamber. In five groups of experimentally naive rats, the effects on photobeam-break responses of two different reinforcement delays (4 s and 10 s) with and without a response-produced auditory stimulus were compared during eight 1-hr sessions. In one control group (0-s delay), an immediate (i.e., 0.25-s) reinforcement contingency was in effect and in another control group (no food), responses were measured in the absence of any reinforcement contingencies. Results showed that rates of acquisition and responding were higher with shorter reinforcement delays and when there was a response-produced auditory stimulus. These results extend previous findings showing that neither direct shaping nor immediate reinforcement is necessary for operant conditioning. However, the present results demonstrate that the speed and extent of conditioning depends on the temporal relation between the response and the reinforcer. The findings are discussed in terms of a conditioned reinforcement analysis of the stimuli produced by operant responses.

In his book, *The Behavior of Organisms*, B. F. Skinner (1938) described an experimental manipulation in which he compared the effects of 1-, 2-, 3-, and 4-s delays of reinforcement on the acquisition of lever pressing in rats. Although he reported that "the rates of acceleration are all comparable with those obtained with simultaneous reinforcement" (p. 73), the cumulative records showed that with only one exception at the 4-s delay, the rates of acquisition at the 2-, 3-, and 4-s

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delays were retarded when compared with simultaneous reinforcement. Skinner attributed these "slight irregularities" to procedural difficulties, namely, the problems inherent in what researchers today would speak of as resetting versus nonresetting delays (see Wilkenfield, Nickel, Blakely, & Poling, 1992). Until recently, only a few experiments (e.g., Harker, 1956; Logan, 1952; Seward & Weldon, 1953) had investigated the effects of delayed reinforcement on discrete responding such as lever pressing. Although these experiments reportedly showed that even short delays can retard or prevent acquisition, recent researchers (e.g., Critchfield & Lattal, 1993; Lattal & Gleeson, 1990) have criticized these early studies for their vague descriptions of training procedures and for not controlling for the possibility of immediate conditioned reinforcement. Interestingly, systematic examination of the effects of delayed reinforcement on the acquisition of discrete responding had not been carried out until very recently (e.g., Critchfield & Lattal, 1993; Dickinson, Watt, & Griffiths, 1992; Lattal & Gleeson, 1990; Wilkenfield et al., 1992). These studies have shown that operant conditioning can occur in rats with reinforcer delays of up to 32 s (64 s in the Dickinson et al., 1992 study) without direct shaping, although the rates of acquisition and the final rates of responding at longer reinforcer delays were relatively low.

In the study by Lattal and Gleeson (1990, Experiment 6), three rats were exposed to a tandem FR 1 DRO 30-s (i.e., resetting) schedule of food delivery. The results showed that lever pressing developed in each rat in the first session, although the session was quite long; the first three sessions ranged from 60 min to 304 min each. Even though lever pressing developed in all rats, the rates of responding across sessions were quite low, at around one response per minute. Despite the relatively slow rates of acquisition and low response rates, the authors concluded that "the remarkable and significant findings are that naive animals learn to bar press in the absence of any response-produced stimulus change when the consequence reliably occurs 30-s after the response that produced it" (p. 35). Of course, even though the experimenters did not explicitly program stimulus changes correlated with responding, it is nevertheless likely that some stimuli were produced by responding, for example, the auditory, tactile, and proprioceptive stimuli produced by the lever press response, and that these stimulus changes functioned as conditioned reinforcers for the operative response (Critchfield & Lattal, 1993; Lattal & Gleeson, 1990).

Critchfield and Lattal (1993) examined the possible role of these response-produced stimuli in two experiments that replicated Experiment 6 by Lattal and Gleeson (1990) and extended it by controlling for exteroceptive stimuli associated with pressing a lever. Instead of lever pressing Critchfield and Lattal used a spatially defined operant, namely, breaking a photoelectric cell beam that was located near the ceiling at the rear of the experimental chamber. According to Critchfield and Lattal, this operant "was of interest because it did not involve contact by the animal with a mechanical device such as a lever

and was thus free of the auditory feedback (and perhaps other types as well) an operandum can produce" (p. 374). In Experiment 1, a tandem FR 1 DRO 30-sec schedule was programmed, however for one group of rats, the tone group, the response that met the FR 1 requirement produced a 0.75-s tone. Results showed that, although the "photobeam-break response" was acquired in all rats, acquisition was faster and responding was quicker to stabilize in the tone group than in the no-tone group suggesting that the presence of the auditory stimulus correlated with responding was responsible for quicker response acquisition and maintenance in that group.

Two of the recent studies on response acquisition conducted parametric examinations of the effects of reinforcement delay (Dickinson et al., 1992; Wilkenfield et al., 1992). In the Wilkenfield et al. (1992) study the effects of reinforcer delays of 0 s, 4 s, 8 s, 16 s, and 32 s on lever pressing by rats with both resetting and nonresetting delays were compared across one 8-hr session. The results of the resetting delay condition are of most interest because the experiments by Critchfield and Lattal (1993) and Lattal and Gleeson (1990) also used resetting reinforcer delays. The findings of Wilkenfield et al. (1992) are consistent with those of Critchfield and Lattal (1993) and Lattal and Gleeson (1990) in that response acquisition occurred at all delay values but, at least for the first 100 minutes, the rate of response acquisition was inversely related to the delay values.

