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WITHIN-SESSION DELAY-OF-REINFORCEMENT GRADIENTS

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Within-session delay-of-reinforcement gradients were generated with pigeons by progressively increasing delays to reinforcement within each session. In Experiment 1, the effects of imposing progressive delays on variable-interval and fixed-interval schedules were investigated while controlling for simultaneous decreases in reinforcer rate across the session via a within-subject yoked-control procedure. Rate of key pecking decreased as a negatively decelerated function of delay of reinforcement within a session. These rate decreases were greater than those during a yoked-interval session in which the rate of immediate reinforcement decreased at the same rate as it did under the progressive-delay procedure. In Experiment 2, delay-of-reinforcement gradients were shallower when the progressive delay intervals were signaled by a blackout than when they were unsignaled. The delay gradients obtained in each experiment were similar to those generated under conditions in which different delays of reinforcement are imposed across blocks of sessions. The present procedure offers a technique for rapidly generating delay-of-reinforcement gradients that might serve as baselines for assessing the effects of other behavioral and pharmacological variables.

Key words: delayed reinforcement, within session, delay gradients, progressive delays, key pecking, pigeons

Delay-of-reinforcement gradients (delay gradients, hereafter) typically are generated by exposing individual organisms to different delay durations across blocks of sessions, often with each delay duration separated from the others in the sequence by an immediate reinforcement condition (e.g., Richards, 1981; Sizemore & Lattal, 1978). Response rates typically are a negatively decelerating function of delay duration. Such delay gradients have been used as baselines against which to assess the effects of other variables (Richards, 1981; Stretch, Gerber, & Lane, 1976). This strategy can be hampered by the unwieldiness of the procedures used to generate gradients. That is, a baseline gradient first must be established using the technique noted above, and this in turn is followed by a reassessment of the gradient with the independent variable in effect. Thus a parametric study of, for example, drug effects on delay gradients requires repeated determinations of the delay gradient. Alternatively, if delay gradients could be generated within a single session, rather than across many sessions and conditions, the assessment of other independent variables on delay gradients would be more efficient.

Ferster (1953) and Dews (1960) attempted to develop sustained behavior under delays of reinforcement by gradually, rather than abruptly, increasing the delay value both within and across sessions. Ferster trained pigeons to peck under a variable-interval (VI) 60-s schedule of food reinforcement and gradually increased the duration of a signaled delay (chamber blackout) to reinforcement. Ferster determined when and how the delays increased based on the subject's responding. Consequently, the delay increases were different for each subject. For 1 subject, for example, the delay was increased from 1 to 60 s, in 10-, 20-, and 40-s intermediary points over the course of 90 hr. Three of 4 subjects reportedly maintained ''normal rates of response under 60-sec. delays'' (Ferster, 1953, p. 278) for several hundred hours. Only one cumulative record from one session was shown, and response rate data across sessions were not presented. Ferster concluded that the ''effect of a delay on the frequency of a response depends critically on the way in which the bird is introduced to the particular delay'' (p. 282). Dews imposed either non-

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resetting or resetting delays (i.e., responses either did not affect, or restarted the delay, respectively) to reinforcement on pigeons' key pecking under a continuous schedule of food reinforcement. For 1 pigeon, the delay duration was increased across sessions from 10 s to 30 s to 100 s, but only after response rates stabilized at each delay value. Average response rates for the 5 pigeons were 5.0 and 0.4 responses per minute under the 100-s nonresetting and resetting delay conditions, respectively.

The procedures of both Ferster (1953) and Dews (1960) might be said to involve progressive delays of reinforcement. In Ferster's experiment, however, the goal was to sustain behavior with long delays rather than to generate a delay gradient. Furthermore, the rate at which the delays changed was determined individually for each subject. Dews systematically increased delays across and within sessions, but response rates at the intermediate delay values were not reported. The present experiments further investigated a progressively increasing delay requirement, but within individual sessions rather than across sessions, to develop a method for rapidly and reliably generating delay gradients within each session.

EXPERIMENT 1

Imposing a delay-of-reinforcement procedure concomitantly decreases reinforcement rate (Lattal, 1987). Experiment 1 therefore examined the effects of both progressively increasing unsignaled delays to reinforcement within individual sessions while separating out the simultaneous decrease in reinforcement rate that accompany such delays.

Method

Subjects

Four male White Carneau pigeons, retired breeders obtained from Palmetto Pigeon Plant in Sumter, South Carolina, were maintained at 85% (± 10 g) of free-feeding body weights. Each had experience with different reinforcement schedules. Each was housed individually in a temperature-controlled room with a 12:12 hr light/dark cycle and had continuous access to water and health grit. Postsession feeding, when required, occurred at least 2 hr after a session.

Apparatus

A Gerbrands Model G7311 operant-conditioning chamber with a work area of 31 cm by 27.5 cm by 32 cm was housed in a Gerbrands Model G7210 sound- and light-attenuating enclosure. The chamber was made of clear plastic except for the aluminum work panel. The panel contained two 2 cm diameter response keys. Each key was located 23 cm from the floor and 15 cm from the center of the panel. Only the right key was used, and it was operated by a force of at least 0.15 N. This key was transilluminated either white or blue by 28-V DC bulbs. The houselights, two white-capped 28-V DC bulbs (No. 1819), were located on the ceiling to the rear of the chamber and provided general illumination throughout the session except when the food hopper was raised. Mixed grain was made available from a Gerbrands feeder through a 5.5 cm by 4.5 cm aperture located on the middle of the response panel, 7.5 cm above the floor. Two white 28-V DC lights illuminated the feeder aperture during the 3-s grain access that defined the reinforcement cycle. A white noise generator and sound from a ventilating fan masked extraneous sounds. Control and recording operations were performed with a Tandy® TX 1000 microcomputer connected to the chambers by a MED-PC® interface system.

