

*MECHANISMS UNDERLYING THE EFFECTS OF  
UNSIGNALLED DELAYED REINFORCEMENT ON KEY PECKING OF  
PIGEONS UNDER VARIABLE-INTERVAL SCHEDULES*

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Three experiments were conducted to test an interpretation of the response-rate-reducing effects of unsignaled nonresetting delays to reinforcement in pigeons. According to this interpretation, rates of key pecking decrease under these conditions because key pecks alternate with hopper-observing behavior. In Experiment 1, 4 pigeons pecked a food key that raised the hopper provided that pecks on a different variable-interval-schedule key met the requirements of a variable-interval 60-s schedule. The stimuli associated with the availability of the hopper (i.e., houselight and keylight off, food key illuminated, feedback following food-key pecks) were gradually removed across phases while the dependent relation between hopper availability and variable-interval-schedule key pecks was maintained. Rates of pecking the variable-interval-schedule key decreased to low levels and rates of food-key pecks increased when variable-interval-schedule key pecks did not produce hopper-correlated stimuli. In Experiment 2, pigeons initially pecked a single key under a variable-interval 60-s schedule. Then the dependent relation between hopper presentation and key pecks was eliminated by arranging a variable-time 60-s schedule. When rates of pecking had decreased to low levels, conditions were changed so that pecks during the final 5 s of each interval changed the keylight color from green to amber. When pecking produced these hopper-correlated stimuli, pecking occurred at high rates, despite the absence of a peck-food dependency. When peck-produced changes in keylight color were uncorrelated with food, rates of pecking fell to low levels. In Experiment 3, details (obtained delays, interresponse-time distributions, eating times) of the transition from high to low response rates produced by the introduction of a 3-s unsignaled delay were tracked from session to session in 3 pigeons that had been initially trained to peck under a conventional variable-interval 60-s schedule. Decreases in response rates soon after the transition to delayed reinforcement were accompanied by decreases in eating times and alterations in interresponse-time distributions. As response rates decreased and became stable, eating times increased and their variability decreased. These findings support an interpretation of the effects of delayed reinforcement that emphasizes the importance of hopper-observing behavior.

*Key words:* observing behavior, superstitious behavior, unsignaled delay of reinforcement, variable-interval schedules, variable-time schedules, key peck, pigeon

Superstitious behavior is attributed to adventitious reinforcement, which may happen when reinforcers are presented response independently. This phenomenon was investigated by Skinner (1948), who presented food to hungry pigeons every 15 s irrespective of what the pigeons did. After hours of this treatment, he observed patterns of behavior that were repetitive and reliable in a single pigeon, but were idiosyncratic across pigeons. He suggested the following explanation:

The conditioning process is usually obvious.

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The bird happens to be executing some response as the hopper appears; as a result it tends to repeat the response. If the interval before the next presentation is not so great that extinction takes place, a second “contingency” is probable. This strengthens the response still further and subsequent reinforcement becomes more probable. (p. 168)

Based on these observations, Skinner proposed that the temporal relation between movements and reinforcers defined the response–reinforcer relation, and that dependent relations between these events were important only to the degree that they assured effective temporal relations.

There were several important consequences of Skinner’s (1948) paper for the emerging experimental analysis of behavior. Perhaps the most influential consequence was expressed by Sidman in *Tactics of Scientific*

*Research* (1960), where he devotes many pages to dealing with problems of adventitious reinforcement when designing experimental procedures. Particularly relevant to the current paper is Sidman's concern about the inherent lack of experimental control that results when delays to reinforcement are arranged:

If the reinforcement does not immediately follow the response that was required for its production, then it will follow some other behavior. Its major effect will then be upon the behavior that bears, adventitiously to be sure, the closest prior temporal relationship to the response. The effect of a delay, it might be said, is to dissipate the reinforcement over a number of unrecorded responses instead of concentrating it on the recorded behavior. (p. 371)

Although Sidman's primary concern was methodological, in this passage he summarized a theory of the response-weakening effects of delayed reinforcement. Such effects are clearly observed in studies of the effects of un signaled delayed reinforcement on schedule-controlled behavior, which is the focus of the present paper.

Response rates of pigeons under variable-interval (VI) schedules of un signaled delayed reinforcement are reliably lower than rates obtained under comparable schedules without delays (Catania & Keller, 1981; Sizemore & Lattal, 1977; Williams, 1976; see Schneider, 1990, for a review). Under delay conditions, the first peck after an interval elapses begins a delay, at the end of which food is presented. No stimulus changes accompany the delay, and responses during the delay have no effects. One interpretation of the effects of such an arrangement emphasizes superstitious behavior. According to this interpretation, un signaled delayed reinforcement makes it likely that reinforcement will be presented when the pigeon is engaging in behavior other than key pecking, which may be adventitiously reinforced. The topography of the superstitious behavior is determined by chance contiguities with reinforcement (Skinner, 1948). Superstitious behavior competes with key pecking, thus reducing its rate (Richards, 1981; Sizemore & Lattal, 1977).

The present experiments are attempts to assess the feasibility of a somewhat different interpretation of the effects of un signaled de-

layed reinforcement on schedule-controlled behavior. To illustrate this interpretation, consider a hungry, magazine-trained pigeon receiving 4-s presentations of a hopper filled with grain according to a response-independent variable-time (VT) 60-s schedule. Although no contingency exists between the pigeon's behavior and food presentation, a contingency remains between the pigeon's behavior and *eating*. The pigeon must peck the grain when the hopper is raised, and attempts to do so when the hopper is not raised do not result in eating. Under such circumstances, stimuli associated with a raised hopper (which typically include houselight and keylights going off, hopper-aperture light coming on, the sound and impact of the hopper as it is raised into place, etc.) become discriminative stimuli in the presence of which entries into the hopper aperture are reinforced with access to grain. The pigeon will eventually spend most of its time attending to hopper-correlated stimuli; that is, it will engage in *observing behavior* (Dinsmoor, 1983, 1985; Wyckoff, 1952). Such observing behavior is likely to vary topographically because no particular topography is necessary to observe the hopper; pigeons may pace or shuffle back and forth near the hopper, for example. Still, it is not necessary to conceive of such observing responses as superstitious behavior; despite the absence of a response-hopper contingency, there remains a contingency between hopper stimuli and food and between observing behavior and contact with these hopper stimuli.

If the VT 60-s schedule is then changed to a VI 60-s schedule, whatever the pigeon had done to observe the stimuli correlated with the raised hopper will be reinforced (occasionally) only following a key peck. Eventually, as rates of key pecking increase and become stable, hopper observing will be restricted to the moments after pecks. An un signaled delay between the peck that causes the hopper to be raised and the actual raising of the hopper allows the key peck and the hopper-observing behavior to be separated in time. Such conditions approximate those arranged by the VT schedule, in the sense that longer bouts of hopper observing after key pecks may be reinforced. Rates of key pecking fall as bouts of hopper observing increase in duration.

