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ACQUISITION OF LEVER-PRESS RESPONDING IN RATS WITH DELAYED REINFORCEMENT: A COMPARISON OF THREE PROCEDURES

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The present study examined the acquisition of lever pressing in rats under three procedures in which food delivery was delayed by 4, 8, and 16 seconds relative to the response. Under the nonresetting delay procedure, food followed the response selected for reinforcement after a specified interval elapsed; responses during this interval had no programmed effect. Under the resetting procedure, the response selected for reinforcement initiated an interval to food delivery that was reset by each subsequent response. Under the stacked delay procedure, every response programmed delivery of food *t* seconds after its occurrence. Two control groups were studied, one that received food immediately after each lever press and another that never received food. With the exception of the group that did not receive food, responding was established with every procedure at every delay value without autoshaping or shaping. Although responding was established under the resetting delay procedure, response rates were generally not as high as under the other two procedures. These findings support the results of other recent investigations in demonstrating that a response not previously reinforced can be brought to strength by delayed reinforcement in the absence of explicit training.

Key words: response acquisition, delayed reinforcement, lever press, rats

In a recent study, Lattal and Gleeson (1990) showed that discrete responses can be acquired with delayed and unsignaled reinforcement. Prior to their study, attempts to demonstrate this outcome either arranged an immediate consequence for responding or failed to provide critical procedural details (e.g., Harker, 1956; Logan, 1952; Seward & Weldon, 1953; Skinner, 1938). Neither of these problems was evident in the work of Lattal and Gleeson, who convincingly demonstrated the acquisition of key pecks in pigeons and lever presses in rats when delayed and unsignaled food deliveries were the consequences of these types of behavior. Neither shaping nor autoshaping was arranged, but responding nonetheless occurred and was maintained (albeit at low rates in many conditions) under both resetting and nonresetting delay procedures. This did not occur in the absence of a response–food dependency (i.e., when food was not delivered or was delivered independently of responding).

Response acquisition occurs when behavior not previously established as operant is demonstrably strengthened (i.e., increased in rate of occurrence) by its consequences. To evaluate adequately the effects of delayed reinforcement on response acquisition, it appears necessary to compare responding under delay procedures to responding under two control procedures. In one, there is no response–reinforcer dependency (e.g., no food delivery or response-independent food delivery is arranged); in the other, the reinforcer immediately follows the response (i.e., a fixed-ratio [FR] 1 schedule is arranged). If more responding occurs under a delay procedure than under the former control procedure, there is evidence of response acquisition. Comparing responding under the delay procedure to responding under the latter control procedure provides a means of evaluating the *relative* effectiveness of delayed reinforcement in establishing behavior. For example, one could attempt to ascertain whether the value of the delay affected the rate of acquisition. Although simple in principle, such comparisons are fraught with difficulty.

Consider a nonresetting delay procedure. Under this procedure, the first occurrence of

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the specified response initiates a delay interval. Food delivery occurs when the delay interval ends, and responses during the delay interval have no programmed consequences. This arrangement differs from an FR 1 schedule with immediate reinforcement not only in imposing a delay but in failing to ensure a direct relation between rate of responding and rate of reinforcement. Moreover, the nonresetting delay procedure permits responses to occur closer in time to the reinforcer than the nominal delay value. Although responses during a delay interval do not produce a reinforcer, they are nonetheless followed by it, and the time from their occurrence to reinforcer delivery inevitably is shorter than the nominal delay. Even when average obtained delays are substantial, obtained delays can be highly variable across responses, and some delays can be quite short. All of these considerations complicate the analysis of delay value as a determinant of acquisition.

By having each response during the delay interval reset the delay, the resetting delay procedure ensures that obtained and nominal delays are equal. But this procedure does not ensure a direct relation between rate of responding and rate of reinforcement. In fact, if interresponse times are shorter than the delay value, increasing response rate decreases reinforcement rate. Moreover, the resetting contingency itself affects behavior. When imposed for established (i.e., previously reinforced) operants, resetting delay procedures generate lower response rates than do nonresetting delay procedures at the same nominal delay value (e.g., Dews, 1960).

A third delay procedure is comparable to an FR 1 schedule with immediate reinforcement in that it ensures a direct relation between rate of responding and rate of reinforcement. In this procedure, hereafter termed *stacked delay,* each response programs reinforcer delivery after a specified interval elapses. This occurs even if the response is emitted during a delay interval initiated by a previous response. With this arrangement, as with the nonresetting delay procedure, obtained delays can be variable, quite short, and different from nominal values. Because the stacked delay procedure ensures a direct relation between rate of responding and rate of reinforcement and also permits obtained delays to be shorter than programmed delays, this procedure might engender more rapid response acquisition than resetting or nonresetting delay procedures do. This possibility has not been examined.

Obviously, there is no single procedure that provides an uncontaminated assay of the effects of delayed reinforcement on the acquisition of discrete responses in a free-operant arrangement. Perhaps for this reason, the topic has been largely ignored. The purpose of the present study was to extend the work of Lattal and Gleeson (1990) by examining response acquisition under a delayed reinforcement procedure not used by those authors (i.e., the stacked delay procedure), comparing three different delay procedures (resetting, nonresetting, and stacked), and providing a parametric assessment of delay duration as a factor in acquisition under each of those procedures. Rats were used as subjects, and a single 8-hr session was arranged for each animal.

METHOD

Subjects

One hundred eight experimentally naive 90-day-old male Sprague-Dawley rats were used as subjects. They were maintained at 80% of their free-feeding weights and were individually housed with unlimited access to water in a constantly illuminated colony area.

Apparatus

Three Plexiglas and aluminum operant conditioning chambers, each 12 cm wide by 20 cm long by 15 cm high, were used. The right side wall (work panel) of each chamber was equipped with two response levers, approximately 3 cm apart and 7.5 cm above the floor, and an automatic food dispenser that delivered 45 mg Noyes food pellets into a tray centered on the front wall, approximately 4.5 cm above the floor. Constant ambient illumination was provided during experimental sessions by a 7-W white bulb (houselight) located on the left wall. An exhaust fan provided ventilation and masked extraneous noise. The levers could be operated by a downward force of approximately 0.20 N. Microswitch operation provided auditory feedback when either lever was pressed. During magazine training, subjects were denied access to the levers by a grating fashioned of flexible hardware cloth that was fitted over the levers. The left lever in each chamber remained inoperative throughout all experiments. Programming of experimental events and recording of data were controlled by a PDP-8/A® computer equipped with interfacing and software (SUPERSKED®) supplied by State Systems, Inc.