Procedure

Each pigeon initially received five reinforcers on fixed-ratio (FR) 1, 3, 5, and 7 schedules, in that order and in a single session. During the remainder of the experiment, in successive pairs of sessions, the effects of two procedures were compared. The first was an unsignaled progressive-delay procedure in which the first key peck after the lapse of either a fixed or variable interfood interval initiated an unsignaled, nonresetting delay that increased by 2 s each time it occurred. The progressive-delay procedure therefore could be described as a tandem schedule comprised of an interval schedule, VI or fixed interval (FI), in the initial component and a progressive-time (PT) 2-s schedule in the terminal component. The interfood intervals during the progressive-delay procedure were arranged by either FI 30-s or VI 30-s schedules in different conditions of the experiment.

The VI schedules consisted of 13 intervals (range, 1.3 to 104.5 s) generated using a Fleshler and Hoffman (1962) progression.

During the next session, the second procedure was in effect. This procedure was a yoked-interval schedule in which reinforcement immediately followed the first peck after the interfood interval lapsed, and the interfood intervals were yoked to the total interfood intervals (fixed or variable interfood interval plus delay duration) obtained during the progressive-delay procedure in the preceding session. The response key was transilluminated white during the delay procedure (odd-numbered sessions) and blue during the yoked-interval procedure (even-numbered sessions).

One session occurred daily, 5 days a week, within the body weight constraints noted in the subjects section above. The progressive-delay sessions terminated following the first 7-min pause during the nondelay portion of the progressive-delay procedure. Pauses during the delay period did not end the session, ensuring that every delay interval initiated by a response ended in food delivery.

Each pigeon was studied for 20 progressive-delay and 20 yoked-interval sessions with either the FI schedule or the VI schedule in effect in the progressive-delay procedure. The above sequence then was repeated with the other interval schedule in effect. Pigeons 3306 and 1326 were exposed first to the VI schedule, and Pigeons 2337 and 2317 were exposed first to the FI schedule.

Table 1

Order of conditions, sessions used in within-session analysis, and breaking point (BP, in seconds).

Pigeon	Condition	Session pairs	BP (s)
2317	FI	27-28	180
		29-30	98
		31-32	162
		35-36	136
		37-38	154
		39-40	170
	VI	69-70	52
		71-72	16
		73-74	36
		75-76	20
		77-78	28
		79-80	34
2337	FI	29-30	170
		31-32	152
		33-34	142
		35-36	134
		37-38	144
		39-40	148
	VI	69-70	180
		71-72	180
		73-74	168
		75-76	240
		79-80	182
		81-82	208
3306	VI	13-14	122
		15-16	204
		17-18	144
		21-22	160
		31-32	152
		35-36	152
	FI	69-70	114
		71-72	30
		73-74	68
		75-76	72
		77-78	8
		79-80	112
1326	VI	29-30	58
		31-32	54
		33-34	22
		35-36	24
		37-38	26
		39-40	24
	FI	69-70	22
		71-72	16
		73-74	12
		75-76	42
		77-78	80
		79-80	64

RESULTS

Table 1 shows the six session pairs used in the within-session analyses and the breaking point in each of the progressive delay sessions. Breaking point was defined as the nominal delay in seconds associated with the last reinforcer of the session. The average breaking point was 101.25 and 103.58 s for the FI and VI initial-link schedules, respectively. The last 12 sessions of each condition (six progressive-delay sessions and the corresponding six yoked-interval sessions) were selected for analysis, except when an overflow occurred in the software array (i.e., the number of responses exceeded the array size). In the case of this event, the preceding session pair was selected. This resulted in the omission of one session pair for Pigeons 3217 and 2337 and eight for Pigeon 3306. For Pigeon 3306, the omissions of these sessions resulted in an underestimation of breaking point (because the selected sessions had shorter breaking points) but not in response rate. The average session response rates (with standard deviation in parenthesis) in the six sessions of the

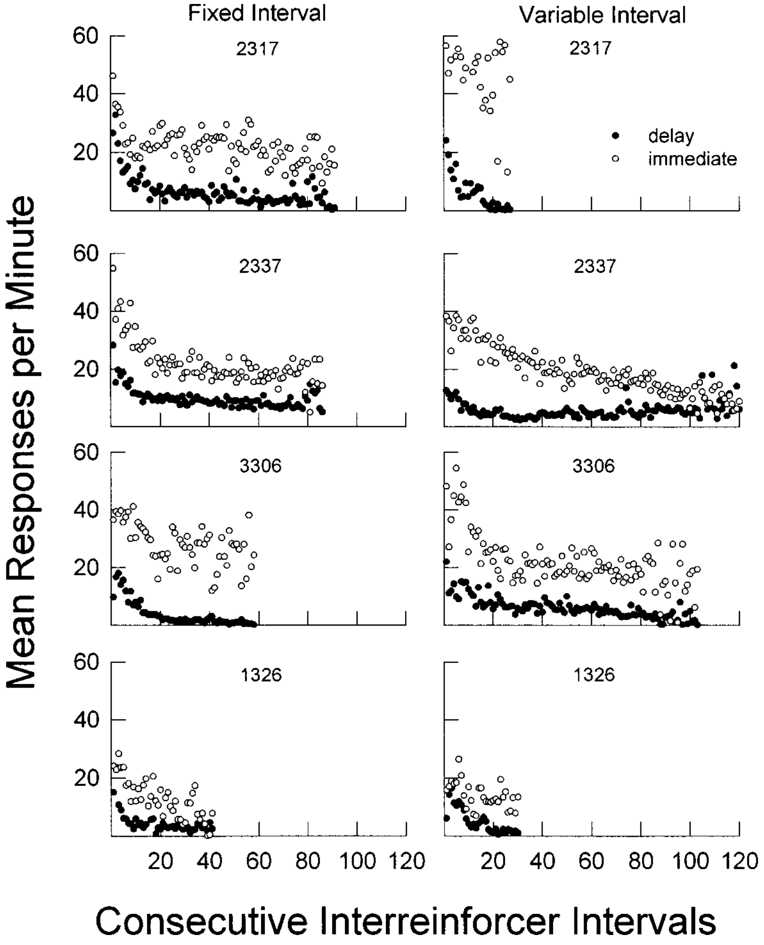

Fig. 1. Mean response rate across consecutive interreinforcer intervals of immediate (open circles) and delayed (filled circles) reinforcement. Each point represents the mean response rate of six sessions. The left panels depict the FI condition, and the right panels depict the VI condition.

progressive delay and yoked interval used in the analysis were 5.83 (2.06) and 22.35 (2.97), respectively. These rates were similar to the average rates of the last six sessions at the end of the VI condition (i.e., the omitted sessions) that were 5.22 (2.05) and 20.4 (2.36) for the progressive delay and yoked interval, respectively.