In the first two experiments reported here, we attempted to tag hopper-observing behavior and observe changes in its rate when relations between the conventional operant key peck and hopper presentation were altered. In Experiment 1, pecks on the left green key (the VI key) produced changes in stimuli that are typically associated with food availability (e.g., houselight and keylights going off), but rather than raising the hopper immediately, the right red key (the food key) was illuminated and a 5-s hopper-access period started. A peck to the food key raised the hopper for 5 s minus the latency to peck. Pecks to the food key were intended to serve as the "topographical tag" for hopper observing and approach (see McLean, 1992, for an example of such an approach in the study of behavioral contrast). Across conditions, stimuli correlated with hopper availability were gradually removed, so that eventually pecks to the VI key still produced the hopper-access period but produced none of the stimuli that indicated that food was available. In this context, pecks to the food key, which were necessary to detect whether food was available, could compete with VI-key pecking in a way that is analogous to hopper observing under delayed reinforcement conditions. In Experiment 2, a VT schedule was arranged so that key pecks were not required for hopper delivery. Key pecks produced a change in key color that was correlated with impending hopper delivery (i.e., they served a hopper-observing function). Finally, Experiment 3 was a replication of the effects of un signaled nonresetting delays to reinforcement appended to VI schedules. Special attention was paid to dependent measures in addition to response rates which, according to the present interpretation, should be altered by delayed reinforcement.

## EXPERIMENT 1

### METHOD

#### *Subjects*

Four adult female White Carneau pigeons (*Columba livia*) with prior experimental experience (with fixed-ratio and fixed-interval schedules) were used in this experiment. They were maintained at approximately 80% of their free-feeding weights via postsession

feeding. When not in experimental sessions, subjects were housed individually in a temperature-controlled colony at the University of Minnesota where they were allowed free access to water and digestive grit. Lights in the colony remained on 24 hr per day.

#### *Apparatus*

Two custom-made two-key experimental chambers were used. The internal dimensions of the chambers were 30 cm across the front panel, 31 cm from the front panel to the back wall, and 35 cm from floor to ceiling. All but one side wall of the chambers were constructed of aluminum, so that they resembled boxes tipped on their sides. They were designed to be used in a large sound-attenuating enclosure into which a device for measuring schedule-induced attack could be placed. For this experiment, a gray plastic wall was placed in front of the open side of the chamber after the pigeon was placed inside; then the door to the enclosure was closed. Two response keys on the front panels were mounted 26 cm from the floor. They could be lit from behind with green or red lights, and required a force of approximately 0.19 N to record a response. A 28-V 1.1-W lamp mounted in the center of the ceiling served as a houselight. A rectangular aperture centered between and 16 cm below the keys provided access to a solenoid-operated food hopper. During hopper presentations the aperture was lit with white light. Pecks to the left key produced a 0.1-s feedback beep from a Mallory Sonalert; pecks to the right key produced this feedback beep under some conditions. Extraneous noise was masked by white noise and ventilation fans. Contingencies were programmed and data were collected by an MS-DOS-based 80286 microcomputer, programmed under Medstate<sup>®</sup> notation (MED Associates, Inc. & Tatham, 1991) software.

#### *Procedure*

The conditions arranged in this experiment are listed and described in Table 1. Because the pigeons had pecked keys under food-reinforcement schedules before, only brief training was required to establish pecking of the left (VI) key. A conventional VI 60-s schedule was arranged for VI-key pecks. This VI schedule, and every other VI or VT

Table 1

Description of stimuli in conditions of Experiment 1. All panel lights were extinguished and the hopper light was lit when the hopper was raised.

Condition	During the VI	During hopper-access period (before food-key peck)
Baseline	HL on, <sup>a</sup> VI key on, food key off, no beep <sup>b</sup>	HL off, VI key off, food key on, beep
5-s delay	Same as baseline with 5-s unsignaled delay to hopper-access period	Same as baseline
Condition 1	HL on, VI key on, food key off, no beep	HL on, VI key on, food key on, beep
Condition 2	HL on, VI key on, food key on, no beep	HL on, VI key on, food key on, beep
Condition 3	HL on, VI key on, food key on, beep	HL on, VI key on, food key on, beep
Condition 3 (del)	Same as Condition 3 with 5-s unsignaled delay to hopper-access period	Same as Condition 3

<sup>a</sup> HL = houselight.

<sup>b</sup> beep = feedback beep produced by food-key pecks.

schedule used in these experiments, consisted of 20 intervals, generated using the method of Fleshler and Hoffman (1962), that were selected randomly without replacement twice during each session. During the first few sessions the longest intervals were reduced so that a much higher reinforcement rate was obtained. After two or three sessions under the VI 60-s schedule, conditions were changed such that VI-key pecks after an interval elapsed turned off the houselight and the VI keylight, illuminated the right (food) key red, and started a 5-s clock, referred to here as the hopper-access period. A peck to the food key turned off that key, produced a feedback beep, and raised the hopper for 5 s minus the latency to this peck. This condition (referred to as “baseline” in Table 1) was intended to serve as an analogue of conventional one-key VI schedules, in which the first

peck after an interval elapses produces a number of stimulus changes in addition to the presentation of the hopper. Pecks to the food key were intended to be functionally analogous to hopper observing and approach. Sessions ended after 40 hopper-access periods had been presented. This condition was reinstated after each subsequent condition, so that each transition was from the baseline condition. All phases were continued for at least 10 sessions, and until response rates and latencies to peck the food key varied little from session to session, as judged visually. The order of conditions and the number of sessions per condition are listed for each pigeon in Table 2.

Following the first baseline condition, the schedule on the VI key was changed to a tandem VI 55-s fixed-time (FT) 5-s schedule. In other words, a 5-s unsignaled delay to the hopper-access period was arranged, at the end of which the houselight and VI key were extinguished and the food key was illuminated. The effect of pecking either key during the FT 5-s schedule was not different from pecks during the VI portion of the schedule. This condition (“5-s delay” in Table 1) was tested to determine whether behavior under the two-key arrangement used here was affected by unsignaled delayed reinforcement in the same manner as behavior in the conventional one-key arrangement.

During the next conditions, the stimuli that followed the first VI-key peck after each VI 60-s interval elapsed (houselight and VI key extinguished, food key illuminated) were gradually removed. In Condition 1, upon

Table 2

Order of conditions and number of sessions in each condition for subjects in Experiment 1.

Condition	Subjects			
	159	409	41	24
Baseline	71	70	59	55
5-s delay	28	41	28	53
Baseline	26	15	28	19
Condition 1	44	55	44	54
Baseline	12	27	12	13
Condition 2	29 <sup>a</sup>	17	21	16
Baseline	13	17	16	32
Condition 3	21	12	24	12
Baseline	12	14	12	13
Condition 3 (del)	34	16	31	28

<sup>a</sup> Procedure altered during Sessions 6–13; see text.