Procedure

Magazine training. Magazine training was the same for all rats. Each subject was initially placed in a chamber with a wire grating installed over the work panel, preventing access to the levers. The houselight was then illuminated and a variable-time 60-s schedule of food presentation was implemented for 60 min. Because the subjects could not touch the levers during magazine training, there was no concern that food presentations would strengthen lever pressing. Magazine training sessions were conducted from 6 to 7 p.m.

Nonresetting delay procedure. Under all procedures, 24 hr after magazine training was completed, the wire grating was removed from the work panel and each of the subjects was returned to the chamber for an 8-hr test session (from 7 p.m. to 3 a.m.). The chamber was illuminated throughout this period. Under the nonresetting delay procedure, a tandem FR 1 fixed-time (FT) t-s schedule of food delivery was arranged for presses of the right lever. Under this schedule, the first depression of the right lever and each subsequent first press of the right lever after food delivery initiated the FT interval, which, when exhausted, resulted in the delivery of food. Right-lever presses that occurred when the FT component was in effect had no programmed consequences, nor did responses at any time on the left lever. Three FT values, 4, 8, and 16 s, were arranged. Nine rats, selected at random, were exposed to each FT value.

Resetting delay procedure. Under this procedure, a tandem FR 1 not-responding-greater-than t ($\bar{R} > t$) schedule of food delivery was programmed for presses on the right lever. Under this schedule, the first right-lever press initiated a delay of 4, 8, 16, or 32 s, after which a food pellet was presented. Any right-lever response that occurred during a delay restarted the delay interval. Left-lever responses were always without programmed consequences. Nine randomly selected rats were exposed to each delay value. The 32-s delay was imposed under the resetting procedure in anticipation of further research examining the maximum delay at which lever pressing would be acquired.

Stacked delay procedure. Under this procedure, a schedule of food delivery was implemented wherein every response on the right lever initiated a fixed period of time which, when exhausted, resulted in delivery of a food pellet. The stacked delay procedure differed from the nonresetting delay in that each and every right-lever press initiated an FT interval that terminated with food delivery, whereas under the nonresetting delay procedure right-lever presses when an FT interval (i.e., delay) was in effect had no programmed consequences. For example, if the delay was 16 s and responses occurred 5, 13, and 56 s into the session, food would be delivered 21, 29, and 72 s into the session under the stacked delay procedure (i.e., 16 s after the occurrence of each response). In contrast, with the same distribution of responses under the nonresetting delay procedure, food would be delivered 21 and 72 s into the session (the second response, emitted during the delay interval initiated by the first response, would not produce food). Under both procedures, left-lever presses were always without programmed consequences. Delays of 4, 8, and 16 s were examined under the stacked procedure. Nine randomly selected rats were exposed to each delay.

Control procedures. For reasons discussed in the introduction, 9 randomly selected rats were exposed to conditions under which food was never delivered. Nine other randomly selected rats were exposed to conditions under which food immediately followed each press of the right lever (i.e., these animals were exposed to an FR 1 schedule). Left-lever presses had no programmed consequences for all control subjects.

RESULTS

For each rat, responses on the operative (i.e., right) lever were recorded in 5-min bins across the entire 8-hr session. Obtained delays on the operative lever during the first 100 min of the session and for the session as a whole, food deliveries for the entire session, and total number of responses on the inoperative lever were also recorded. To facilitate exposition of these data, results for each procedure are presented

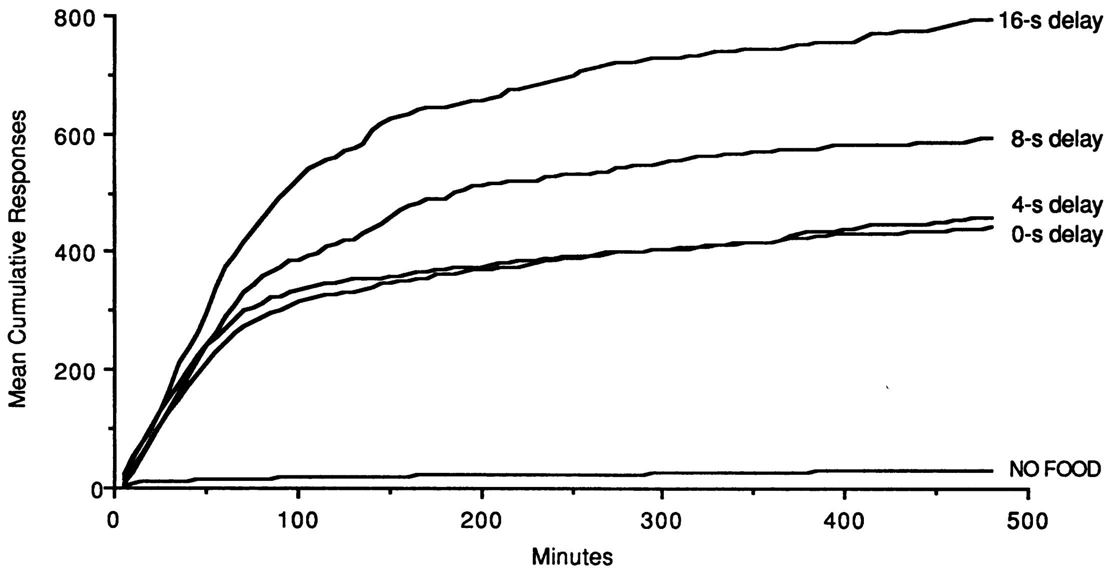

Fig. 1. Mean cumulative responses on the operative lever across the 8-hr session for rats exposed to 4-, 8-, and 16-s nonresetting delays. Data are also presented for rats that did not receive food and for rats that received food immediately after each press of the operative (i.e., right) lever. Nine rats were exposed to each condition, and data were recorded in 5-min bins.

separately, after which results are compared across the three procedures. Although operative-lever data for the entire session are presented, operative-lever data for the first 100 min are emphasized because responding characteristically was acquired (i.e., obviously increased in rate relative to levels evident in no-food controls) during this period.