Figure 1 shows mean response rates for progressive-delay (delay) and yoked-interval (immediate) sessions across consecutive interreinforcer intervals for each pigeon. Response rates were calculated by dividing the number of responses in an interval by the duration of the interval, which included the postreinforcement pause (PRP). In the progressive delay, both initial-link (FI or VI) and terminal-link (PT) responses and times were used in the calculations. Response rates in both conditions were relatively high initially and declined across the session. Yoked-interval response rates were higher and often more variable than response rates during the progressive delay.

Figure 2 shows average PRP for progressive-delay (delay) and yoked-interval (immediate) sessions across consecutive interreinforcer intervals for each pigeon. In general, PRPs increased and became more variable in both progressive-delay and yoked-interval procedures as the session progressed, although the PRPs typically were longer and more variable during the progressive delay. The PRPs of Pigeons 2317 and 1326 during the yoked-inter-

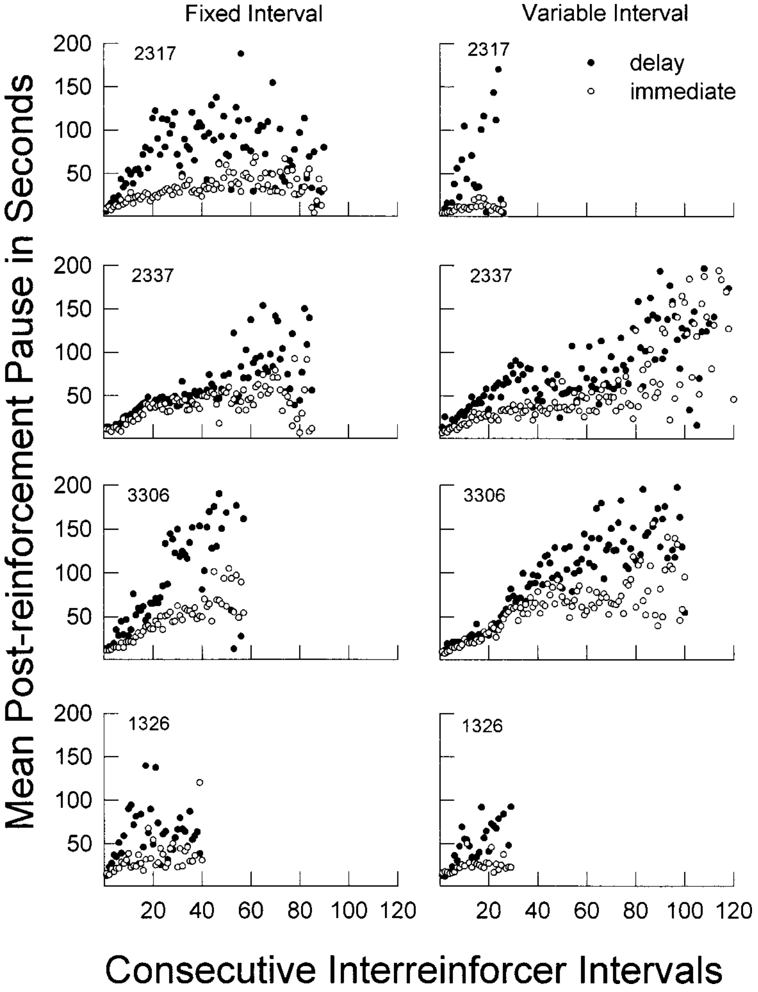

Fig. 2. Mean postreinforcement pause (in seconds) across consecutive interreinforcer intervals of immediate (open circles) and delayed (filled circles) reinforcement. Each point is the mean of six sessions. The left panels depict the FI condition, and the right panels depict the VI condition.

val procedure involving the VI schedule were an exception, in that they were relatively consistent across the session.

Response rate was calculated using only the initial-link components (FI and VI) and plotted in Figure 3 as a function of programmed or nominal delays (i.e., 0, 2, 4, 6, 8, . . .). Because the breaking points were not equal in the six sessions used in the analysis, the number of data points decreases from six as one moves toward the right side of the delay gradient. At least two data points were required to compute the average in the present figure.

The averaged response gradients conformed to a negatively decelerated response-rate function of delay. The delay gradients were quantified using a modified version of Mazur's (1987) hyperbolic delay discounting function, $B = B_I/(1 + kD)$, where B is response rate, D is the nominal or programmed delay duration. The two free parameters B_I and k represent the response rate under conditions of immediate reinforcement and the degree of the rate-decreasing effects of delay, respectively. These parameters were estimated using a curve-fitting routine (Prism®) that minimized the sum-of-squares error between the predicted curve and the obtained data. The predicted curved and the resulting parameter estimates are included in Figure 3. The hyperbolic equation provided a good ac-