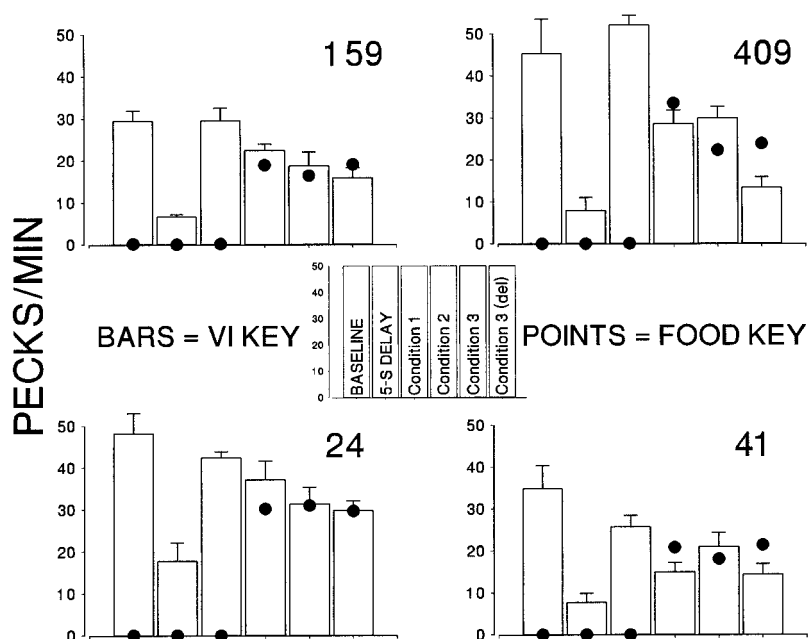


Fig. 1. Mean rates of pecking the VI key (indicated by the bars, +1 SD) and the food key (indicated by the points) obtained from the final 10 sessions of each condition in Experiment 1. The bars in the inset panel indicate the conditions from which the data were obtained. The bar labeled "baseline" depicts the mean (+1 SD) of the mean rates obtained during the six exposures to this condition. Variability around the points depicting food-key rates is not indicated, because in nearly every case the variability was less than the size of the points that indicate the means.

completion of the VI interval, a peck on the VI key illuminated the food key but did not extinguish the houselight or the VI key. Condition 2 was identical to Condition 1 except that the food key was illuminated constantly (except when the hopper was raised); pecks to this key prior to the VI-key peck that ended the interval did not produce a feedback beep. During the first five sessions of this condition, Pigeon 159 failed to peck the food key and therefore earned no reinforcers. During this pigeon's next six sessions one half, or 20, of the hopper-access periods were accompanied by a darkened VI key. When Condition 2 was reinstated, this pigeon continued to peck the food key and obtain all available reinforcers. Condition 3 was identical to Condition 2, except that each peck on the food key also produced the feedback beep that followed food-key pecks that raised the hopper. Following this phase, conditions were unchanged except for the insertion of a 5-s unsignaled delay to the hopper-access period, arranged as in the 5-s delay phase, except that there were no stimulus changes after the delay had

elapsed (referred to as "Condition 3 [del]" in Table 1).

Rates of VI-key and food-key pecking, latencies to peck the food key after the start of the hopper-access period, and reinforcers per session were collected each session.

### RESULTS

Figure 1 depicts mean rates of pecking the VI key and the food key obtained from the final 10 sessions of each condition. Rates and patterns of VI-key pecking during baseline are typical of those obtained under VI 60-s schedules. Rates of VI-key pecking fell to low levels when a 5-s unsignaled delay to the hopper-access period was arranged.

In Condition 1, in which the food key was illuminated but the VI key and houselight were not extinguished following the peck that satisfied the VI contingency, rates of pecking did not vary systematically from rates obtained during baseline conditions. Lower VI-key rates were obtained when the food key was illuminated constantly (indicated by the three rightmost bars in each panel), with the

Table 3

Mean obtained hopper durations (5 s minus latency to peck the food key) for the last 10 sessions of each condition in Experiment 1. Standard deviations are in parentheses.

Condition	Subjects			
	159	409	41	24
Baseline	4.13 (0.09)	1.83 (0.16)	3.81 (0.17)	3.52 (0.07)
5-s delay	3.86 (0.15)	2.19 (0.26)	3.51 (0.19)	3.23 (0.10)
Baseline	4.21 (0.10)	2.01 (0.18)	4.10 (0.11)	3.92 (0.08)
Condition 1	4.18 (0.07)	4.23 (0.03)	4.20 (0.02)	4.21 (0.05)
Baseline	4.30 (0.06)	2.36 (0.20)	4.11 (0.05)	3.40 (0.06)
Condition 2	3.84 (0.20)	4.46 (0.11)	3.84 (0.16)	4.27 (0.11)
Baseline	4.34 (0.06)	2.44 (0.20)	4.32 (0.05)	4.14 (0.05)
Condition 3	3.44 (0.27)	4.31 (0.08)	3.44 (0.27)	4.45 (0.11)
Baseline	4.41 (0.03)	2.79 (0.11)	4.24 (0.10)	4.10 (0.19)
Condition 3 (del)	3.98 (0.21)	3.88 (0.13)	3.39 (0.21)	4.02 (0.14)

lowest rates obtained when a delay to the hopper-access period was also in effect. It was also during these last three conditions that rates of food-key pecking increased above zero. Food-key rates varied little across these conditions, except for Pigeon 409, for whom food-key rates during Condition 2 were higher than in the remaining two conditions.

Mean obtained hopper durations, calculated by subtracting the latency to peck the food key from 5 s, are listed for the last 10 sessions of each condition in Table 3. Small and unsystematic changes in mean hopper durations were obtained for Pigeons 159, 24, and 41. Hopper durations were increased for Pigeon 409 in each condition in which the VI key and the houselight remained illuminated during the hopper-access period.

#### DISCUSSION

The two-key procedure arranged in Experiment 1 allowed us to eliminate stimulus changes correlated with the hopper-access period while retaining the dependent relation between VI-key pecks and food delivery. In other words, VI-key pecking and hopper observing (i.e., food-key pecking) could be separated. Rates of VI-key pecking were reduced to low levels when a 5-s unsignaled delay to the hopper-access period was arranged, which increases our confidence that the two-key procedure is a functional analogue of the conventional unsignaled delay procedure. VI-key pecking rates were reliably reduced under the conditions in which VI-key pecks produced no stimulus changes associated with hopper availability. During these same con-

ditions, rates of pecking the food key increased. The relevance of this result to understanding the effects of unsignaled delayed reinforcement depends on the plausibility of the suggestion that food-key pecks in this procedure are similar in function to hopper-observing behavior.

Condition 1, in which the hopper-access period was associated only with the illumination of the food key, did not reliably reduce VI-key pecking rates. Under this condition rates became stable at levels relatively near those obtained under baseline conditions. It is likely that discriminative control of food-key pecking by the illumination of the food key alone was established quickly and was maintained during this phase, so that VI-key pecking proceeded in a manner similar to that during baseline conditions.

In addition to the functional similarities between these conditions and conventional conditions with unsignaled delayed reinforcement, it is important to consider the differences between them. For example, in the current conditions the behavior that brought the pigeon into contact with hopper availability was *required* (i.e., the hopper was not raised if the food key was not pecked), but under conditions with unsignaled delayed reinforcement the hopper is raised regardless of what the pigeon does following the initiation of the delay. It is central to the interpretation suggested here that, even though hopper presentations are response independent once the delay has begun, hopper observing is required for eating to occur. This dependent relation assures behavior that, like

food-key pecking here, competes with and reduces the rate of key pecking. Another difference is that the actual delay between a VI-key peck and hopper presentation is relatively short under this procedure, but can and often does approximate programmed delays under conditions with unsignaled delayed reinforcement. The actual interval between a VI-key peck and the hopper being raised in Conditions 1, 2, and 3 can be determined by subtracting the obtained hopper durations in Table 3 from 5 s. Despite relatively short obtained delays, which were similar across conditions, rates of VI-key pecking were reduced under many of the conditions tested here.