Nonresetting delay. Figure 1 shows mean cumulative responses across the 8-hr session for groups of rats exposed to 4-, 8-, and 16-s delays under the nonresetting procedure. Also shown are the mean cumulative responses for subjects in the no-food and 0-s delay (immediate reinforcement) groups. Substantial lever pressing occurred in all groups except the one that did not receive food. Rats that did not receive food pressed the left and right levers at comparable rates. This indicates the absence of response bias for either lever.

When group means are considered, the most lever pressing occurred in subjects exposed to the 16-s delay. Subjects exposed to the 8-s delay responded (on average) at higher levels than the 4-s delay subjects. The curve for the latter group of subjects is very similar to that of the 0-s delay group.

Figure 2 shows cumulative responses across the first 100 min of the 8-hr session for subjects exposed to 0-, 4-, 8-, and 16-s delays. Mean group performance and data for individual subjects are presented. At all delay values, lever pressing increased across time for each subject. In general, the longer the programmed delay, the greater the variability of responding across subjects. When data for individual rats are considered (Figure 2 and Table 1), there was considerable overlap in the overall levels of operative-lever responding across the three delay values.

Table 1 shows the averaged obtained delays on the operative lever, response rates on the operative and inoperative levers, and the number of food deliveries for each subject exposed to the nonresetting delay procedure. Comparable data for control subjects appear in Table 2. Under all procedures, subjects were tested in squads of 3 each day due to the length of the sessions and the availability of equipment. Each subject was assigned an identification number based on three characteristics: the delay value to which it was exposed, whether it was in the first, second, or third squad tested at a particular delay, and whether it was tested in Chamber 0, 1, or 3. Subject 4-3-0 NR, for example, was exposed to the 4-s nonresetting delay in the third squad of 3 subjects in Chamber 0.

At each delay value, the average obtained delays were shorter than the programmed val-

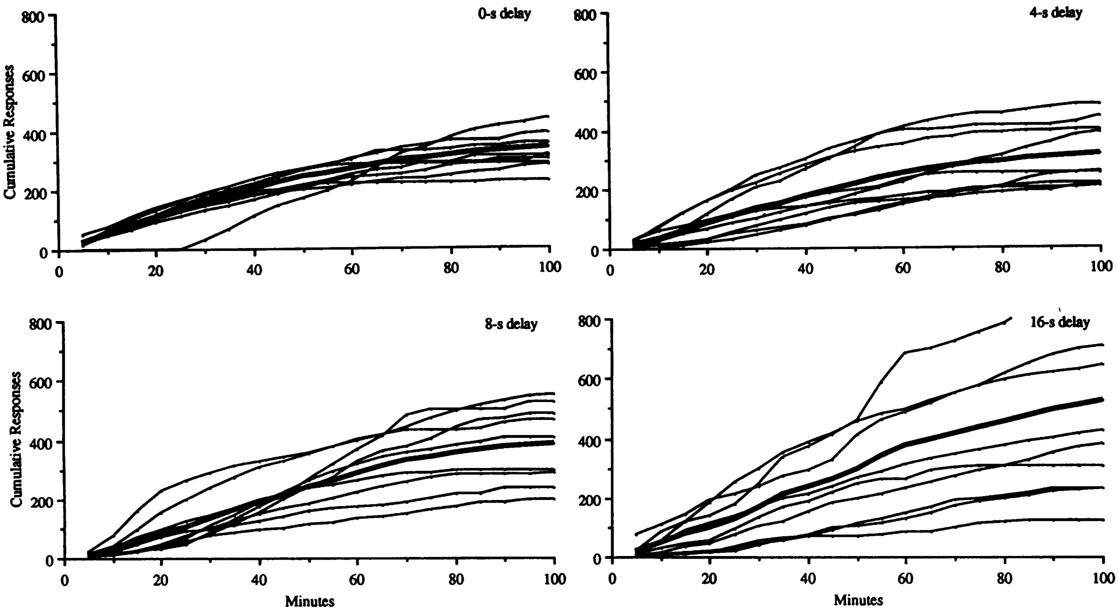

Fig. 2. Cumulative responses on the operative lever across the first 100 min of the session under the nonresetting delay procedure. Each thin line represents data for 1 of 9 individual rats exposed to the listed condition. The thick line represents the group mean.

Table 1

Average obtained delays, response rates, and food deliveries per session for nonresetting delay subjects.

Subject	Obtained delay (in seconds)	Operative lever resp/min first 100 min	Operative lever resp/min total session	Inoperative lever resp/min total session	Food deliveries
4-1-0 NR	3.57	2.48	0.74	0.10	324
4-1-1 NR	3.83	3.89	1.29	0.14	530
4-1-3 NR	3.96	2.03	0.49	0.15	222
4-2-0 NR	3.42	3.99	0.96	0.15	321
4-2-1 NR	3.87	2.04	0.61	0.07	266
4-2-3 NR	3.41	4.84	1.33	0.29	436
4-3-0 NR	3.67	2.13	0.61	0.07	226
4-3-1 NR	3.66	2.54	0.89	0.40	298
4-3-3 NR	3.57	4.42	1.29	0.04	424
8-1-0 NR	5.23	2.39	0.67	0.06	143
8-1-1 NR	5.87	1.98	0.61	0.17	163
8-1-3 NR	5.99	4.08	1.17	0.71	305
8-2-0 NR	6.13	5.52	1.40	0.45	330
8-2-1 NR	6.02	5.26	1.69	0.73	432
8-2-3 NR	5.75	4.89	1.46	0.34	334
8-3-0 NR	5.78	2.99	0.80	0.39	205
8-3-1 NR	5.38	2.88	2.04	0.09	223
8-3-3 NR	5.64	4.69	1.25	0.23	292
16-1-0 NR	9.19	9.44	2.74	0.83	238
16-1-1 NR	11.54	2.36	0.62	0.51	119
16-1-3 NR	10.80	3.07	0.96	0.50	168
16-2-0 NR	10.32	7.13	1.92	0.67	264
16-2-1 NR	10.57	2.36	0.60	0.07	110
16-2-3 NR	10.50	6.47	1.90	0.78	284
16-3-0 NR	11.46	4.27	1.64	0.74	332
16-3-1 NR	10.14	3.85	1.36	0.18	229
16-3-3 NR	13.22	1.26	0.94	0.11	217

Table 2

Response rates, average obtained delays, and food deliveries per session for no-food and immediate-reinforcement subjects.