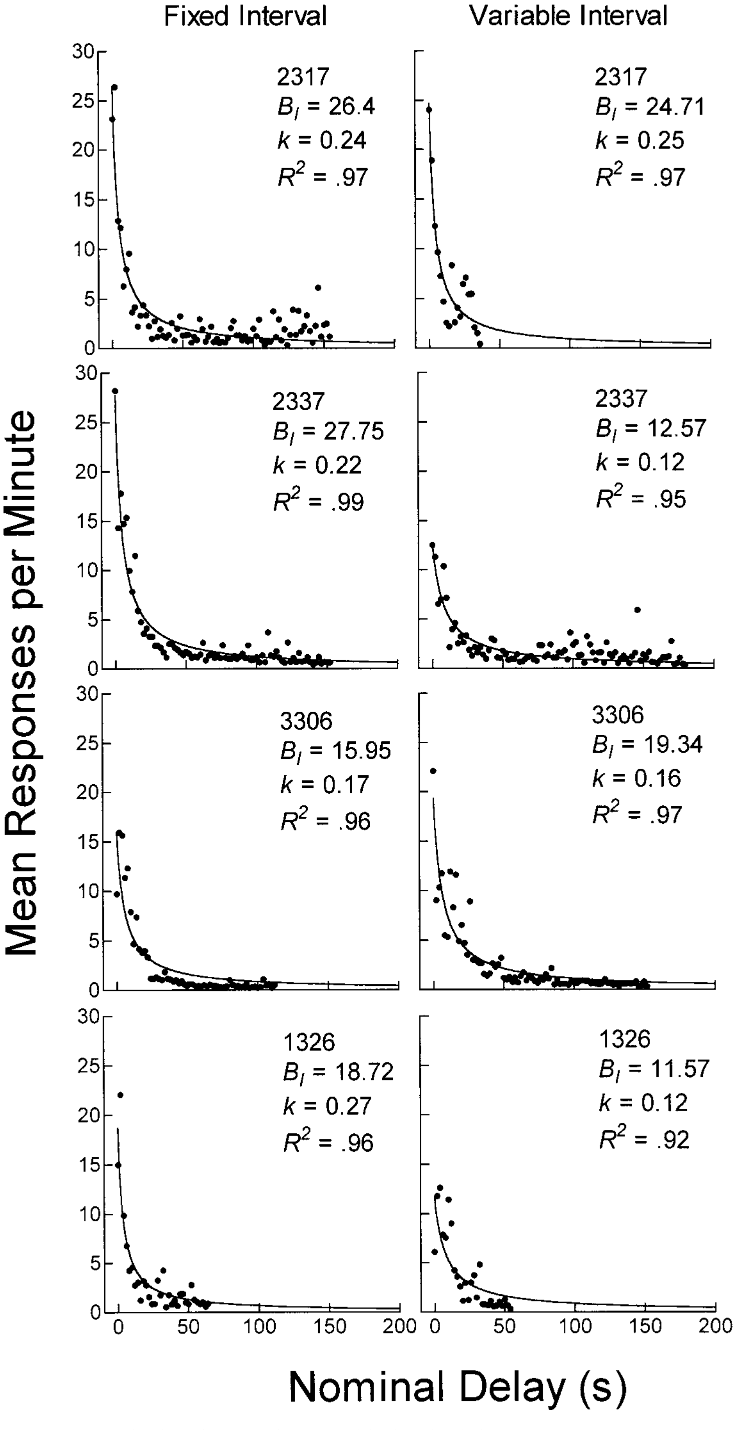

Fig. 3. Mean response rate calculated from the initial-link schedule as a function of nominal delay (in seconds). Solid lines represent the best-fit function of the hyperbolic equation (see text). Parameter estimates are presented for each graph. The left panels depict the FI condition, and the right panels depict the VI condition.

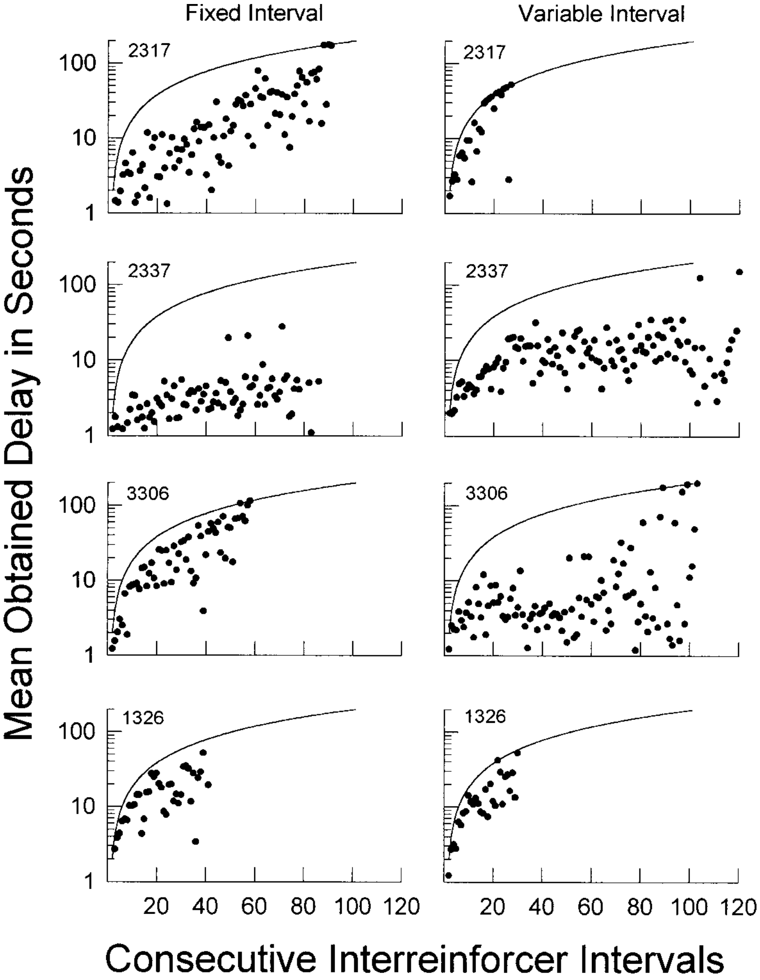

Fig. 4. Mean obtained delay (in seconds) as a function of consecutive interreinforcer intervals. The left panels depict the FI condition, and the right panels depict the VI condition. The solid lines for each plot are the progression of nominal delay durations. Note the logarithmic *Y* axes.

count of the data as revealed by the R^2 values. There were no systematic differences in the parameter estimates between the VI or FI initial-link schedules. The average (with standard deviation in parenthesis) estimates of B_I and k were 22 (5.8) and 0.22 (0.04) for the FI, and 17 (6.2) and 0.16 (0.06) for the VI conditions, respectively. A similar analysis using individual sessions revealed a fair degree of between-session similarity in the delay gradients. The exception was Pigeon 3306 in the VI condition, where the standard deviation was more than half of the parameter estimate, $B_I = 23$ (19) and $k = 0.22$ (0.22). This may reflect the fact that the sessions used for analysis for this pigeon were not always contiguous.