Although the studies by Lattal and Gleeson (1990), Critchfield and Lattal (1993), Dickinson et al. (1992), and Wilkenfield et al. (1992) leave no doubt that operant conditioning can occur with delays of food delivery by as much as 32 s and in the absence of explicit shaping, none of these studies conducted a parametric examination of the role of delay of food delivery in combination with an explicitly programmed response-produced stimulus. The present experiment replicated the studies by Lattal and Gleeson (1990, Experiment 6), Critchfield and Lattal (1993), and Wilkenfield et al. (1992, resetting delay procedure) by combining various features of each so that a parametric examination of the role of reinforcer delay with response-produced feedback could be undertaken. Specifically, acquisition of a spatially defined operant in rats as a function of food delivery delayed by 0.25 s, 4 s, and 10 s both with and without a response-produced auditory stimulus was examined. As in the Critchfield and Lattal (1993) experiment, the operant was breaking a photoelectric cell beam located near the ceiling at the rear of the experimental chamber. Although all of the aforementioned studies used a delay value of either 30 s (Critchfield & Lattal, 1993; Lattal & Gleeson, 1990) or 32 s (Dickinson et al., 1992; Wilkenfield et al., 1992), a comparable delay value was not included in the present experiment because extremely low rates of acquisition and responding were observed at much shorter (i.e., 10-s) delays. Although a resetting delay contingency has built-in suppressive effects on responding (Wilkenfield et al., 1992), a resetting-delay procedure was used in the present

experiment to make comparisons with the experiments by Lattal and Gleeson (1990, Experiment 6), Critchfield and Gleeson (1993), and Wilkenfield et al. (1992, resetting delay procedure) easier.

Method

Subjects

Twenty four experimentally naive female Sprague-Dawley rats were used as subjects. Rats were approximately 120 days old at the time of the experiment. They were maintained at approximately 80% of their free-feeding weights and were housed individually with unlimited access to water. When necessary, stable body weights were maintained by supplementing within-session food intake with rodent chow immediately following each session.

Apparatus

Four Lafayette Instrument Company Model 8000 operant conditioning chambers, each 21.5 cm wide by 28.5 cm long by 27 cm high, were used. The grid floor of each chamber was approximately 5.5 cm above the bottom tray. Each chamber was situated inside a ventilated, sound-attenuated enclosure. The work panel of each chamber was equipped with one response lever 7 cm above the floor that required a force of approximately 0.25 N to operate. Although lever presses were recorded they had no programmed consequences. A feeder dish, into which 45-mg Noyes food pellets could be delivered, was located to the right of the response lever and 2.5 cm above the floor. Each chamber was equipped with a photobeam light source and detector (Med Associates, Inc., Model DIG-723 S1) located 7 cm from the ceiling and 2 cm from the rear wall. Constant ambient illumination was provided during experimental sessions by a 7-W white bulb (house light) located on the rear wall of the enclosure. An exhaust fan was used to provide ventilation and to mask extraneous noise. Programming of experimental events and recording of data were controlled by a Mitac 286[®] computer equipped with interfacing and software (MED-PC[®], Version 2) supplied by Med Associates, Inc.

Procedure

Magazine training. Magazine training was identical for all rats. Each rat was placed into the illuminated experimental chamber with approximately four food pellets in the food cup. When the pellets were consumed, a variable-time (VT) 40-s schedule of food delivery began. The magazine training session lasted until 40 food pellets had been delivered. All rats were given two such magazine training sessions usually on successive days.

Control groups. According to Wilkenfield et al. (1992), in order to evaluate adequately the effects of delayed reinforcement on response acquisition, it is necessary to compare responding under delay

procedures with that under two control procedures. In one control procedure no food is delivered. In the other control procedure food immediately follows each response, that is, a fixed-ratio (FR) 1 schedule is arranged. Therefore, the present study incorporated both types of control procedures. In the first control group, the no-food group, rates of photobeam-break responding were measured for 4 rats in the absence of any food delivery. In the second control group, the 0-s delay group, food delivery was programmed to occur immediately (0.25 sec) after each photobeam-break response in 4 rats.

Experimental groups. Experimental groups also consisted of 4 rats each. Rats in the 4-s and the 10-s delay groups were exposed to tandem fixed-ratio (FR) 1 not-responding-greater-than t ($\bar{R} > t$) schedule of reinforcement where t equaled 4 s and 10 s respectively. For rats in the 4-s and 10-s tone groups, the response that met the FR 1 requirement of the tandem schedule produced a 0.25-s tone by a sonalert. Any further photobeam-break responses that occurred during the delay were counted but did not produce the tone. For all groups, the first photobeam-break response after food delivery started a timer. When the programmed delay interval timed out, a food pellet was delivered. Each response during the delay interval restarted the timer.

Results

For each session, operative photobeam-break responses, photobeam-break responses during the delay interval, total number of lever presses, and number of food deliveries were recorded. For the first session only, photobeam-break responses were recorded in 2-min bins. Figure 1 shows cumulative photobeam-break responses during the first session averaged for subjects in each group, and Figure 2 shows the same data for individual subjects in each group. Photobeam-break responses during the first session are presented graphically because, with the possible exception of rats in the 10-s delay group, response acquisition was observed to occur in all rats during this period (see also Wilkenfield et al., 1992). By the end of the first session, photobeam-break responding occurred in all groups except the no-food group, although there was some responding by rats in the no-food group during the early part of the session. This can be seen more clearly in Figure 2 (top left panel). All rats in the no-food group began the session with some responding, but by about the 20th bin, responding had ceased. Perhaps this greater-than-zero level of photobeam-break responding in the no-food group represented the activating effects of food delivery or the adventitious reinforcement of standing up in the rear of the chamber during the two magazine training sessions. In either case, as would be expected, such behavior diminished once food ceased being presented. In general, rates of responding increased in all groups relative to rates in the no-food group indicating acquisition (i.e., operant conditioning) of photobeam-breaking. However, the rates of acquisition were significantly