Subject	Obtained delay (in seconds)	Operative lever resp/min first 100 min	Operative lever resp/min total session	Inoperative lever resp/min total session	Food deliveries
E-1-0	no S^R	0.26	0.08	0.18	0
E-1-1	no S^R	0.29	0.13	0.11	0
E-1-3	no S^R	0.12	0.06	0.04	0
E-2-0	no S^R	0.17	0.05	0.06	0
E-2-1	no S^R	0.33	0.10	0.08	0
E-2-3	no S^R	0.07	0.02	0.04	0
E-3-0	no S^R	0.08	0.01	0.01	0
E-3-1	no S^R	0.22	0.10	0.06	0
E-3-3	no S^R	0.06	0.06	0.04	0
0-1-0	0.01	4.36	1.53	—	735
0-1-1	0.01	3.90	1.02	—	493
0-1-3	0.01	3.06	1.01	—	486
0-2-0	0.01	2.82	0.74	0.08	356
0-2-1	0.01	4.63	1.14	0.07	545
0-2-3	0.01	2.34	0.58	0.03	277
0-3-0	0.01	2.78	0.91	0.07	438
0-3-1	0.01	3.52	1.07	0.11	512
0-3-3	0.01	2.82	0.66	0.03	319

Note. Dashes indicate data missing due to equipment failure.

ues. For all subjects at all delays, response rates on the operative lever exceeded rates on the inoperative lever. Response rates on the operative lever were calculated both for the first 100 min of the session and for the entire session. Because of limitations in the computer program, response rates on the inoperative lever could only be calculated over the entire session. Therefore, comparisons of response rates on the two levers refer to the entire session. Data storage capacity was insufficient to permit calculation of obtained delays on the inoperative lever.

Resetting delay. Figure 3 shows mean cu-

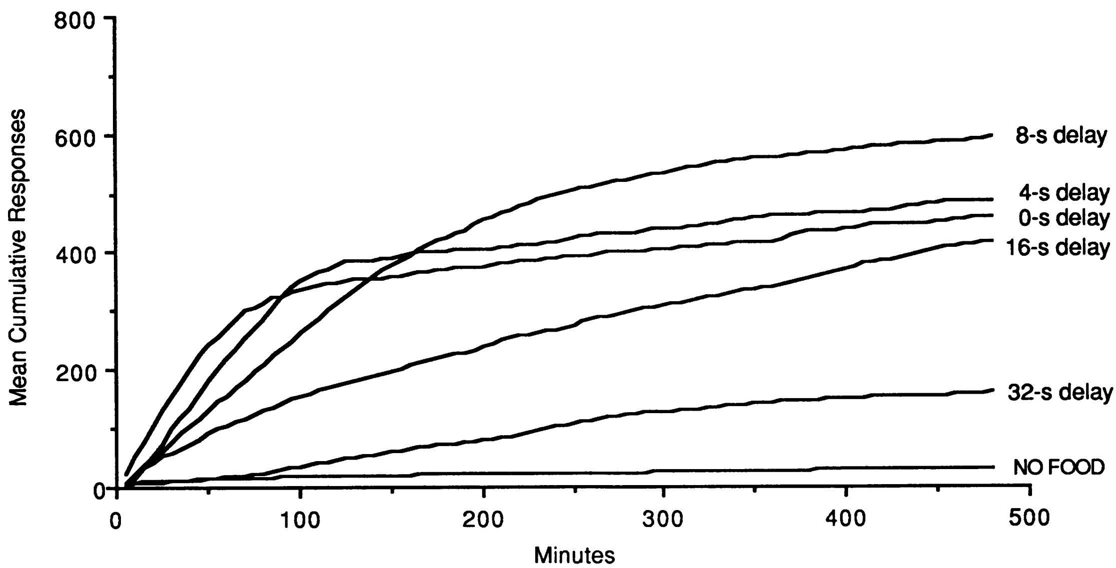

Fig. 3. Mean cumulative responses on the operative lever across the 8-hr session for rats exposed to 4-, 8-, and 16-s resetting delays. Details are as in Figure 1.

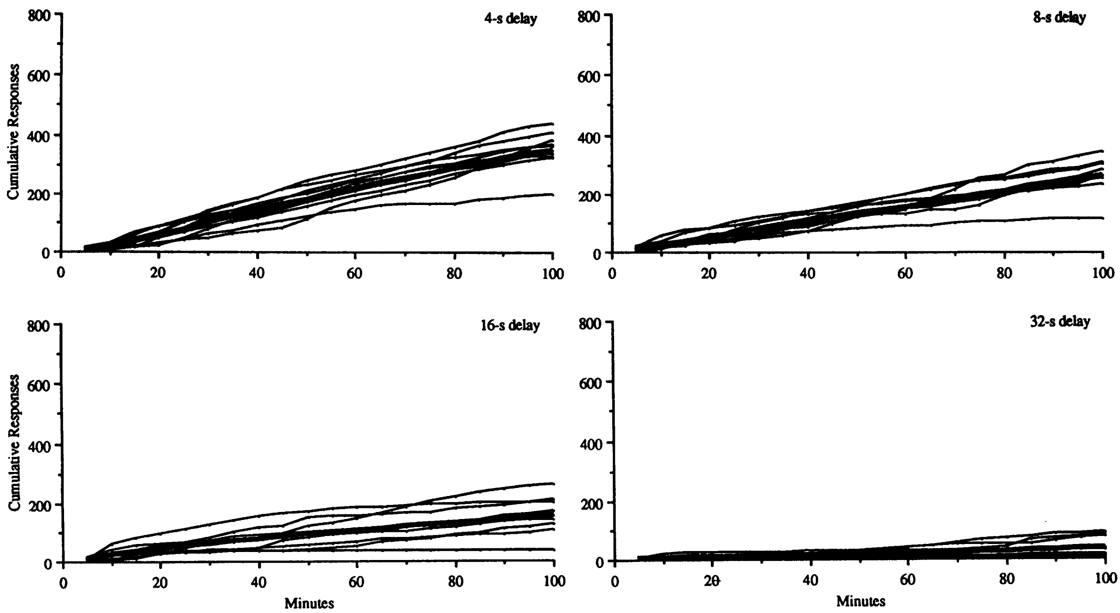

Fig. 4. Cumulative responses on the operative lever across the first 100 min of the session under the resetting delay procedure. Details are as in Figure 2.

mulative responses across the entire session for groups of rats exposed to 4-, 8-, 16-, and 32-s delays (control data appear in all figures showing only group data). Single-subject and mean group data for the first 100 min are presented in Figure 4. For subjects as a group, substantial lever pressing occurred at all delay values. In general, there was an inverse relation between the rapidity of response acquisition and length of delay: Responding developed most rapidly in the group exposed to the 4-s delay, followed in order by the 8-, 16-, and 32-s delay groups.