In summary, in Experiment 1 it was shown that behavior analogous to hopper observing could compete with VI-key pecking under conditions in which VI-key pecks did not produce any of the stimuli correlated with hopper availability. Experiment 2 was an attempt to show that stimuli correlated with hopper availability could maintain behavior at high rates even in the absence of a dependent relation between behavior and hopper presentation.

## EXPERIMENT 2

### METHOD

#### *Subjects*

The 4 pigeons used in Experiment 1 were transported to West Virginia University to serve in this experiment. They had free access to food for several weeks before their weights were reduced to 80% of free-feeding levels. Their housing conditions differed little from those in Minnesota, except that home cages were approximately 23,040 cm<sup>3</sup> larger and a light/dark cycle operated in West Virginia.

#### *Apparatus*

Four custom-built experimental chambers were used. The internal dimensions of each chamber were 33 cm across the front panel, 31 cm from the front panel to the back wall, and 37.5 cm from floor to ceiling. Chambers were constructed of wood with aluminum front panels. Three response keys on the front panel were mounted 26 cm from the floor. The center key could be lit from behind with green or amber lights. The side

keys were dark and inoperative. The center key required a force of approximately 0.19 N to record a response. A 28-V 1.1-W lamp 7 cm above the center key served as a houselight. Other details of the apparatus were similar to that used in Experiment 1.

#### *Procedure*

Experimental sessions were conducted 6 or 7 days per week at approximately the same time each day. Sessions were terminated after 40 reinforcers had been delivered. Initially subjects were exposed to a VI 60-s schedule of food reinforcement with the center key illuminated green. The first response after the VI had elapsed produced 4-s access to grain. When key-pecking rates were stable as judged visually, conditions were changed so that the hopper was presented response independently on a tandem VT 55-s FT 5-s schedule. Before response rates fell to zero, which required 5 to 19 sessions depending on the pigeon, conditions were changed such that if a peck occurred during the FT 5-s schedule the keylight changed from green to amber and remained amber until the hopper was presented. Pecks during this period did not alter the delay to food; for example, if a peck occurred 2 s into the FT 5-s period, food was delivered 3 s later, regardless of what the pigeons did subsequently. Note also that this condition did not alter the response-independent nature of the schedule. Reinforcement was presented at the same rate whether or not pigeons pecked.

When rates of responding under this condition were stable, the correlation between the change in key color and the presentation of the hopper was eliminated. Key-color changes were presented following pecks according to the same tandem VT 55-s FT 5-s schedule as arranged previously. Thus, after a VT 55-s interval had elapsed, a 5-s period during which the first peck changed the color of the key for 5 s minus the latency to peck the key occurred. The hopper, however, was presented on an independent tandem VT 55-s FT 5-s schedule, so that key-color changes and hopper presentations were not explicitly correlated. Before rates of key pecking fell to zero, which required 16 to 31 sessions depending on the pigeon, the condition with food-correlated keylight changes was reinstated.

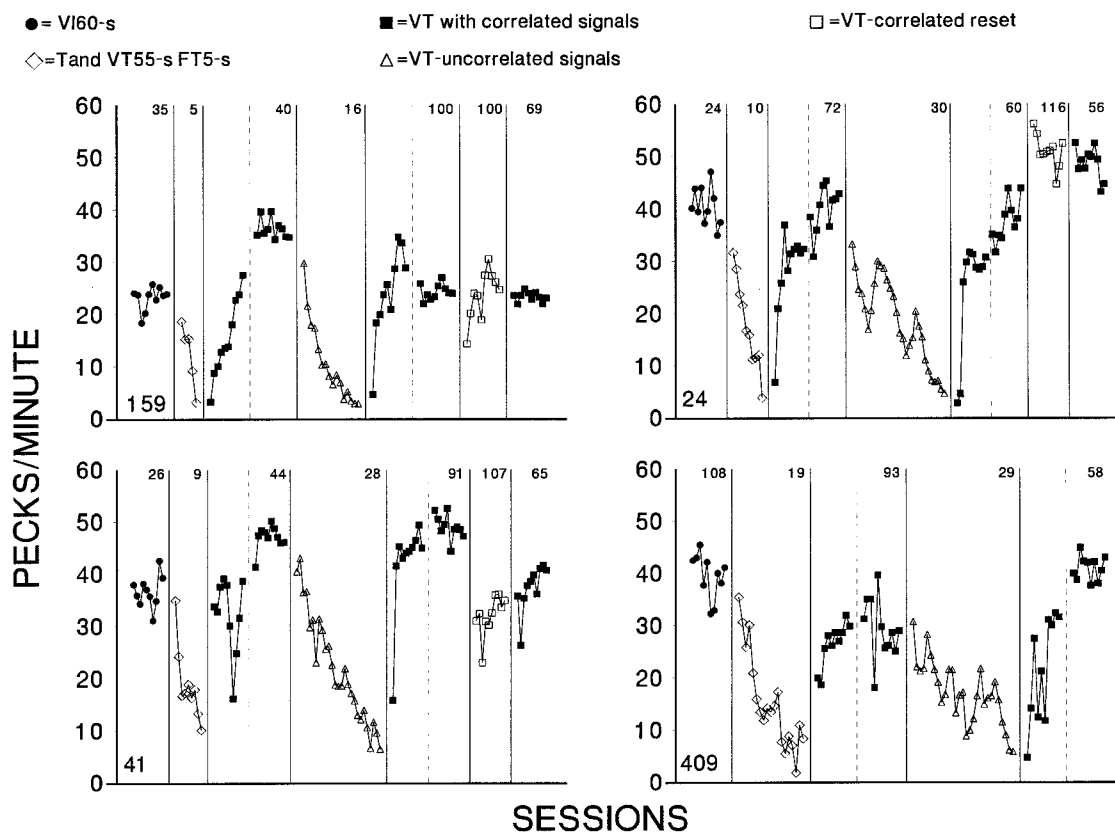


Fig. 2. Response rates (pecks per minute) during each condition of Experiment 2. Solid vertical lines separate conditions, and broken vertical lines separate the first 10 from the last 10 sessions of some conditions. No broken line indicates that rates from all sessions of a condition are shown. The numbers of sessions in each condition appear above the data near the lines that separate conditions.

When rates of key pecking were again stable, conditions were arranged for Pigeons 41, 24, and 159 such that any response that occurred after the change in key color reset the FT 5-s portion of the tandem schedule (here referred to as the reset condition). When response rates were stable, subjects were returned to the condition with food-correlated keylight changes. Pigeon 409 was not exposed to these last two conditions because of time constraints.

Some conditions remained in effect for many sessions after stable rates had been obtained. Rates of pecking prior to the food-correlated stimulus, rates of pecking during the stimulus, and cumulative records of responding were collected daily.