different for each group. The slopes of the lines in Figure 1 indicate that rats in the 0-s delay group evidenced the fastest response acquisition, although for at least two rats responding ceased by the end of the session, one at around the 10th bin and the other at around the 20th bin (see Figure 2, top right panel). This cessation in responding may have been caused by satiation. This is supported by the observation that when rats in the 0-s delay group were removed from the chamber at the end of the first (and each subsequent) session, the experimenter found that food pellets had accumulated in the food dish. Moreover, responding by the 0-s delay rats resumed again at fairly high levels in the second session (see Figure 3, top right panel). Although the 0-s delay group evidenced the quickest acquisition, by the end of the first session the 4-s tone group approached the 0-s delay group. When the two 4-s groups (4-s delay and 4-s tone) are compared and the two 10-s groups (10-s delay and 10-s tone) are compared, it is clear that the respective tone groups demonstrated both faster response acquisition and higher overall levels of responding. Again, these differences can be more clearly seen by comparing the respective individual group graphs in Figure 2 (middle and bottom panels respectively). Interestingly, although there is evidence of consistent, albeit small, increases in response rates for the 10-s delay group, the curve for that group is still substantially lower than that of the no-food group (see Figure 1). In general, then, group mean data from the first session indicate that operant conditioning occurred in all groups except the no-food group, but that the rates of acquisition were substantially higher for the delay groups with the correlated auditory stimulus.

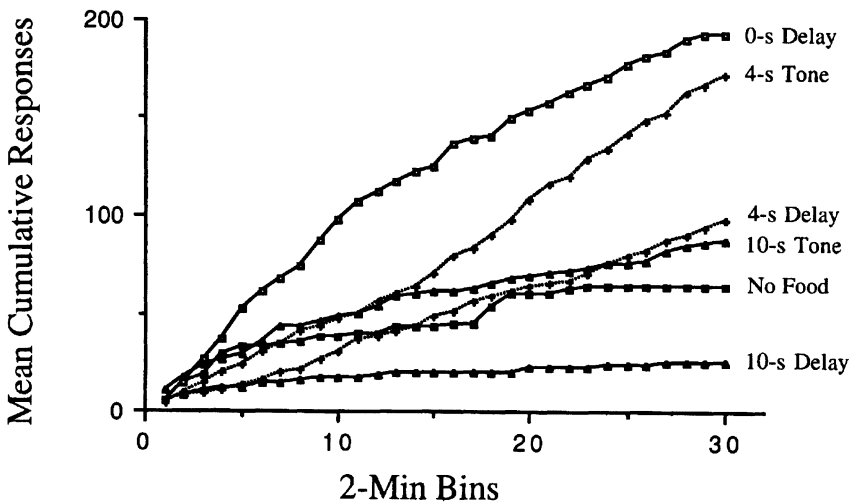


Figure 1. Mean cumulative photobeam-break responses for all groups in the 2-min bins during the first session.

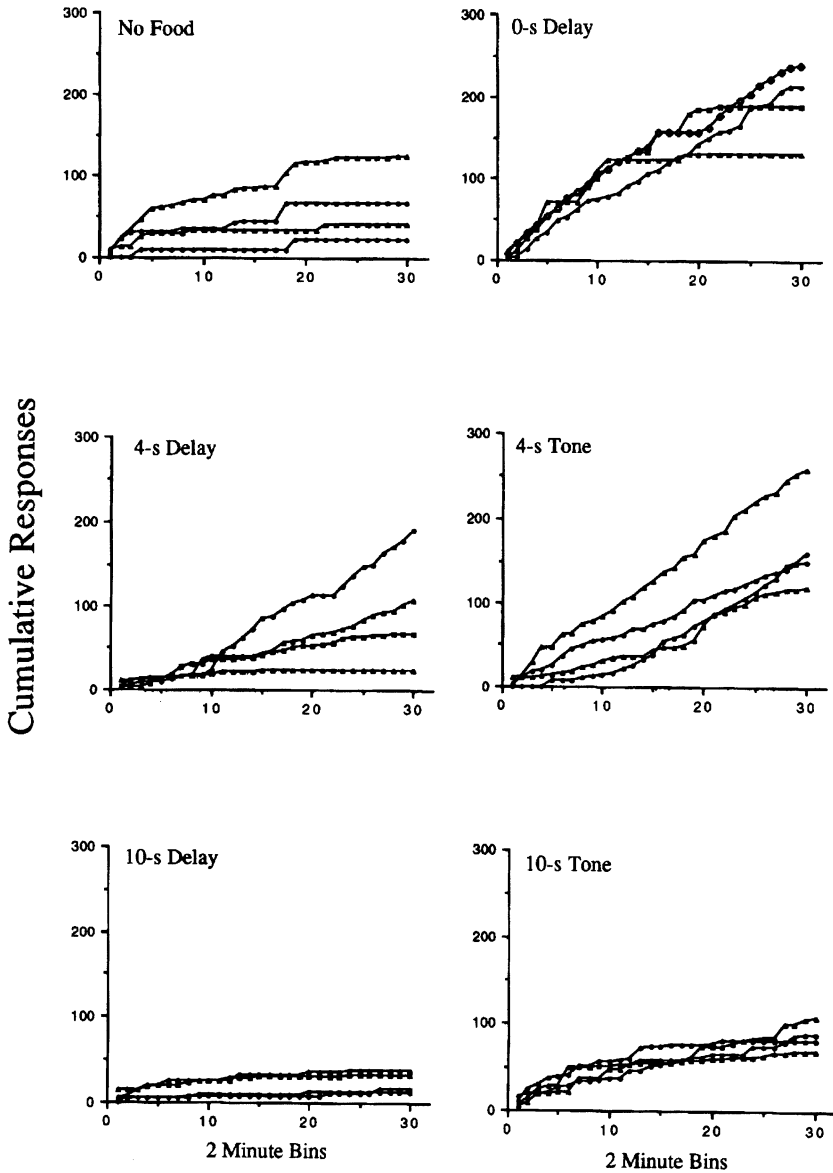


Figure 2. Cumulative photobeam-break responses in the 2-min bins during the first session for individual subjects in each group.