Although variability is present within each group, general patterns of responding evident in group data can be discerned in the performance of individual animals. Clear evidence of response acquisition within 100 min is evident in all animals exposed to delays of 4-, 8-, and 16-s, and in 6 of 9 rats exposed to the 32-s delay.

Table 3 shows mean obtained delays on the operative lever, response rates on the operative and inoperative levers, and the number of food deliveries for each subject at each delay. The $\bar{R} > t$ schedule arranged in the resetting delay procedure ensured that obtained delays were equal to programmed delays. With the exception of Subject 4-1-1 RS, response rates were greater on the operative lever than on the inoperative one when the delay was 4 s. At the 8-s delay, 3 of 9 subjects pressed the inoperative lever more frequently than the one that programmed food delivery. More responding occurred on the inoperative lever than on the operative one for all subjects in the 16-s delay group and for all but 2 subjects in the 32-s delay group.

Stacked delay. Figure 5 shows mean cumulative responses across the entire session for groups of rats exposed to 4-, 8-, and 16-s delays. Single-subject and mean group data for the first 100 min are presented in Figure 6. For subjects as a group, substantial lever pressing occurred at all delay values. Responding developed most rapidly in the group exposed to the 4-s delay; there was no obvious difference in the speed of acquisition for subjects exposed to 8- and 16-s delays. Although variability is present within each group, general patterns of responding evident in group data are apparent in the performance of individual animals. Clear evidence of response acquisition within 100 min is evident in all animals.

Table 4 shows for each subject the average obtained delay on the operative lever, response rates on the operative and inoperative levers, and the number of food deliveries. Obtained delays always were shorter than programmed values. For all subjects, response rates on the

Table 3

Average obtained delays, response rates, and food deliveries per session for resetting delay subjects.

Subject	Obtained delay (in seconds)	Operative lever resp/min first 100 min	Operative lever resp/min total session	Inoperative lever resp/min total session	Food deliveries
4-1-0 RS	4.0	3.40	0.78	0.20	375
4-1-1 RS	4.0	4.06	0.66	0.84	316
4-1-3 RS	4.0	3.64	0.74	0.13	355
4-2-0 RS	4.0	4.39	0.72	0.15	346
4-2-1 RS	4.0	3.25	0.91	0.26	435
4-2-3 RS	4.0	3.66	0.90	0.21	432
4-3-0 RS	4.0	3.28	0.99	0.06	389
4-3-1 RS	4.0	3.83	1.15	0.35	316
4-3-3 RS	4.0	1.99	0.77	0.06	343
8-1-0 RS	8.0	3.41	0.80	0.19	384
8-1-1 RS	8.0	2.36	0.48	2.89	228
8-1-3 RS	8.0	2.81	0.69	0.33	331
8-2-0 RS	8.0	3.06	0.88	0.17	424
8-2-1 RS	8.0	1.12	0.70	1.49	336
8-2-3 RS	8.0	2.63	0.92	2.19	440
8-3-0 RS	8.0	2.61	1.28	0.57	381
8-3-1 RS	8.0	2.51	1.5	1.12	410
8-3-3 RS	8.0	3.04	1.27	0.21	357
16-1-0 RS	16.0	1.68	0.34	1.39	164
16-1-1 RS	16.0	1.25	0.44	0.99	209
16-1-3 RS	16.0	2.60	0.57	2.09	275
16-2-0 RS	16.0	2.10	0.36	2.03	173
16-2-1 RS	16.0	1.02	0.41	1.61	196
16-2-3 RS	16.0	0.37	0.26	0.35	125
16-3-0 RS	16.0	1.98	0.50	8.96	240
16-3-1 RS	16.0	1.41	0.36	1.53	171
16-3-3 RS	16.0	1.56	0.56	1.44	270
32-1-0 RS	32.0	0.82	0.59	0.70	141
32-1-1 RS	32.0	0.88	0.33	0.73	59
32-1-3 RS	32.0	0.31	0.07	0.07	15
32-2-0 RS	32.0	0.09	0.64	0.99	116
32-2-1 RS	32.0	0.02	0.01	0.03	2
32-2-3 RS	32.0	0.07	0.40	0.61	64
32-3-0 RS	32.0	0.74	0.55	0.28	144
32-3-1 RS	32.0	0.17	0.41	0.56	76
32-3-3 RS	32.0	0.09	0.03	0.04	11

operative lever exceeded rates on the inoperative one.

Procedural comparison. In an attempt to facilitate comparison across procedures, regression lines were fitted by the least squares method to cumulative response data for all groups of subjects. In this analysis, slopes were determined for each rat by regressing, in successive 5-min blocks, cumulative responses on cumulative session time. The mean of these slopes for each group is shown in Figure 7. Only data for the first 100 min of the session were considered in preparing this figure because response acquisition characteristically was evident during this period, after which cumulative response curves flattened appreciably. By comparing the mean slopes across groups of subjects, one can determine in a crude way the relative speed of response acquisition: the greater the slope, the faster the development of responding. Figure 7 presents the slopes obtained at each delay value under the three delay procedures and under the two control conditions.

With all procedures and delays, slopes exceeded the slope obtained with subjects that did not receive food. This indicates response acquisition. Moreover, statistical analysis revealed that mean slopes differed significantly from the 0-s delay value only under the re-