The progressive delay procedure involved nonresetting delays; therefore, obtained delays could be shorter than the programmed delays if responses occurred during the delay. This can be seen in Figure 4 that shows the mean obtained delay across consecutive interreinforcer intervals. The mean obtained delay is the average time between the last response and reinforcement during each interreinforcer interval of the progressive-delay condition. The mean obtained delays were somewhat variable (especially Pigeon 3306 when the VI schedule was studied) over sessions but usually were shorter than the nominal delays, which are indicated by the solid lines. The obtained delays of Pigeon 2317 during VI, Pigeon 3306 during FI, and Pigeon 1326 in both VI and FI increased in a manner that coincided with the programmed increases in the nominal delays. The other mean obtained delays for the other conditions also increased over the sessions but less systematically.

Sizemore and Lattal (1978) plotted response rate as a function of obtained delay in addition to nominal delay to better reflect the controlling variable. Figure 5 portrays the delay gradients in this manner. The graphs were constructed using the raw response rate and the raw obtained delays that were used to generate the averages in Figures 3 and 4, respectively. The response rates and obtained delays were arranged in two columns with rows representing consecutive interreinforcer intervals. The response rate column was shifted down one row so that the response rate could be plotted as a function of the preceding delay. Next, the columns were sorted according to the obtained delay column, and rows were pruned using Prism's pruning function. Specifically, every three rows were averaged to produce one output row. For example, six rows of obtained delays (1, 1.5, 1.75, 1.84, 2, 2) and response rates (30, 35, 34, 23, 21, 15) would be pruned to two rows (1.42, 1.95 and 33, 19.67). Response rates decreased with delay in a negatively-decelerated fashion. As in Figure 3, there were no systematic differences between the FI and VI conditions.

DISCUSSION

Response rate and pausing varied systematically as a function of within-session changes in reinforcement delay. Such changes during the progressively delayed reinforcement procedure resulted jointly from increasing delay durations and interreinforcer intervals. The differences between the progressive-delay and the yoked-interval sessions reveal the contribution of reinforcement delay to the effects. When reinforcement rate changes are thus factored out, it is clear that progressively increasing delays yield gradients similar to those when delays of reinforcement are imposed across successive conditions.

Within-session delay gradients were generated by the progressive-delay procedure in both the VI and FI initial-link schedules. In general, the effects of progressively increasing delays were similar when imposed on either a VI or FI schedule. Direct comparisons of the effects of these delays on VI and FI schedules may not be meaningful because both schedules were arranged as the initial component of a tandem schedule with a progressively changing time period in the terminal component. Such an arrangement poses two problems as far as direct comparison of schedule type is concerned. First, the 2-s delay increment simultaneously increased the interreinforcer intervals, and the nature of those increases differed depending on the initial-link schedule. Assuming that responding ensured an immediate change out of the initial link once it timed out, the interreinforcer intervals on the FI schedule may have increased more systematically than did those intervals on the VI schedule. Because of the random selection of intervals in the VI schedule, the increases in interreinforcer intervals that occurred under the VI schedule are described best as quasiprogressive: They increased over the long run but not necessarily from reinforcer to reinforcer. Second, even though the FI schedule nominally ensured fixed interfood intervals, it was often the case, particularly as the session progressed, that delays were not initiated immediately on the FI timing out, thereby making the obtained interfood intervals more variable, that is, more like those arranged by the VI initial component condition. Given these dynamic similarities between the two schedules, it is not surprising that systematic differences between responding when VI and FI constituted the initial links were not observed.

EXPERIMENT 2

Signaled delays of reinforcement reduce response rates less than their unsignaled counterparts (Azzi, Fix, Keller, & Silva, 1964; Lattal, 1984; Richards, 1981; Schaal & Branch, 1988, 1990), but both yield the familiar negatively decelerated functional relation between delay duration and response rate. A similar effect obtained with progressive delays of reinforcement would further suggest the correspondence between the ef-