RESULTS

Response rates typical of VI schedules of food reinforcement were obtained for all pi-

geons, with a range across subjects of 20 to 50 pecks per minute (see Figure 2). Response rates fell to near-zero levels within 5 to 19 sessions when food was presented response independently in the VT 55-s FT 5-s condition. When pecks during the FT portion of an interval produced a change in key color, rates rose to levels near or above those obtained in the VI 60-s condition. When response-dependent changes in key color were not correlated with hopper presentation, rates fell to levels near those obtained in the previous VT 55-s FT 5-s condition. When the food-correlated stimulus was again presented after a peck during the FT 5-s portion of the tandem schedule, response rates increased again. Rates were changed little for Pigeon 159 during the RESET condition, rates of Pigeon 41 decreased somewhat, and rates of Pigeon 24 increased (Pigeon 409 was not exposed to this condition). Finally, response rates changed

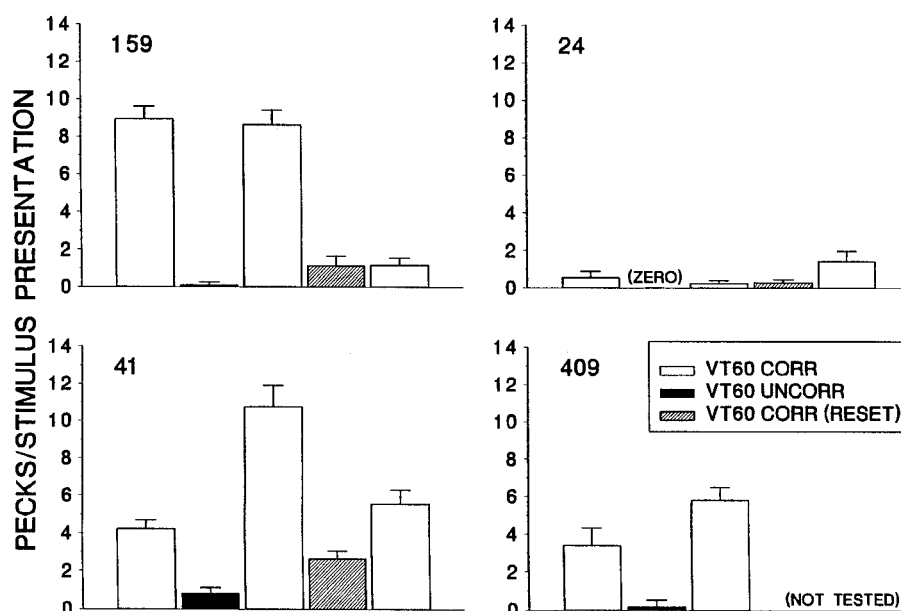


Fig. 3. Pecks per presentation of the amber stimulus (means of last 10 sessions) either correlated or uncorrelated with food presentation, and when pecks to the stimulus reset the FT 5-s portion of the schedule in Experiment 2. Vertical lines show standard deviations.

little when pecks to the food-correlated stimulus no longer reset the FT portion of the schedule.

Figure 3 shows pecks during each presentation of the stimulus either correlated or uncorrelated with food presentation and when pecks to the stimulus reset the FT 5 s. Pigeons 159, 41, and 409 pecked the stimulus more often when it was correlated with hopper presentation than when it was not. Pigeon 24 pecked the food-correlated stimulus at low rates regardless of its relation to the reinforcer. When pecks to the food-correlated stimulus reset the FT portion of the schedule, Pigeons 159, 41, and 24 pecked it infrequently (recall that Pigeon 409 was not exposed to this or the final condition). Pigeons 159 and 24 continued to respond to the correlated stimulus at low levels when pecks no longer reset the FT portion of the schedule, and Pigeon 41 responded at only slightly higher levels.

DISCUSSION

This experiment was intended to show that operant behavior that brings pigeons into contact with stimuli correlated with hopper availability is maintained in the absence of a dependent relation between pecking and

hopper presentation. The results lend support to the suggestion that rates of key pecking decrease under conditions with un signaled delays to reinforcement because hopper-observing behavior increases in rate. In this experiment hopper-observing behavior was key pecking that produced a hopper-correlated stimulus. Ordinarily the topography of hopper observing during conditions with un signaled delayed reinforcement is not under the experimenter's explicit control. Nevertheless, variability in those topographies is restricted by the lingering dependency between hopper detection and eating. Here we consider alternative explanations for the current results as well as findings from other behavioral procedures that support the current observing-behavior interpretation.

The high rates of pecking by 2 pigeons during the food-correlated stimulus suggest that the reliable pairing of the amber keylight with food resulted, through a Pavlovian or stimulus-stimulus contingency, in the amber keylight becoming a conditional stimulus (CS). This suggests two explanations of the behavioral effects of the amber keylight that differ subtly from the present explanation. First, high rates of key pecking elicited by the amber light could lead to short obtained de-

lays between pecking and the delivery of food, thus strengthening key pecking directly via adventitious reinforcement. An attempt was made to control for this possibility by imposing the reset contingency, which assured that obtained delays to reinforcement were at least 5 s long. Under this condition, overall response rates were altered slightly, but were still much higher than rates in conditions without stimuli correlated with hopper availability. In addition, Pigeon 24 rarely responded to the correlated stimulus throughout the experiment, with or without the added reset contingency, and overall response-rate patterns were similar to those of the other subjects. Therefore, high rates of pecking during the VT 55-s schedule with correlated stimuli were observed regardless of the obtained delays to reinforcement.

Second, the Pavlovian contingency may simply have established the conditioned reinforcing effects of the stimulus. During conditions in which pecking could produce the food-correlated stimulus, even a relatively low rate of pecking assured frequent pairings of the amber keylight with food. These pairings could be considered Pavlovian conditioning trials, which established the conditioned reinforcing efficacy of the food-correlated stimulus. This interpretation is consistent with the high rates observed when the key-color change was correlated with food and the low rates obtained when the correlation was eliminated (Gibbon, Locurto, & Terrace, 1975). Relevant to this discussion is a study of sign tracking in pigeons (Silva, Silva, & Pear, 1992), in which a CS (light) was presented at various distances from an unconditioned stimulus (US, grain hopper). Pigeons tended to approach the CS (i.e., sign track) when it was near (22 cm) the hopper. Pigeons tended to approach the hopper (i.e., goal track), however, when the CS and the hopper were farther apart (60 cm). This finding suggests that, although the Pavlovian procedure established the function of the CS, the specific behavior that occurred when the CS was presented was one that allowed pigeons to get to the hopper (or at least did not interfere with hopper detection and eating). It is likely that Pavlovian conditioning established the reinforcing efficacy of the key-color change in the current study. Still, based on this discussion, it is expected that food-correlated keylights

would reinforce key pecking near the hopper (as in the present study), but as the key was moved away from the hopper, a form of observing behavior that allowed pigeons to be near the hopper may predominate and key pecking may cease.