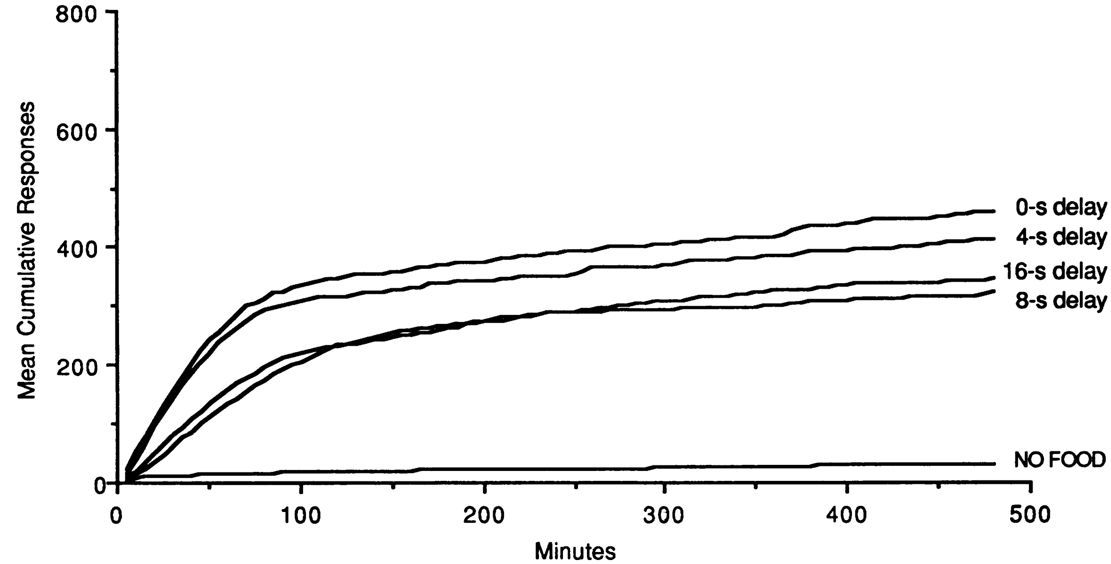

Fig. 5. Mean cumulative responses on the operative lever across the 8-hr session for rats exposed to 4-, 8-, and 16-s stacked delays. Details are as in Figure 1.

setting delay procedure with delays of 16 and 32 s ($p < .05$). All other mean slopes did not differ significantly ($p > .05$) from the 0-s control value. Statistical analysis was accomplished by conceptualizing the data as individual groups and subjecting them to one-way analysis of variance followed by planned comparisons using the Bonferroni method (Huitema, 1980). Although appropriate for the present data, this analysis is not powerful.

One way to conceptualize the present data is to compare performance under a given procedure and delay to performance under the 0-s delay control condition, as above. Another con-

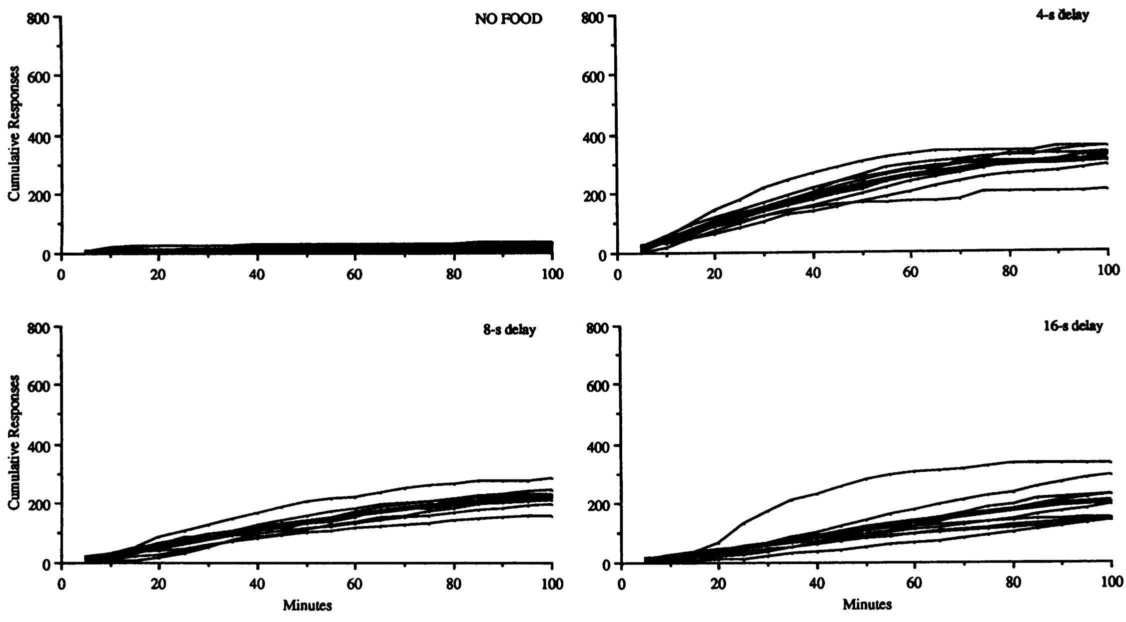

Fig. 6. Cumulative responses on the operative lever across the first 100 min of the session under the stacked delay procedure. Details are as in Figure 2.

Table 4

Average obtained delays, response rates, and food deliveries per session for stacked delay subjects.

Subject	Obtained delay (in seconds)	Operative lever resp/min first 100 min	Operative lever resp/min total session	Inoperative lever resp/min total session	Food deliveries
4-1-0 SD	3.36	3.21	1.03	0.09	493
4-1-1 SD	3.46	3.26	0.98	0.15	470
4-1-3 SD	3.50	2.90	0.81	0.08	389
4-2-0 SD	2.95	3.02	0.81	0.06	399
4-2-1 SD	3.19	3.32	0.92	0.25	442
4-2-3 SD	2.80	3.53	1.06	0.09	504
4-3-0 SD	2.90	3.05	0.76	0.04	366
4-3-1 SD	3.08	3.55	0.85	0.39	410
4-3-3 SD	3.08	2.04	0.55	0.11	263
8-1-0 SD	5.43	2.31	0.59	0.15	280
8-1-1 SD	7.06	1.56	0.68	0.44	325
8-1-3 SD	6.46	2.07	0.51	0.22	247
8-2-0 SD	5.56	2.11	0.74	0.12	355
8-2-1 SD	5.77	2.45	0.79	0.28	380
8-2-3 SD	5.10	1.95	0.71	0.09	341
8-3-0 SD	5.99	2.32	0.55	0.18	265
8-3-1 SD	6.77	2.25	0.80	0.26	383
8-3-3 SD	4.85	2.85	0.64	0.10	305
16-1-0 SD	10.10	2.93	1.01	0.45	487
16-1-1 SD	12.56	1.50	0.42	0.21	202
16-1-3 SD	8.82	3.34	1.39	0.14	575
16-2-0 SD	11.69	2.29	0.85	0.39	409
16-2-1 SD	11.22	1.48	0.74	0.69	353
16-2-3 SD	11.80	1.37	0.66	0.26	319
16-3-0 SD	—	1.92	0.74	0.34	357
16-3-1 SD	13.26	1.43	0.55	0.39	265
16-1-3 SD	10.78	2.27	0.72	0.25	347