As was already noted, data from the first session are presented because response acquisition (i.e., operant conditioning of the photobeam-break response) was observed to occur during that session.

However, most of the recent studies on response acquisition with delayed reinforcement in rats have used rather long sessions, especially at the beginning of the experiment. For example, although Lattal and Gleeson (1990, Experiments 5 and 6) conducted daily 1-hr sessions, as previously stated, the first two or three sessions were approximately 60 to 300 min in duration. In the Critchfield and Lattal (1993) study, daily sessions were also conducted, although in their experiment each session lasted for 6 hours or until 60 reinforcers had been delivered. Critchfield and Lattal reported, however, that it was not uncommon to reach the 6-hr maximum during the early sessions. Finally, Wilkenfield et al. (1992) used one extended (8-hr) session. In the present experiment, the effects of independent variables were also measured over 8 hours, however the 8 hours were broken up into 1-hr sessions conducted usually over 8 consecutive days. Thus, Figures 3 and 4 are presented to show rates of responding across all eight 1-hr sessions. Response rates were calculated by dividing the total number of photobeam-break responses (i.e., those that met the FR 1 requirement + those that occurred during the delay) by 60 min. Figure 3 shows response rates across all 8 sessions for individual subjects in each group. As expected, rats in the no-food group responded at or below 1 response per minute. Rats in this group continued to respond at very low rates probably because, being food deprived, they were active, and that activity included moving around the chamber and occasionally rearing up on their hind legs and, sometimes, breaking the photoelectric beam. Also, it appears that response rates for 3 rats in the 0-s delay group reached their asymptote during the first session. For rats in the 4-s and 10-s groups, response rates were more variable. However, the data show that response rates continued to increase across all eight sessions more for rats in the 4-s and 10-s tone groups than for rats in the 4-s and 10-s delay groups. This can be seen more clearly in Figure 4 which shows the same data but averaged for each group. Interestingly, rates of responding increased over the 8 sessions more for the 10-s tone group than for the 4-s delay group.

Taken together, data from the present experiment show that rates of acquisition as measured only during the first session were highest for the 0-s group followed in order by the 4-s tone, 4-s delay, 10-s tone, no-food, and 10-s delay groups. When mean response rates are viewed over all 8 sessions (Figure 4), however, the picture changes. Excluding the 0-s delay group, which was included in this experiment as a control group, the data presented in Figure 4 show clearly that by the 7th session, response rates in the two tone groups exceeded response rates by the two delay (i.e., non-tone) groups. It is not clear what effect extended sessions would have had on these differences. There are other differences between the 4-s and 10-s delay and tone groups which are evident by looking at the number of reinforcers earned per session. Table 1 shows the number of reinforcers per session for subjects in all reinforcement groups. For obvious reasons, the 0-s delay group earned

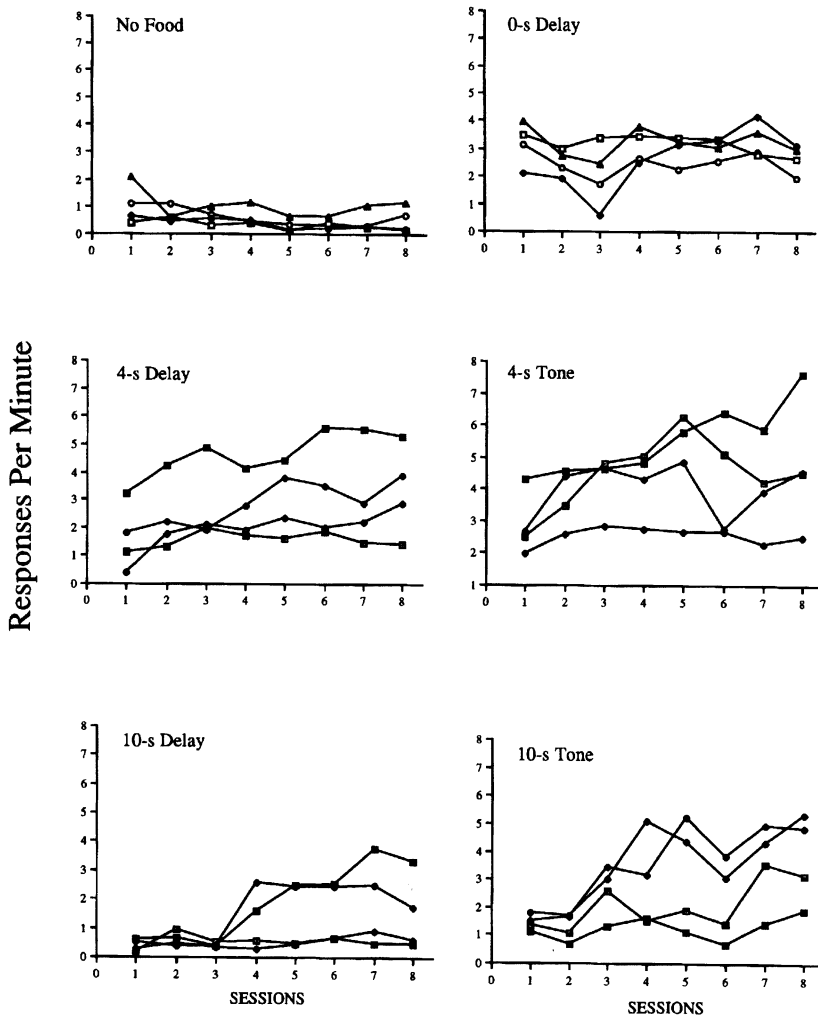


Figure 3. Photobeam-break responses per minute across all sessions of the experiment for individual subjects in each group.

the most reinforcers, even though, as already stated, often not all of the food pellets were consumed. Moreover, the maximum number of reinforcers earned occurred in the first session for all but one rat. Again, the more significant differences occurred between the two 4-s groups and between the two 10-s groups. The mean number of reinforcers earned in the 4-s and 10-s tone groups was approximately twice the number earned in the 4-s and 10-s delay groups. In addition, in all groups except for the 0-s delay group, the maximum number of reinforcers occurred after the first session and in some cases not until sessions later in the experiment.