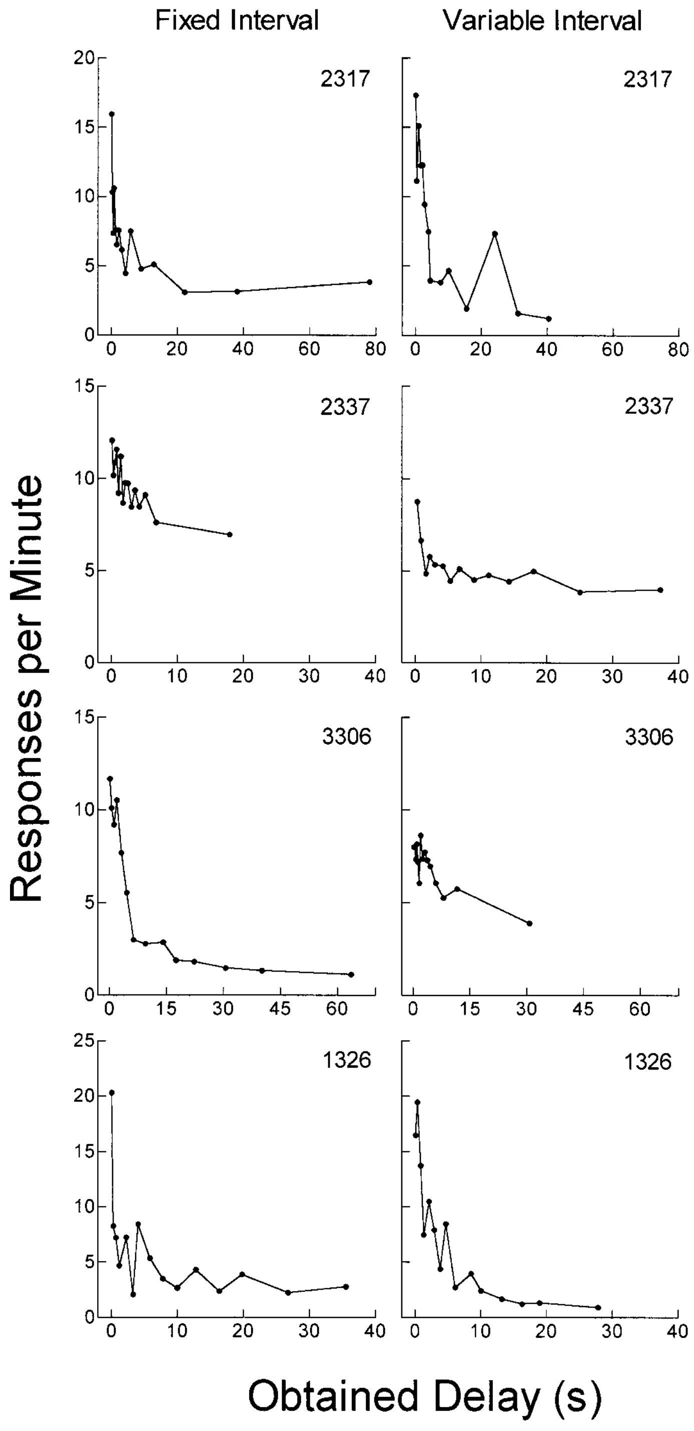

Fig. 5. Response rate calculated from the initial-link schedule as a function of obtained delay (in seconds). The left panels depict the FI condition, and the right panels depict the VI condition. See text for description of how the graphs were constructed.

fects of such delays and the more usual fixed delays of reinforcement.

METHOD

Subjects

Four male White Carneau pigeons with previous key-pecking experience on different reinforcement schedules were used. The conditions under which the pigeons were maintained were as described in Experiment 1.

Apparatus

An operant conditioning chamber with three wooden walls and an aluminum work panel was used. The dimensions were 30.5 cm by 32.5 cm by 37.5 cm. The work panel contained two response keys, each 2.5 cm in diameter and 25.5 cm above the floor and 12.5 cm across from each other, but only the right key was operative. The key was transilluminated white with a 28-V DC bulb. A houselight, located in the bottom right corner of the work panel 3 cm above the floor, provided general illumination throughout the session except when the hopper was raised. The food aperture, 5.5 cm by 5.5 cm, was centered on the work panel 8 cm above the floor. Other details of the apparatus were as described in Experiment 1.

Procedure

Preliminary training was as described in Experiment 1. The pigeons then were exposed to a progressive-delay procedure, also as described in Experiment 1, in which the VI schedule was in effect, but the delays were either accompanied by a blackout, thereby creating a signaled-delay procedure, or the delays were unsignaled. The schedule, therefore, was either a chained or tandem VI 30-s PT 2-s schedule when the signaled and unsignaled delays, respectively, were in effect. The response key was white at all times except during reinforcement or blackout. Each successive delay increased by 2 s, thereby conforming to an arithmetic progression of delay values. The order that the pigeons received exposure to the conditions was counterbalanced. Table 2 shows the order of conditions and the number of sessions at each condition. Each condition was in effect for a minimum of 20 sessions and until performance stabilized. Stability was achieved when the difference between the mean number of reinforcers in the first and last six sessions of a six-session block was within 10% of the mean number of reinforcers for the six sessions. Sessions terminated when a 7-min pause occurred in the VI 30-s component, thereby ensuring that all earned reinforcers were collected. Sessions occurred 5 days a week, within the body-weight constraints described in Experiment 1.

Table 2

Order of experimental conditions, number of sessions in each condition, mean breaking point (BP), and standard deviation for the last six sessions of the unsignaled and signaled conditions.

Pigeon	Condition	Sessions	*M* BP	*SD*
2720	Unsignaled	28	66.33	44.42
	Signaled	21	269.33	43.61
	Unsignaled	22	22.00	6.06
3736	Unsignaled	36	58.00	31.13
	Signaled	23	117.66	23.91
	Unsignaled	23	46.33	19.20
4700	Signaled	24	252.33	73.99
	Unsignaled	28	53.33	22.07
	Signaled	21	257.00	51.88
4727	Signaled	30	155.66	19.57
	Unsignaled	22	29.00	9.18
	Signaled	22	215.00	67.10

RESULTS

The data from the last six sessions of each condition were used in each of the following analyses. Average breaking point and standard deviation for the signaled and unsignaled conditions can be seen in Table 2. Breaking points were four times longer when the delays were signaled; (M = 210 s, SD = 62 vs. M = 46 s, SD = 17). In the signaled delay condition, pigeons often responded up until delays of 200 s occurred. Figure 6 shows average response rates in the signaled and unsignaled conditions as a function of nominal delay. Response rates were calculated by dividing the number of responses in the VI initial link of an interval by the duration of that link, which included the PRP. Response rates in both conditions were high initially and declined across the session. Response rates generated under the signaled delay condition were maintained at higher levels than rates under unsignaled delays and consequently the delay gradients were steeper when the delays were unsignaled. This observation was confirmed with the quantitative