### EXPERIMENT 3

Experiment 3 examined once again the effects on key pecking of conventional VI schedules of un signaled delayed reinforcement. Particular attention was paid to dependent variables in addition to response rates that, according to the present interpretation, should be altered by un signaled delayed reinforcement. For example, because alterations in the detection of the hopper and the consumption of food are central to the current explanation, photocells were installed in the hoppers so that latencies to eat from the hopper could be recorded. Also, VI schedules of immediate reinforcement characteristically arrange for the differential reinforcement of long interresponse times (IRTs) (Kramer & Rilling, 1970; Kuch & Platt, 1976). Un signaled delayed reinforcement lessens the temporal precision of reinforcer delivery that is required for IRT differentiation, so changes in the distribution of IRTs due to delayed reinforcement would be expected.

### METHOD

#### *Subjects*

Three naive male White Carneau breeders, maintained at 80% of their free-feeding weights via postsession supplemental feedings, were used as subjects in this experiment. Their housing, care, and maintenance were as described for pigeons in Experiment 2.

#### *Apparatus*

The apparatus was the same as that used in Experiment 2, except that photocells were mounted on either side of the recessed area that provided access to the hopper. The photocells were positioned near the magazine's entrance at a level such that the beam was broken whenever a pigeon put its head into the recessed area to eat.

#### *Procedure*

Following adaptation, magazine training, and autoshaping to the center key (lit green),

pigeons were exposed to VI schedules of increasing values until they responded on a VI 60-s schedule of 4-s access to grain. The pigeons were exposed to delayed reinforcement conditions successively, Pigeon 712 first, followed by P4 and 829.

During delayed reinforcement conditions, a 3-s un signaled delay preceded reinforcer presentations, that is, a tandem VI 57-s FT 3-s schedule was in effect. Pecks during the delay did not reset the delay. When response rates and eating times were again stable, the VI 60-s condition was reinstated for several sessions before the experiment ended.

Rates of key pecking, eating times (calculated by subtracting the latency to break the photocell beams from the 4-s hopper duration) recorded for each reinforcer delivery, obtained delays (the time from food presentation to the last peck that preceded it) recorded for each reinforcer delivery, and the temporal location of each peck and reinforcer in the session, which were used to construct IRT distributions, were collected daily.

#### RESULTS

Response rates typical of those produced by VI schedules of reinforcement were obtained for all pigeons in the VI 60-s condition, with a range across subjects of 35 to 60 pecks per minute (see Figure 4). Rates of pecking decreased with the introduction of a 3-s un signaled delay to reinforcement and increased to baseline levels with the return to the VI 60-s schedule. Note in particular the fluctuations in rates from session to session as they approached stable levels near the end of the delay condition, and the similarity in these fluctuations between subjects. Rates of pecking during some sessions increased to levels near those obtained with immediate reinforcement, even though these sessions followed sessions in which relatively low rates and long obtained delays were obtained.

Mean eating times ranged from 2.0 to 3.0 s across subjects in the initial VI 60-s condition (see Figure 5). Mean eating times immediately decreased and the variability around the means increased with the introduction of the 3-s delay condition, but subsequently eating times increased across sessions and decreased in variability for Pigeons 712 and P4. Mean eating times for Pigeon 829 also increased during this condition, but

less obviously than for the other pigeons (mean eating times increased by roughly 0.25 s from the start to the end of the condition). When the VI 60-s schedule was reinstated, variability around the mean eating times decreased immediately, and mean eating times were longer than during the first VI 60-s condition.

The disruption in eating that accompanied the introduction of the condition with un signaled delays is revealed more completely in Figure 6. This figure shows, for each pigeon, the eating time for each reinforcer presentation during the delayed reinforcement condition. Scanning the figure from left to right reveals that several hopper presentations were missed entirely early in the phase, but by the end of the phase this occurred infrequently. In fact, the first three hopper presentations of this condition were missed by Pigeons 712 and P4. Pigeon 712 retreated to the back of the chamber when the first two hopper presentations occurred and returned to the key slowly, in a manner sometimes observed early in magazine training. Also, the heaviest cluster of eating times slowly increased during the condition. Although there was some variability in eating times prior to this condition (see Figure 5), no reinforcers were missed entirely in the five sessions prior to the condition with un signaled delays for any pigeon.

Mean obtained delays to hopper presentation for each session of the condition with un signaled delayed reinforcement are shown in Figure 7. Not surprisingly, they were inversely related to the changes in response rates shown in Figure 4, with longest mean delays obtained when rates of pecking were lowest.

IRT distributions from the sessions for which data are presented were similar to distributions obtained during the preceding three sessions of each experimental condition (see Figure 8). IRT distributions obtained under immediate reinforcement conditions were typical of those obtained under VI schedules. In each case the distribution of IRTs was altered during the delayed reinforcement condition. These alterations differed across subjects, some including a shift to the left in the modal IRT (829 and P4) and others involving a shift to the right in the mode (712). Distributions for each subject,

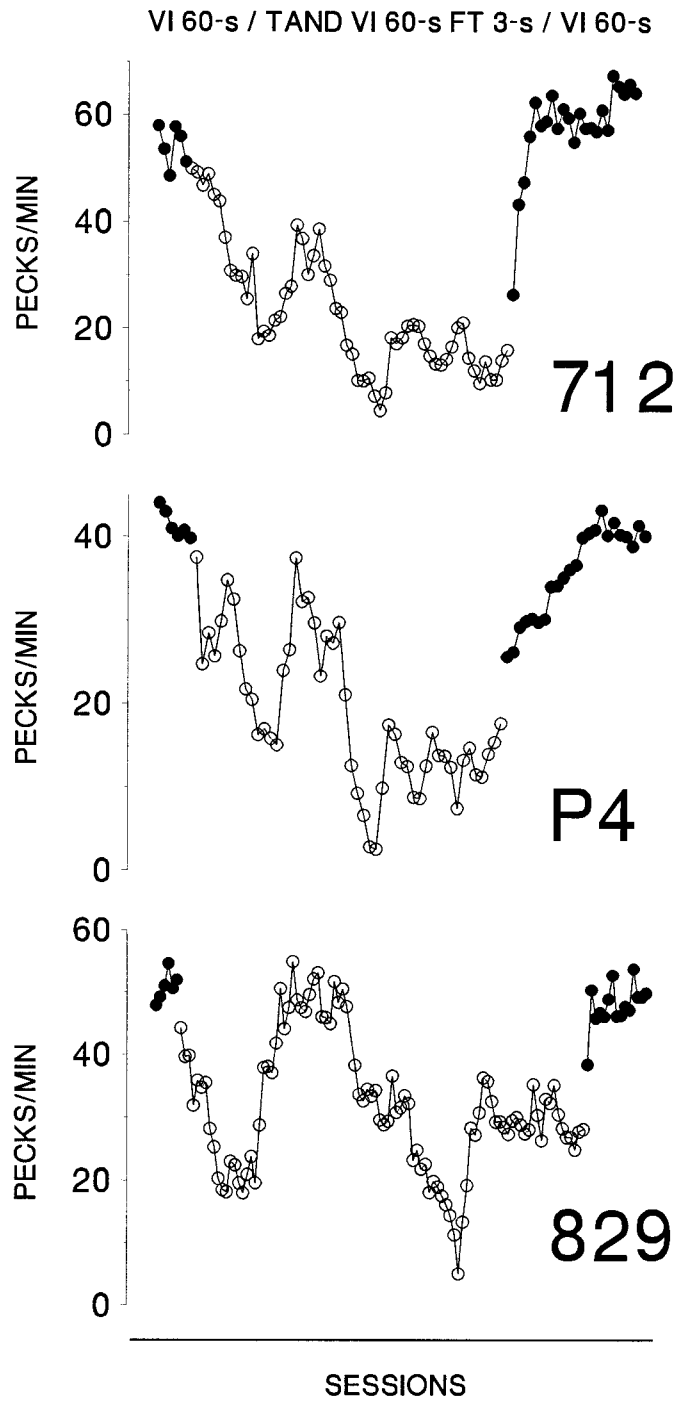


Fig. 4. Response rates (pecks per minute) obtained during the final six sessions of conditions with immediate reinforcement (filled circles) and during each session of conditions with 3-s unsignaled delayed reinforcement (open circles) in Experiment 3.