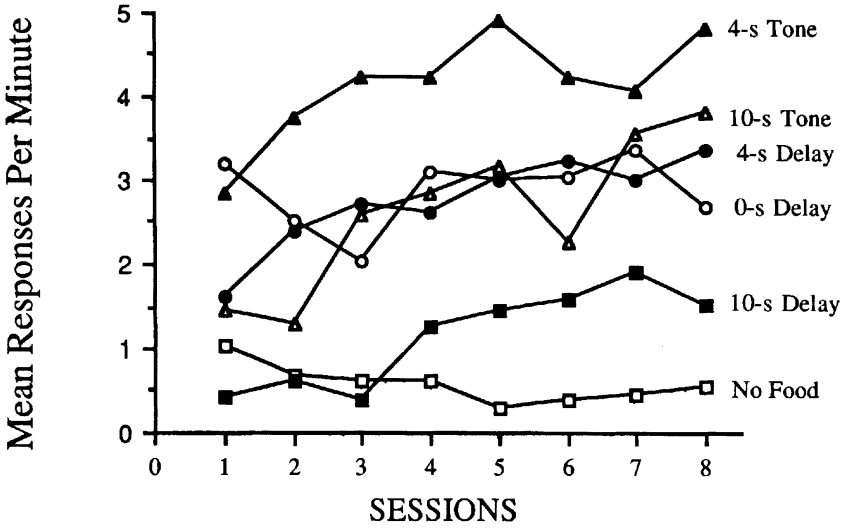


Figure 4. Photobeam-break responses per minute across all sessions of the experiment for all groups.

Table 1

Number of Reinforcers per Session for Subjects in All Reinforcement Groups

		Sessions								Sum	Mean	SD
		1	2	3	4	5	6	7	8			
0-s Delay	S1	188	140	104	160	136	153	174	118	1173	147	28
	S2	209	180	202	206	204	200	169	158			
	S3	239	166	148	227	195	181	215	178			
	S4	128	116	35	151	187	197	251	188			
		<u>1253</u>								<u>157</u>	65	
		5503								172		
4-s Delay	S1	25	39	68	79	79	93	77	71	531	66	23
	S2	33	67	54	80	122	119	89	107			
	S3	58	96	118	111	126	156	138	146			
	S4	8	48	78	74	75	73	72	88			
		<u>516</u>								<u>65</u>	25	
		2667								83		
4-s Tone	S1	79	141	184	172	217	194	183	195	1365	171	43
	S2	103	121	136	159	216	203	230	262			
	S3	112	161	170	184	187	127	190	194			
	S4	43	76	103	110	96	103	98	93			
		<u>722</u>								<u>90</u>	22	
		4842								151		
10-s Delay	S1	3	18	13	12	13	21	15	15	110	14	5
	S2	7	10	8	9	9	14	20	19			
	S3	9	11	10	32	46	72	85	91			
	S4	8	4	7	39	48	66	79	61			
		<u>312</u>								<u>39</u>	30	
		874								27		
10-s Tone	S1	26	16	43	32	44	44	82	93	380	48	27
	S2	34	37	77	75	105	81	91	97			
	S3	16	21	21	24	19	18	34	38			
	S4	29	36	57	85	88	72	103	105			
		<u>575</u>								<u>72</u>	29	
		1743								54		

Critchfield and Lattal (1993) have stated that the frequency of responses during the resetting delay interval might be taken as a possible index of response efficiency, that is, the lower the frequency of responses, the more efficient the behavior. In the present experiment, substantial photobeam-break responding occurred during the delay interval for rats in the experimental groups. Table 2 shows the frequency of photobeam-break responses during the delay interval for rats in the experimental groups. The mean number of delay responses was similar for all groups except the 10-s delay group which suggests that, contrary to the Critchfield and Lattal (1993) study in which fewer delay responses occurred in the tone group, the correlated tone in the present study either did not result in more efficient responding (i.e., in fewer delay responses) or other factors worked against this response efficiency. For example, it is possible that, in the 4-s delay group and the 4-s and 10-s tone groups, the temporal relation of the reinforcer to operative responses was responsible for both short-term (i.e., during the delay interval) as well as long-term increases in responding. Thus, the delivery of food for the 4-s delay group might have been close enough in time to function as a strong enough unconditioned reinforcer. For rats in the 4-s and 10-s tone groups the tone, which was temporally contiguous with the operative response, functioned as a conditioned reinforcer. These temporal relations between photobeam-break responding and consequences might explain why delay responding by rats in those groups continued to occur during the delay interval even when such

Table 2

Frequency of Photobeam-Break Responses During the Actual Delay per Session for Subjects in All Delay Groups