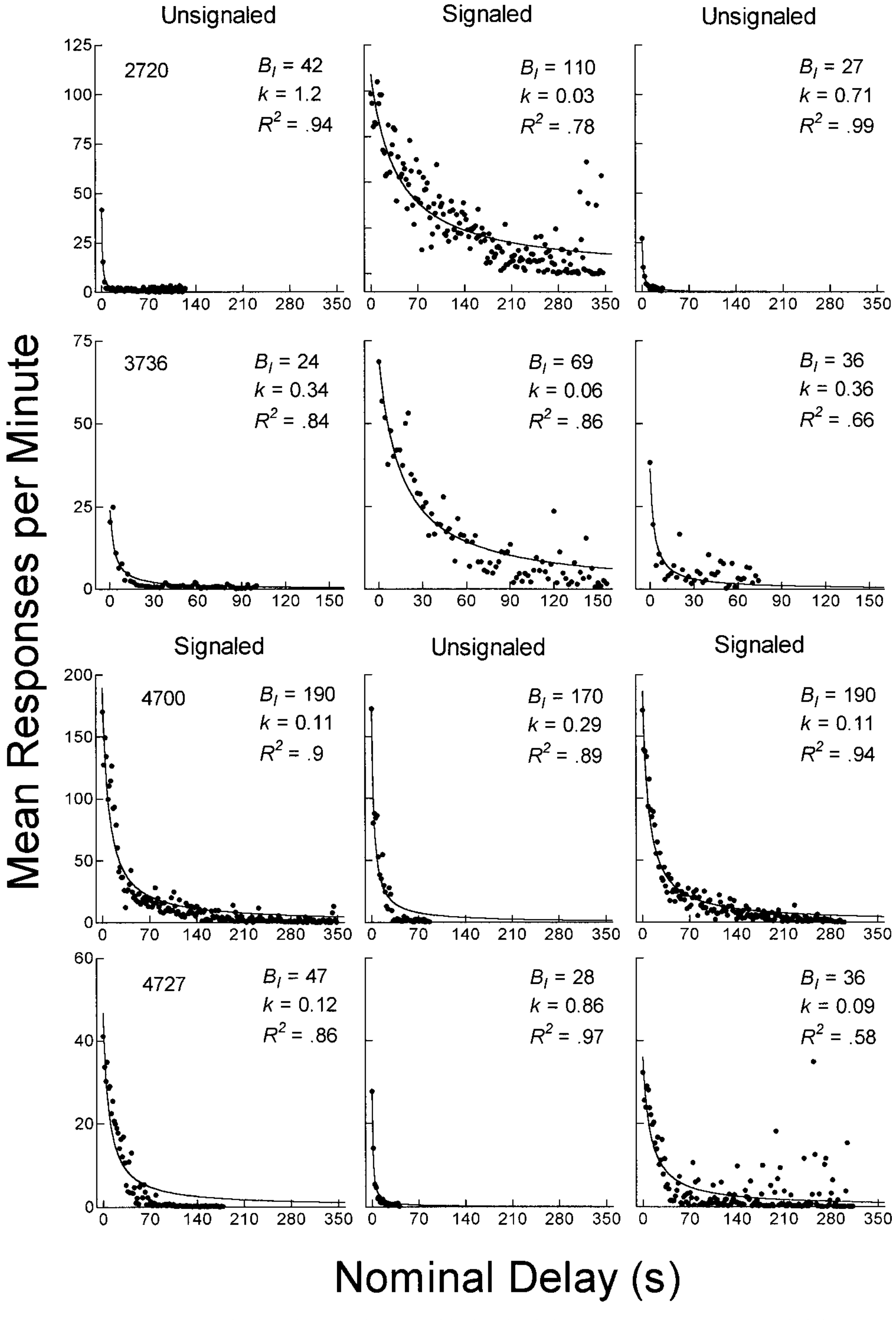

Fig. 6. Mean response rate calculated from the initial-link schedule as a function of nominal delay (in seconds). Solid lines represent the best-fit function of the hyperbolic equation (see text). Parameter estimates are presented for each graph. Each row of panels shows data from a single pigeon. The condition is labeled above the graphs. The order that the conditions occurred is maintained by the graphs. Note the different scales used on the axes.

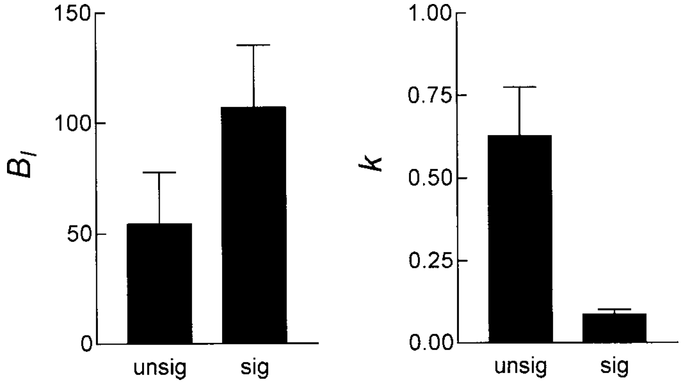

Fig. 7. Mean B_I (left panel) and k (right panel) parameter estimates generated under the unsignaled and signaled conditions. Error bars represent the standard error.

analysis used in Experiment 1. The predicted curves and parameter estimates are included in Figure 6. Overall, the equation provided a good fit to the data as indicated by the R^2 values. Larger values of B_I were obtained under the signaled delay condition, whereas larger values of k were obtained under the unsignaled delay condition (see Figure 7). Thus the signaled delay condition maintained higher response rates at the 0-s delay and produced shallower delay gradients.

Figure 8 shows average obtained delays across successive interreinforcer intervals. The obtained delays in both delay procedures generally increased across the session; however, the obtained delays in the signaled delay procedure were closer to the nominal or programmed delays, which are shown by the solid line.

Discussion

Within-session delay gradients, similar to those obtained in Experiment 1, were obtained when delays were either signaled or unsignaled. The gradients were steeper when delays were unsignaled. Thus responding was more persistent when delays were signaled, as indicated by the higher breaking points under those conditions. Both of these latter findings are consistent with experiments using signaled and unsignaled delays that are fixed across an individual session, suggesting that variables affecting responding under such fixed delays operate similarly when delays progressively increase across the session.

The delay gradients obtained during the unsignaled delay conditions were similar to those obtained under the VI condition of Experiment 1; response rates were high during the shorter delays and decreased rapidly as the delay durations progressively increased. Upon closer inspection, breaking points were somewhat longer and the shape of the delay gradient as indexed by k was shallower in Experiment 1. This could reflect a between-subject difference or some procedural variable that differed between the two experiments. For example, perhaps the alternating schedule of immediate reinforcement elevated response rates in the progressive delay sessions in Experiment 1.

GENERAL DISCUSSION

Progressively increasing an unsignaled delay between a response and the subsequent reinforcer reduced response rates relative to those obtained with immediate reinforcement occurring at equivalent rates and temporal distributions. Signaling the progressive delays extended the delay durations over which responding was maintained, but both signaled and unsignaled delays yielded orderly within-session delay gradients.