Note. Dashes indicate data missing due to equipment failure.

ceptualization, which allows for a more powerful statistical analysis, is to compare slopes across delay values under a particular procedure (Huitema, personal communication). Presumably, if delay of reinforcement does systematically impede response acquisition, within a given delay procedure slopes should decrease as a function of programmed delay. The analysis of monotone alternatives was used to ascertain whether slopes under a given procedure systematically changed as a function of delay in the present study. This analysis revealed that slopes significantly and monotonically decreased with delay value under the resetting delay procedure ($t = -6.66$, $df = 96$, $p < .01$). Although slopes also decreased with delay under the stacked procedure, this pattern was not statistically significant ($t = -1.69$, $df = 96$, $p > .05$). Under the nonresetting procedure, mean slopes increased with delay. This pattern was statistically significant ($t = 2.81$, $df = 96$, $p < .01$).

Although mean slopes provide a convenient summary of acquisition, undue emphasis on them may lead to faulty conclusions. Slope functions notwithstanding, consideration of the performance of individual subjects (Figure 2) indicates that the rate of response acquisition did not increase consistently as a function of delay under the nonresetting procedure. For example, cumulative responses increased rapidly with time in 3 animals exposed to the 16-s delay. In the remaining 6, responses increased much more slowly, certainly at a rate no greater than that observed in most subjects exposed to shorter delays. Speed of acquisition, as reflected in the mean slope of cumulative response curves, does not provide an accurate reflection of the performance of individual subjects under the nonresetting delay procedure. Certainly the present data, viewed in their entirety, do not strongly support the notion that increasing the delay consistently increased speed of acquisition under this procedure, although on average the total number of responses emitted during the entire session and in the first 100 min was directly related to programmed delay length. The safest conclusion concerning the nonresetting delay procedure appears to be that there was no consistent relation between speed of acquisition and delay value. Interestingly, mean slopes do provide a reasonable reflection of the performance of individual animals under the resetting and stacked delay procedures, in which cumulative response curves of individual animals generally flattened (i.e., speed of acquisition decreased) as delays increased (Figures 4 and 6).

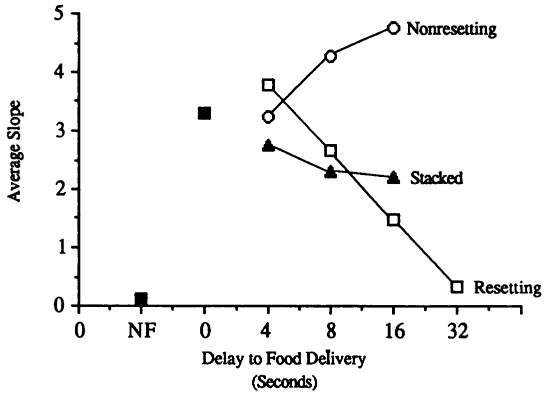

Fig. 7. Slopes of regression lines fitted to mean cumulative response curves for the first 100 min of the session under all conditions. The greater the slope value, the faster the rate of response acquisition in terms of total responses emitted.

DISCUSSION

Results of the present study, which employed three different procedures to arrange delays, confirm a previous report that discrete responses can be acquired with delayed and unsignaled reinforcement in the absence of shaping or autoshaping (Lattal & Gleeson, 1990). They also extend the findings of Lattal and Gleeson with respect to food deprivation. In their studies, Lattal and Gleeson maintained rats at 70% of free-feeding body weights. They speculated that this relatively high level of deprivation may have facilitated response acquisition. In the present study, response acquisition consistently occurred in rats maintained at 80% of free-feeding weights. Thus, it appears that deprivation to 70% of free-feeding weight is not required for response acquisition, although it may be a contributing variable.

To be strengthened by reinforcement, whether delayed or immediate, responses obviously have to occur. The first occurrence of a given response class characteristically is controlled by nonoperant relations. As Skinner put it, "The rat must press the lever at least once 'for other reasons' before it presses it 'for food' " (1969, p. 175). Those "other reasons" were sufficiently powerful in the present study so that each of 108 rats pressed both levers early in the session. Although the exact time to the first response was not recorded, most rats emitted at least one response in the first 5-min bin, and all rats emitted at least one response by the end of the third 5-min bin (i.e., within 15 min of session onset). One variable that almost certainly contributed to the rapid occurrence of lever pressing was chamber size. The probability that nondirected movements (e.g., rearing) will result in lever depression should increase as chamber size decreases, and the chambers used in the present study were small.

Three variables (in addition to chamber size) probably facilitated movements that led to an initial lever press in the present study. One was the presence of odors resulting from prior testing with other rats, which may have led to exploratory behavior. Another was food deprivation, which generally increases activity in rats (Richter, 1927). The third was a history of receiving food in the chamber during magazine training. That history probably caused the rats to explore the food tray and surrounding area, which included the levers. No attempt was made to ascertain the relative contribution of each of these variables to initial lever pressing, but the performance of control subjects that did not receive food made it clear that the variables responsible for initial lever presses were insufficient to engender substantial responding across time. Unless food was delivered, relatively little lever pressing occurred. When food was delivered, cumulative lever presses exceeded no-food control levels at all delays under each of the three procedures. The difference in cumulative lever pressing under delay and no-food procedures provides evidence of response acquisition.

Although substantial levels of operative-lever responding occurred under all procedures and at all delays, performance differed substantially within and across the various groups of rats. Nonetheless, when speed of acquisition was summarized by the slope of lines fitted to cumulative response data, with two exceptions responding was acquired as rapidly under delay procedures as under the FR 1 (i.e., 0-s delay) control condition. The two exceptions were the 16- and 32-s delays under the resetting delay procedure. At those delays, slopes differed significantly from the slope obtained with the 0-s delay controls, although they were greater than the slope obtained in the no-food controls.