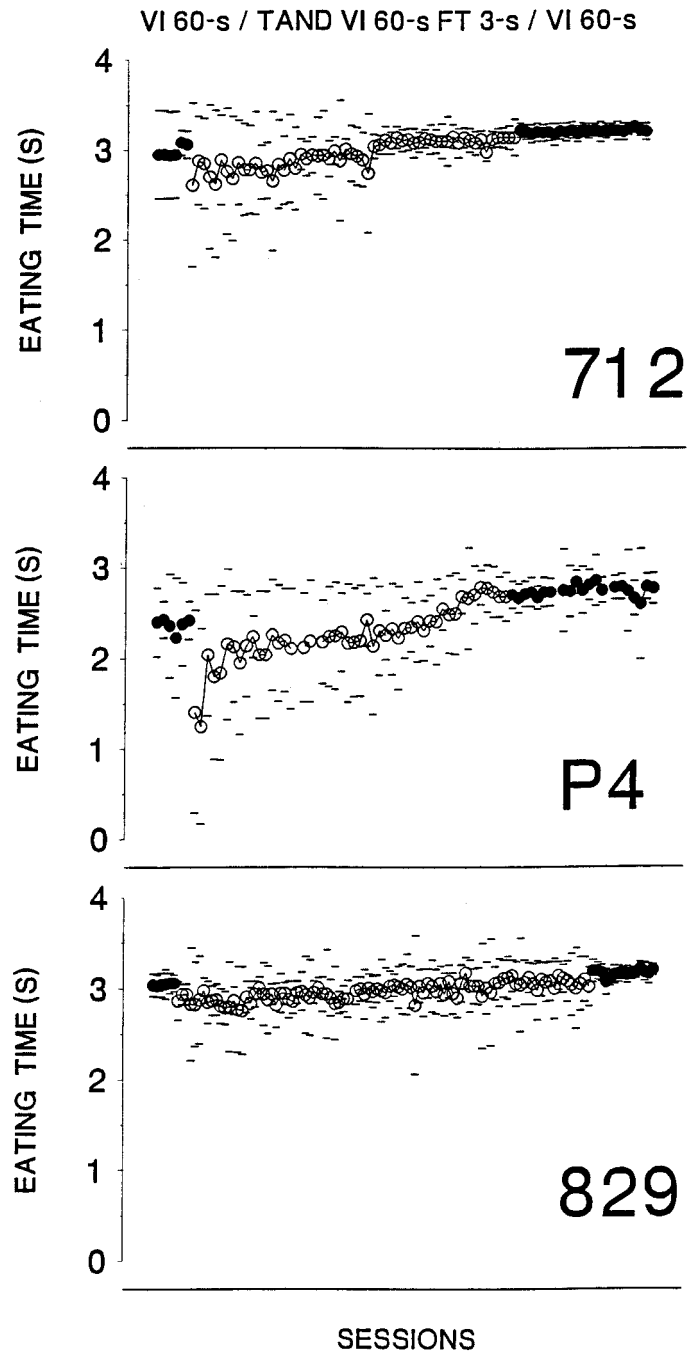


Fig. 5. Eating times (4 s minus latency to feed) obtained during each session of conditions with immediate reinforcement (filled circles) and 3-s unsignaled delayed reinforcement (open circles) in Experiment 3. Short lines above and below each point represent  $\pm 1$  SD.

however, could be described as spread out during the delayed reinforcement condition relative to the immediate reinforcement condition.

#### DISCUSSION

This experiment replicates several others that have shown that unsignaled nonresetting delays to reinforcement reduce rates of key pecking relative to rates obtained under comparable immediate reinforcement schedules (see Schneider, 1990, for a review). The transition from high response rates under immediate reinforcement conditions to low response rates under conditions with unsignaled delayed reinforcement was, for each pigeon, a "bumpy" one that included decreases in rates followed by increases followed by decreases, and so forth, until stable rates were obtained. Other dependent measures were also altered by delayed reinforcement. Eating times were reduced and were more variable, and early in the condition some reinforcers were missed entirely. Mean eating times recovered during the course of the delayed reinforcement condition. Obtained delays mirrored changes in response rates, and IRT distributions were altered during delayed reinforcement conditions.

The reliably bumpy transition in response rates in this experiment has been observed by the first author in previous studies (e.g., Schaal & Branch, 1988), and has been obtained in other laboratories under similar delayed reinforcement conditions (see Figure 1 in Williams, 1976). These large fluctuations during the transition from low to high response rates argue against an interpretation of rate decreases as reflecting in any simple way the progressively poorer response-strengthening effect of gradually more delayed reinforcers. As a progressively larger proportion of obtained delays approaches the maximum delay (in this case, 3 s), one might expect response rates to be reduced further and to become stable at a point at which response rates reflect the reduced reinforcing effect of the delayed reinforcers. This description of the possible relation between obtained delays and subsequent response rates does not correspond to the pattern of rates observed across sessions (Figure 4). A relation between obtained delays and response rates is, apparently, a dynamic one that may

be determined, in part, by the local response rates when certain delays are experienced. For example, hopper presentations that are nearly contiguous with pecks may have disproportionately large strengthening effects when local response rates are low, as they are at times during the transition from immediate to delayed reinforcement. Alternatively, when response rates are very low, stimuli produced by each key peck are more positively related, in a Pavlovian conditioning sense, to hopper presentation. If these stimuli function as conditioned reinforcers, one might expect their reinforcing efficacy to wax and wane as does their correlation to food presentations as response rates change.

Figures 5 and 6 show clearly that hopper detection, as indicated by alterations in eating times, was disrupted under conditions with unsignaled delayed reinforcement. This disruption suggests that discriminative control of hopper approach was disrupted, most obviously early in the phase when many hopper presentations were missed entirely (Figure 6). After this initial effect of discontinuous hopper presentations, acquisition of discriminative control over hopper approach by stimuli that do not include pecks may take place. The recovery of eating times during this phase suggests such an acquisition process. As this continues, sequences of pecks followed by hopper-observing behavior may be reliably followed by food presentation, so that, eventually, a chain of behavior that includes pecks (or bursts of pecks) and hopper observing is formed, with the result that rates of pecking are typically lower, eating times recover and become less variable, and obtained delays become relatively stable. Because the hopper-observing behavior is not specified by the experimenter, it is allowed to vary across pigeons. In some isolated cases, in fact, this behavior may include high rates of pecking that, at least, keep the pigeon relatively near the hopper at the moment of its presentation.