The present within-session delay gradients were similar to those obtained using between-condition manipulations of delay duration. As in Experiment 1, Sizemore and Lattal (1977, cf. Lattal, 1984, 1987) showed that delay of reinforcement has a response-reducing effect on responding beyond those that accompany changes in the underlying rate and distribution of reinforcement when delays of reinforcement are imposed on schedule-

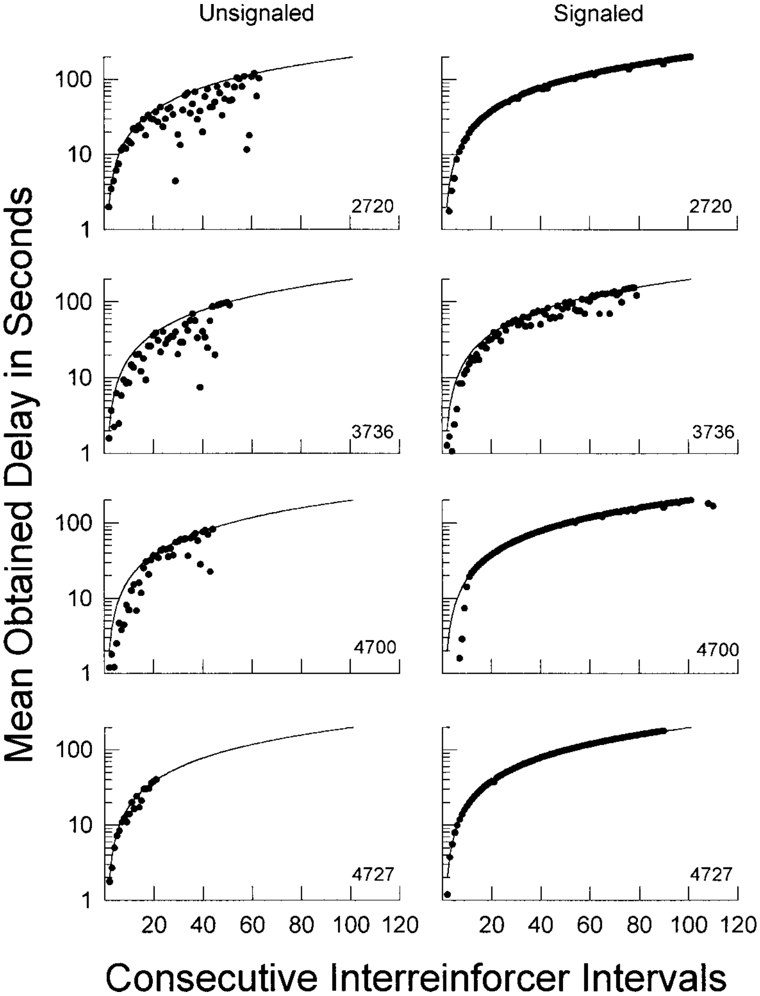

Fig. 8. Mean obtained delay (in seconds) across consecutive interreinforcer intervals in the last six sessions of the unsignaled (left panel) and signaled (right panel) delay conditions. The solid lines for each plot are the progression of nominal delay durations. Note the logarithmic *Y* axis.

maintained behavior. Unsignaled delay durations of 10 s generally reduce responding substantially when imposed as part of a between-condition analysis of delay duration effects (Richards, 1981; Sizemore & Lattal, 1978; Williams, 1976), and similar effects occurred in the present experiments. Richards showed that signaled delays maintain higher rates of responding, except perhaps at brief (less than or equal to 1 s) delay durations, than do equivalent unsignaled delays, and that signaled delays yield shallower gradients than do nominally equivalent unsignaled delays, effects replicated here in Experiment 2.

Such parallels between delay-of-reinforcement effects within individual sessions and those obtained when different delay durations are studied over successive conditions suggest that gradients generated through either procedure are similar. The present progressive-delay procedure for generating delay gradients can avoid at least two problems created by studying multiple delay conditions across blocks of sessions. First, the progressive-delay procedure allows the rapid development of delay gradients within individual sessions, thereby decreasing the amount of time required to establish a full gradient. Second, it also obviates the need for immediate reinforcement baseline conditions interposed between successive delay durations. When such baseline response rates are not equal, questions arise about comparing absolute response rates across successive delay durations.

An alternative to a progressive delay arrangement for studying within-session delay gradients is a multiple schedule in which each of several delay values could be correlated with a distinct stimulus. Multiple schedules, however, do not allow the study of the large range of delays that a progressive-delay procedure allows. In a multiple schedule, the effects of delays are assessed by rate of response or latency to respond. In addition to these two measures, the progressive-delay procedure continues to a breaking point (the delay value beyond which responding is not sustained) and allows assessment of response persistence in the face of successively increasing delay durations.

One advantage of the breaking point analysis is that it indexes persistence or strength independently of response rate (Hodos, 1961; Hodos & Kalman, 1963), a problem also addressed under the rubric of behavioral momentum by Nevin, Mandell and Atak (1983). By intruding response-independent food presentations or by imposing extinction, Nevin (1974, Exp. 4) showed that longer delays lead to less persistent responding than do shorter delays. In the present Experiment 1, a progressive delay was compared to immediate reinforcement with an outcome similar to that of Nevin in that responding continued under the immediate reinforcement condition beyond the point where it ceased under the progressive-delay procedure. The results of Experiment 2 show that responding is more persistent when delays are signaled as opposed to unsignaled.

The breaking point is used frequently as an index of response persistence in other progressive contingencies as well. In progressive-ratio schedules, for instance, lower breaking points usually are correlated with degraded reinforcers; for example, reinforcers that are less concentrated (Hodos, 1961), of lower volume (Hodos & Kalman, 1963), of a lower drug dosage (DePoortere, Li, Lane, & Emmett-Oglesby, 1993), or of which the organism is less deprived (Hodos & Kalman, 1963). The present Experiment 1 suggests that delay of reinforcement similarly degrades the reinforcer in that breaking points were reached sooner under the progressive delay as opposed to the immediate reinforcement condition in that experiment.

The present results suggest the utility of the progressive delay-of-reinforcement contingency for generating reliable, within-session delay gradients that might serve as a baseline for the investigation of the effects of other variables on behavior maintained by delayed reinforcement. Progressive delays of reinforcement, like progressive increases in ratio or interval requirements (cf. Lattal, Reilly, & Kohn, 1998), systematically decrease response rates and correlated changes in other behavioral measures as the contingencies become increasingly demanding or temporally extended. This functional relation therefore appears to be a general characteristic of progressive contingencies, independent of the specific parameter that is investigated.

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