The resetting delay procedure ensured that operative-lever responses were never followed by food delivery prior to expiration of the programmed delay. With this procedure, speed of acquisition declined monotonically with the nominal delay value. This relation is consistent with the proposition that the response-strengthening effects of each reinforcer decrease as the delay to reinforcement increases. Support for this proposition has been previously provided in several studies, including those evaluating the effects of delayed reinforcement on speed in a runway (Logan, 1960), rate of responding under a variable-interval schedule in a single-response situation (Pierce, Hanford, & Zimmerman, 1972; Silver & Pierce, 1969), and choice in a concurrent operant arrangement (Chung & Herrnstein, 1967). It appears that one variable responsible for the observed relation between delay value and cumulative responding under the resetting delay procedure of the present study was the elapsed time between responding and food delivery per se. Another operative variable was the imposition of an $\bar{R} > t$ schedule (as the second component of a tandem FR 1 $\bar{R} > t$). Prior studies (e.g., Zeiler, 1971, 1976, 1979) have shown that arranging an $\bar{R} > t$ schedule reduces the rate of occurrence of established operants, and that the magnitude of the response reduction obtained is directly related to the length of t. The value of t defined the delay of reinforcement under the resetting procedure. At long delays, subjects were exposed to a powerful response-suppressing contingency, as well as delayed reinforcement. These variables probably acted together to produce relatively low levels of cumulative responding.

Under both the nonresetting and stacked delay procedures, obtained delays were shorter and more variable than programmed delays. Moreover, it was possible that food delivery immediately followed operative-lever responses. Although these procedures ensured only that operative-lever presses and food deliveries were contingent, they permitted temporal contiguity, which in all likelihood played a role in operative-lever response acquisition and maintenance (cf. Ferster, 1953; Gleeson & Lattal, 1987; Lattal, 1987; Sizemore & Lattal, 1978).

In contrast to findings under the nonresetting and stacked delayed procedures, in which all subjects pressed the operative lever more often than the inoperative lever, rats exposed to resetting delays often exhibited higher rates of responding on the inoperative lever. One interpretation of this outcome is that both operative- and inoperative-lever responses were reinforced by food delivery, although the arrangement was response dependent in the former case and response independent in the latter. More inoperative-lever responses occurred because delays to food delivery were generally shorter than delays following operative-lever responses, which were always equal to the programmed value. In addition, the $\bar{R} > t$ contingency probably decreased the probability of operative-lever responses during delay intervals and may have increased the likelihood of behavior incompatible with operative-lever responses, such as leaving the area of that lever. In a small cage with few response options, this may have increased the probability of inoperative-lever responses, which were adventitiously reinforced. No such interaction was possible under the nonresetting or stacked procedures, which engendered relatively little inoperative-lever responding.

A noteworthy aspect of the present data concerns the relation of programmed delay to mean cumulative responses under the nonresetting delay procedure. By the end of 100 min and throughout the remainder of the session, the mean cumulative response curve was highest for subjects exposed to the 16-s delay, next highest for subjects exposed to the 8-s delay, and lowest for subjects exposed to the 4-s delay. Differential satiation across the three groups may have been responsible for this outcome. At any given time in the session, it is probable that more food was consumed under shorter delay conditions compared to longer delay conditions, with greater possibility of satiation. The observed responding may reflect the effects of response strengthening by reinforcement and response inhibition by satiation.

Of course, differential satiation was possible under the other procedures, but those procedures have features that may have compensated for this effect. Specifically, under the resetting procedure, the reduction in response–food contiguity associated with longer delays may have compensated for the fact that satiation developed less rapidly at those delays. Under the stacked delay procedure, satiation may have been approximately equal across delays because all responses produced food delivery. Incorporating yoked-control subjects with established lever-pressing repertoires would provide a means of evaluating the effects of satiation under the various procedures and delays. For yoked-control subjects, food would became available when it was earned by the experimental partner and would be delivered dependent upon a lever press.

REFERENCES

Chung, S.-H., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior,* **10,** 67–74.

Dews, P. B. (1960). Free-operant behavior under conditions of delayed reinforcement. I. CRF-type schedules. *Journal of the Experimental Analysis of Behavior,* **3,** 221–234.

Ferster, C. B. (1953). Sustained behavior under delayed reinforcement. *Journal of Experimental Psychology,* **45,** 218–224.

Gleeson, S., & Lattal, K. A. (1987). Response-reinforcer relations and the maintenance of behavior. *Journal of the Experimental Analysis of Behavior,* **48,** 383–393.

Harker, G. S. (1956). Delay of reward and performance of an instrumental response. *Journal of Experimental Psychology,* **51,** 303–310.

Huitema, B. E. (1980). *The analysis of covariance and alternatives.* New York: Wiley.

Lattal, K. A. (1987). Considerations in the experimental analysis of reinforcement delay. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 5. The effect of delay and of intervening events on reinforcement value* (pp. 107–123). Hillsdale, NJ: Erlbaum.

Lattal, K. A., & Gleeson, S. (1990). Response acquisition with delayed reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes,* **16,** 27–39.

Logan, F. A. (1952). The role of delay of reinforcement in determining reaction potential. *Journal of Experimental Psychology,* **43,** 393–399.

Logan, F. A. (1960). *Incentive: How the conditions of reinforcement affect the performance of rats.* New Haven, CT: Yale University Press.

Pierce, C. H., Hanford, P. V., & Zimmerman, J. (1972). Effects of different delay of reinforcement procedures on variable-interval responding. *Journal of the Experimental Analysis of Behavior,* **18,** 141–146.

Richter, C. P. (1927). Animal behavior and internal drives. *Quarterly Review of Biology,* **2,** 307–343.

Seward, J. P., & Weldon, R. J. (1953). Response latency as a function of change in delay of reward. *Journal of Comparative and Physiological Psychology,* **46,** 184–189.

Silver, M. P., & Pierce, C. H. (1969). Contingent and noncontingent response rates as a function of delay of reinforcement. *Psychonomic Science,* **14,** 231–232.

Sizemore, O. J., & Lattal, K. A. (1978). Unsignalled delay of reinforcement in variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **30,** 169–175.

Skinner, B. F. (1938). *The behavior of organisms.* New York: Appleton-Century-Crofts.

Skinner, B. F. (1969). *Contingencies of reinforcement: A theoretical analysis.* New York: Appleton-Century-Crofts.

Zeiler, M. D. (1971). Eliminating behavior with reinforcement. *Journal of the Experimental Analysis of Behavior,* **16,** 401–405.

Zeiler, M. D. (1976). Positive reinforcement and the elimination of reinforced responses. *Journal of the Experimental Analysis of Behavior,* **26,** 37–44.

Zeiler, M. D. (1979). Reinforcing the absence of fixed-ratio performance. *Journal of the Experimental Analysis of Behavior,* **31,** 321–332.

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