		Sessions								Sum	Mean	SD
		1	2	3	4	5	6	7	8			
4-s Delay	S1	43	41	47	21	18	18	10	13	211	26	15
	S2	74	65	60	86	104	92	84	124	689	86	21
	S3	133	158	172	135	139	179	195	171	1282	160	23
	S4	16	57	48	41	65	46	59	84	<u>416</u>	<u>52</u>	20
										2598	81	
4-s Tone	S1	70	67	104	129	159	112	70	76	787	98	34
	S2	156	154	144	130	131	179	123	195	1212	152	25
	S3	48	103	108	76	105	37	46	81	604	76	29
	S4	75	79	66	54	64	56	38	57	<u>489</u>	<u>61</u>	13
										3092	97	
10-s Delay	S1	10	39	17	21	14	18	13	13	145	18	9
	S2	10	17	10	9	16	25	33	19	139	17	8
	S3	28	28	12	64	102	80	138	108	560	70	45
	S4	24	18	15	114	98	80	71	41	<u>461</u>	<u>58</u>	38
										1305	41	
10-s Tone	S1	56	49	111	57	70	41	131	95	610	76	32
	S2	55	63	131	114	209	148	205	193	1118	140	61
	S3	52	19	59	72	49	24	50	75	400	50	20
	S4	78	67	124	221	173	110	155	215	<u>1143</u>	<u>143</u>	58
										3271	102	

responses ultimately delayed food delivery. For rats in the 10-s delay group, operative responses were separated from food delivery by significantly longer delays which might account for the lower number of delay responses in that group. Taken together the results from Tables 1 and 2 indicate that rats in the tone groups earned more reinforcers than those in the non-tone groups, but, rats in the tone groups also produced more photobeam-break responses during the resetting delay intervals than their counterparts in the non-tone groups. Both of these effects may be explained by the strong conditioned reinforcing effects of the tone.

Even though lever pressing produced no programmed consequences, some lever pressing did occur in all rats. Table 3 shows the frequency of lever presses for subjects in all groups. In general, the frequency of lever pressing was higher during the earlier sessions, perhaps reflecting some carry-over effect from the magazine training condition during which lever presses might have been adventitiously

Table 3

Frequency of Lever Presses per Session for Subjects in All Groups

		Sessions								Sum	Mean	SD
		1	2	3	4	5	6	7	8			
No Food	S1	26	27	4	1	2	0	0	2	62	8	12
	S2	1	2	3	9	0	0	1	0	16	2	3
	S3	55	9	22	44	12	12	5	5	164	21	19
	S4	16	4	4	9	3	3	2	2	<u>43</u>	5	5
										285	9	
0-s Delay	S1	7	9	6	8	2	10	6	4	52	7	3
	S2	12	5	4	4	4	2	3	1	35	4	3
	S3	11	0	3	0	1	2	0	2	19	2	4
	S4	3	2	1	1	0	3	0	2	<u>12</u>	<u>2</u>	1
										118	4	
4-s Delay	S1	17	2	0	1	1	0	0	0	21	3	6
	S2	11	1	0	4	0	1	16	5	38	5	6
	S3	16	3	5	9	9	1	5	3	51	6	5
	S4	0	0	0	0	0	0	1	0	<u>1</u>	<u>0</u>	0
										111	3	
4-s Tone	S1	121	17	6	2	2	6	0	6	160	20	41
	S2	42	4	1	5	1	2	2	2	59	7	14
	S3	3	5	5	3	0	1	0	3	20	3	2
	S4	22	13	0	1	1	1	0	2	<u>40</u>	<u>5</u>	8
										279	9	
10-s Delay	S1	8	86	36	12	8	8	2	2	162	20	29
	S2	40	21	11	15	5	5	7	6	110	14	12
	S3	3	20	31	16	6	5	2	1	84	11	11
	S4	28	7	5	5	7	4	6	2	<u>64</u>	<u>8</u>	8
										420	13	
10-s Tone	S1	50	35	30	4	5	4	4	4	136	17	19
	S2	19	6	10	1	5	5	9	9	64	8	5
	S3	20	5	5	5	4	0	1	3	43	5	6
	S4	0	0	6	0	4	3	0	6	<u>19</u>	<u>2</u>	3
										262	8	

reinforced. Perhaps for this reason substantial lever pressing occurred in the no-food group although the frequency of lever pressing declined across the eight sessions. Also, very little lever pressing would be expected to occur in the 0-s delay group which, in fact, was observed. Lever pressing in the experimental groups was mixed. More lever pressing occurred in the 4-s tone group than in the 4-s delay group although as can be seen in Table 3, most of this difference occurred in the first session and, therefore, may have represented the carry-over effect mentioned above. In fact, for most rats in the experimental groups, with the possible exception of the 10-s delay group, more lever pressing was observed during the first session than during subsequent sessions.

Discussion

The present study combined various features of recent studies that have examined the acquisition of operant behavior with delayed reinforcement. As in Dickinson et al. (1992) and Wilkenfield et al. (1992), the present experiment consisted of a parametric examination of reinforcement delay. Specifically, delays of 0.25 s, 4 s, and 10 s were investigated. However, like Critchfield and Lattal (1993), instead of a discrete response, a spatially defined operant was used. The present findings are consistent with recent reports that behavior can be operantly conditioned with delays of reinforcement and in the absence of direct shaping. They also confirm the results of the Wilkenfield et al. (1992) study by showing that food deprivation to 80% of free-feeding weights is sufficient for response acquisition under these conditions. Perhaps more importantly, the present results demonstrate that the speed and extent of conditioning is a function of the temporal relation between the response and its consequence. Whereas other studies have emphasized the conclusion that reinforcement need not immediately follow responses for acquisition to occur (Critchfield & Lattal, 1993; Dickinson et al., 1992; Lattal & Gleeson, 1990; Wilkenfield et al., 1992), the emphasis of the present report is on the importance of temporal contiguity between responses and reinforcers in operant conditioning. For example, even though response acquisition was observed with reinforcer delays of 4 s and 10 s, the rates of acquisition and responding in those two groups were substantially lower than those for the 0-s delay group. In fact, rates of responding were even lower in the 10-s delay group than rates of responding in the no-food group, although part of this difference could be the rate-decreasing effects of the DRO schedule in the experimental groups. Even so, rates in the 10-s delay group increased slowly over the eight sessions of the experiment. Indeed, similar decrements in rate of acquisition and responding at longer delays were also reported by Critchfield and Lattal (1993), Dickinson et al. (1992), Lattal and Gleeson (1990), and Wilkenfield et al. (1992, resetting delay condition). Decremental effects of reinforcement delays have also been found when un signaled nonresetting reinforcer delays were imposed on responding

by pigeons maintained under variable-interval (VI) 60-s schedules of reinforcement (Schaal & Branch, 1988). The critical question, then, raised by the present findings as well as those of other recent reports on the effects of reinforcement delay on response acquisition is not whether operant conditioning can occur at relatively long delays, but rather what variables contribute to response acquisition at any delay. The debate about the role of temporal contiguity between response and reinforcer may therefore be recast in terms of the variables that influence conditioning, regardless of the delay (see Williams, Preston, & de Kervor, 1990).

Some of the variables that may affect rates of acquisition and responding of discrete responses, such as lever pressing, are the stimuli (e.g., proprioceptive, auditory, and tactile) that are associated with the response (Critchfield & Lattal, 1993; Lattal & Gleeson, 1990), that is, the immediate stimulus consequences of responding. This possibility was tested in the present experiment as well as in the experiments by Critchfield and Lattal (1993) by using a spatially defined operant—breaking a photoelectric beam—and by comparing acquisition of this operant both with and without a discrete stimulus change (tone) occurring immediately (0.25 s and 0.75 s respectively) after each operative response. In both studies, the presence of an immediate response-produced tone resulted in both faster acquisition and higher rates of responding than conditions without the tone. Again, similar results have been found with pigeons responding under VI schedules of reinforcement (Schaal & Branch, 1988). For example, after Schaal and Branch (1988) demonstrated decremental effects of reinforcer delays of 1, 3, or 9 s, they found that the introduction of a brief stimulus change (key lit red for 0.5 s) quickly returned rates to near the level maintained by immediate reinforcement. Even though a spatially defined operant controls for some of the possible response-produced stimulus changes, as Critchfield and Lattal point out, even a spatially defined operant is not without some response-produced stimulus consequences that may be differentially related to reinforcer delivery. For example, breaking the photoelectric beam in both studies required that the animal rear up on its hind legs near the back of the chamber. Even though individual responses probably did not produce any auditory feedback, they did result in visual, proprioceptive, and even tactile changes. The latter occurred frequently when the rats extended their paws forward to maintain balance and touched the rear wall of the chamber. The possibility of these unintended response-produced stimulus changes notwithstanding, the results of the present experiment suggest that the introduction of the tone immediately contingent on photobeam-break responses was responsible for the faster acquisition and higher overall response rates.

Some researchers have explained the facilitative effects of such interposed stimuli in terms of the marking hypothesis (e.g., Lieberman Davidson, & Thomas, 1985; Lieberman, McIntosh, & Thomas, 1979).

This hypothesis suggests that the inclusion of a stimulus change immediately after each response “directs attention to the preceding response, thereby marking it in memory” (Lieberman et al., 1985, p. 611). Such an explanation, however, simply describes the effect and uses the description as the explanation. In other words, there is no evidence of the memory or the attention directed to the response except for the facilitative effects of the stimulus on the response. Moreover, even though there appears to be evidence for the marking hypothesis, in some cases the facts can be explained more parsimoniously in terms of known behavioral principles (Williams, 1991).

The most obvious explanation of the effects of the signal in signaled delay of reinforcement experiments using known behavioral principles is in terms of conditioned reinforcement. Using a two-choice conditional discrimination, Williams (1991) compared the marking and conditioned reinforcement explanations of the effects of stimuli (e.g., a tone) by interposing such stimuli in delay-of-reinforcement intervals of 3, 6, or 12 s. In the marking condition, both correct and incorrect choice responses were followed by a brief tone even though only correct choice responses produced food, whereas in the conditioned reinforcement condition the tone followed only correct choice responses. Moreover, conditioned reinforcement conditions were divided into those with a brief tone, that is, the tone occurred at the beginning of the interval and lasted for only 0.5 s or 1.0 s, and those with a tone that extended throughout the duration of the delay interval. A no-signal condition was included as a control condition. A marking interpretation would predict that because the presumed conditioned reinforcement value of the tone is equated for both correct and incorrect choice responses, any facilitative effect of the tone on correct responses is caused by the “marking” effects of the tone. A conditioned reinforcement interpretation, in contrast, would predict facilitative effects of the tone only on correct responses, that is, those that produce food. The dependent measure in Williams’ (1991) study was trials to criterion to acquire the conditional discrimination. The results showed that compared to the no-signal condition only the conditioned reinforcement conditions significantly reduced the number of trials to criterion. Moreover, Williams found no significant differences between the two conditioned reinforcement conditions, that is, those with the brief vs extended tone. In addition, the results of Williams’ (1991) experiment showed that the number of trials to criterion increased with the delay value. This finding is consistent with the present findings that, relative to the 0-s delay group, rates of acquisition of the photobeam-break response were substantially lower with increases in the delay value.

Thus, based on the findings by Williams (1991) that support a conditioned-reinforcement interpretation, it seems appropriate to interpret the effects of the tone on the acquisition of photobeam-break responding in the present study in terms of its conditioned reinforcing value. However, even if we accept the interpretation that the tone in the present study functioned as a conditioned reinforcer, which would,

incidentally, strengthen a temporal contiguity position (see Spence, 1947), we would have to explain how such conditioned reinforcing effects can be endowed when the tone was never temporally contiguous with food delivery. One possible explanation was addressed by Schaal and Branch (1990). Like Williams (1991), they compared the effects of a brief signal and those of one that lasted the duration of the delay interval. They found that the brief signal was as effective a conditioned reinforcer as the long signal, but only when the animal experienced the long signal first. When the brief signal occurred before the long signal it was much less effective. These results may also explain why the brief tone in the Williams (1991) study was as effective as the long duration tone, namely, all subjects experienced the long duration tone before the brief tone. According to Williams (1991, p. 268), "The apparent reason for the effect of order of presentation is that signals continue to be effective conditioned reinforcers after their initial pairing with the food reinforcement, despite continued training in which they are temporally separated from the food." Although such an interpretation is reasonable, the results of the present study (and of Critchfield & Lattal, 1993) remain puzzling. The brief 0.25-s tone in the present experiment apparently functioned as an effective conditioned reinforcer as was evidenced by the significant differences between the groups with and without the response-produced tone. However, unlike the Williams (1991) or Schaal and Branch (1990) studies, the brief tone was never preceded by a longer tone that was temporally contiguous with the food. In fact the tone was never closer than 4 s from the delivery of food.

Perhaps we can make sense of these apparently conflicting results by focusing not on the temporal delay between the operative response and the reinforcer, but rather on the temporal delay between the stimuli produced by the response and the reinforcer. In other words, perhaps the delay of reinforcement gradient observed in the present experiment as well as the experiments by Critchfield and Lattal (1993), Lattal and Gleason (1990), and Wilkenfield et al. (1992) is not a delay of response-reinforcement gradient at all but rather a delay of stimulus-reinforcer gradient. For example, even though facilitative effects of the tone were observed in both the 4-s and 10-s tone groups, rates of acquisition and responding in the 10-s tone group never approached those in the 4-s tone group. Even though the tone occurred immediately after each operative response in both groups, the time between the occurrence of the tone and the delivery of food was greater in the 10-s tone group. Although the present experiment did not test this possibility there is evidence from other studies that supports this respondent-conditioning interpretation of the conditioned-reinforcing function of the tone (e.g., Schaal & Branch, 1988, 1990). For example, Schaal and Branch (1990) examined the relation between the duration of a signal for delay and rates of key pecking by pigeons. In one component of a multiple (mult) VI 60-s schedule a brief (0.5-s) signal which began a 27-s delay interval was gradually increased in duration, whereas in a second component of

the mult schedule the signal was initially 27 s in duration (i.e., it lasted the duration of the delay interval) and was then gradually shortened. Results showed that response rates were an increasing function of the duration of the signal. Moreover, as the delay-signal duration decreased, response rates at specific durations were higher than at identical durations when the delay-signal duration increased. Finally, and perhaps most relevant to the present experiment, when shorter delay signals were introduced abruptly (vs gradually) after they had already occurred during the entire delay interval, response rates were higher than under comparable conditions when the delay signal was introduced gradually. In the present study the longest delay interval was 10 s and the results showed that even when the 10-s interval is signaled by a brief tone, the facilitative effects of the tone were less than comparable effects of the tone on responding at the 4-s delay interval. When Schaal and Branch (1988) lengthened the briefly signaled delay interval from 9 s to 27 s, they found substantial decreases in response rates by pigeons responding under VI 60-s schedules of reinforcement. Taken together, these findings support the suggestion that it might be the temporal relation between the signal and food that was responsible for the stronger conditioned reinforcing value of the signal (Schaal & Branch, 1990). In the future, researchers might replicate the Schaal and Branch (1990) experiments by comparing long- and short-duration signals on response acquisition using a spatially defined operant as in the present experiment.

Finally, another variable that may influence the rate of acquisition is the amount of time the organism spends in the experimental chamber. As was previously stated, in recent studies that examined the effects of reinforcer delay on response acquisition, the initial sessions during which response acquisition was first observed were quite long (e.g., Critchfield & Lattal, 1993; Lattal & Gleeson, 1990; Wilkenfield et al., 1992). In the present study response acquisition was observed in all subjects within the first session, although at the longer delays acquisition continued in subsequent sessions. It thus appears that session length, or time in the experimental apparatus, is an important variable in assessing the effects of reinforcer delays on operant conditioning. Of course, because time is a construct, it cannot be the time per se that is the critical variable, but rather what transpires in the chamber. Some recent evidence suggests that response acquisition is influenced not only by the strength of the relationship between the target response and reinforcement but also between all other responses and reinforcement. In other words, not only does the target response produce consequences (i.e., food), but all other responses fail to produce the same consequence. For example, Dickinson et al. (1992) demonstrated that rats who spent 30 min in the experimental chamber prior to being exposed to the reinforcement contingencies showed acquisition of bar pressing with 64-s reinforcer delays whereas as rats who spent no time in the chamber prior to the introduction of the reinforcement contingencies did not evidence any acquisition of bar pressing at the 64-s

delay. Based on the discussion of conditioned reinforcement above, we can venture to say that the stimuli produced by responding are correlated either with reinforcing consequences, such as food, or not. In unsignaled conditions response acquisition may take a long time because responses that produce reinforcers are competing initially with responses that do not (see Williams et al., 1990). Thus, the time to establish the stimuli produced by the operative response as effective conditioned reinforcers should be directly proportional to the duration of the response-reinforcer delay. The results of the present experiment as well as those of Critchfield and Lattal (1993) suggest that introducing a discrete stimulus change (e.g., a tone or a light) immediately after the response should facilitate this process by decreasing the time to acquisition.

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