A point clarifying the functional role of the altered eating times should be made. It is not our intention to assert that response rates are altered by delayed reinforcement because pigeons experience a lower reinforcer magnitude. One would not expect to observe rate reductions this large, or the pattern of response rates during the transition, if rather than delaying reinforcement the duration of

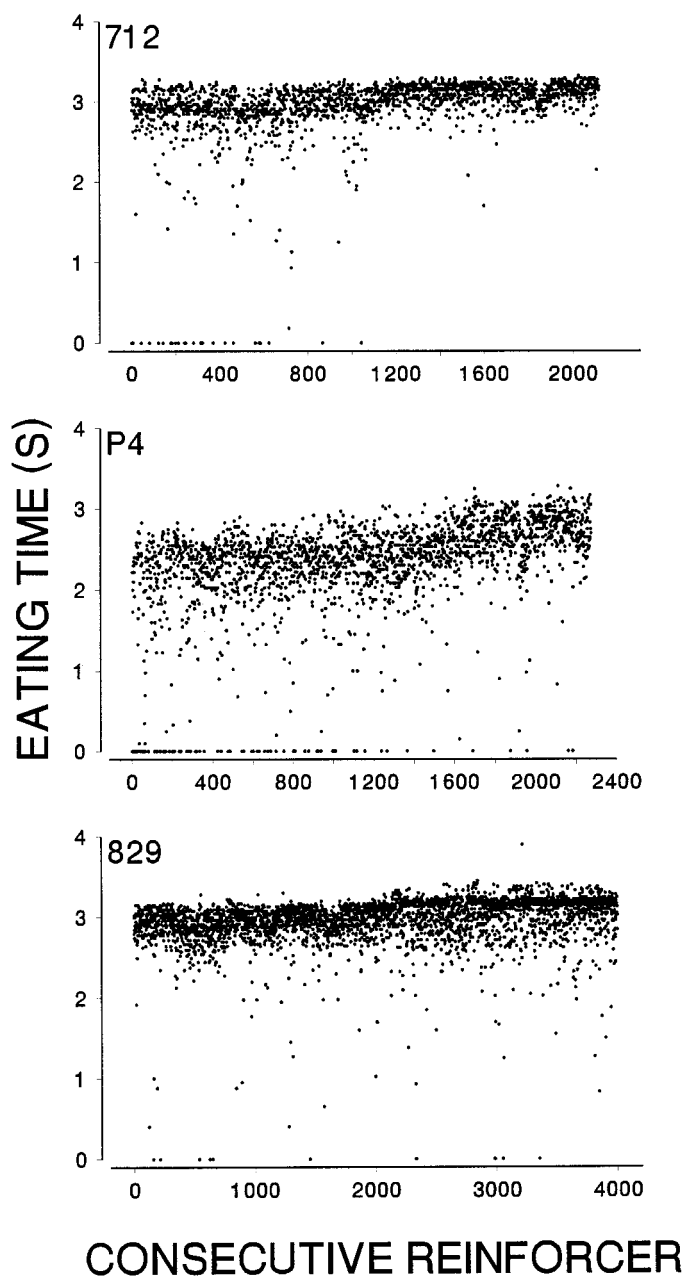


Fig. 6. Eating time obtained for each reinforcer presentation during the delayed reinforcement condition in Experiment 3.

immediate hopper presentations was shortened to approximate the eating times experienced by these pigeons. This is because, first, shorter-but-still-immediate hopper presentations would not alter the IRT-differentiation feature of VI schedules, and so this change due to delayed reinforcement would

not occur. Second, for the most part, the mean changes in eating times were not large. It is not uncommon in our laboratory to reduce hopper durations from 4.0 to 2.0 or 2.5 s if pigeons gain too much weight during sessions. These reductions in hopper durations typically have little or no effect on subsequent

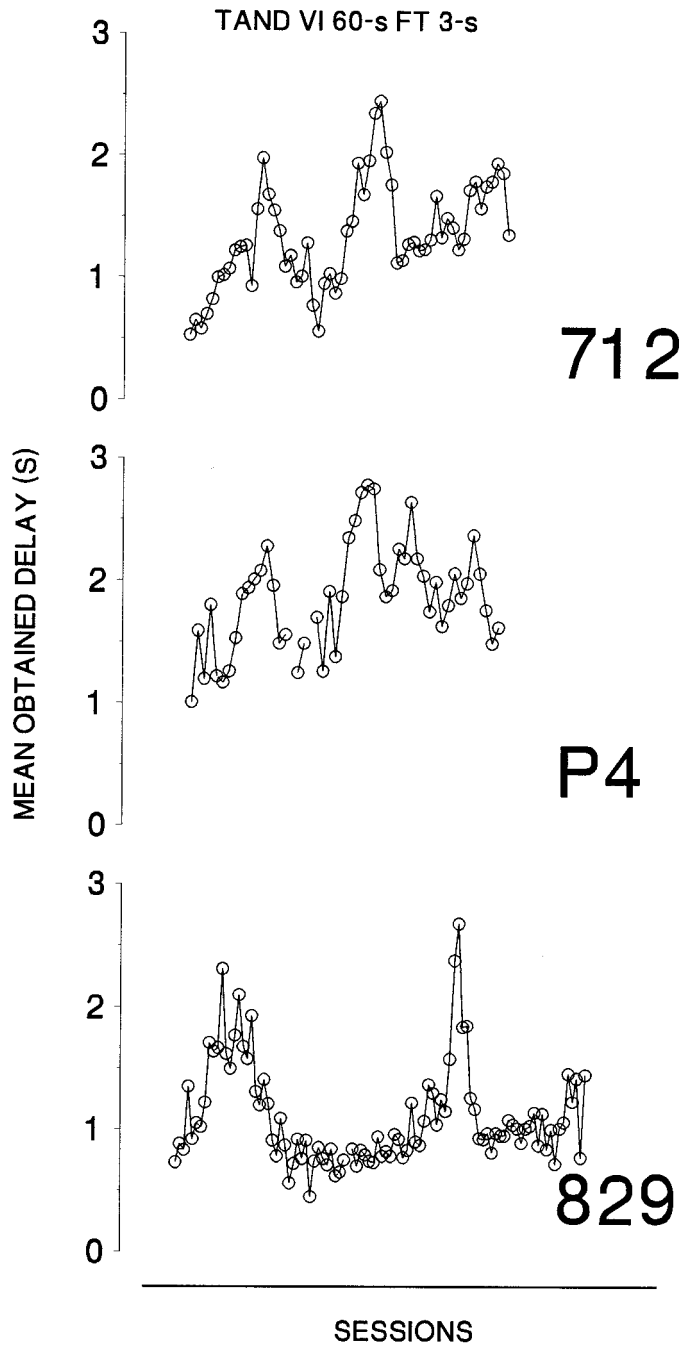


Fig. 7. Mean obtained delays to reinforcement (time between hopper presentations and the last pecks that preceded them) for each session of the condition with unsignaled delayed reinforcement in Experiment 3.

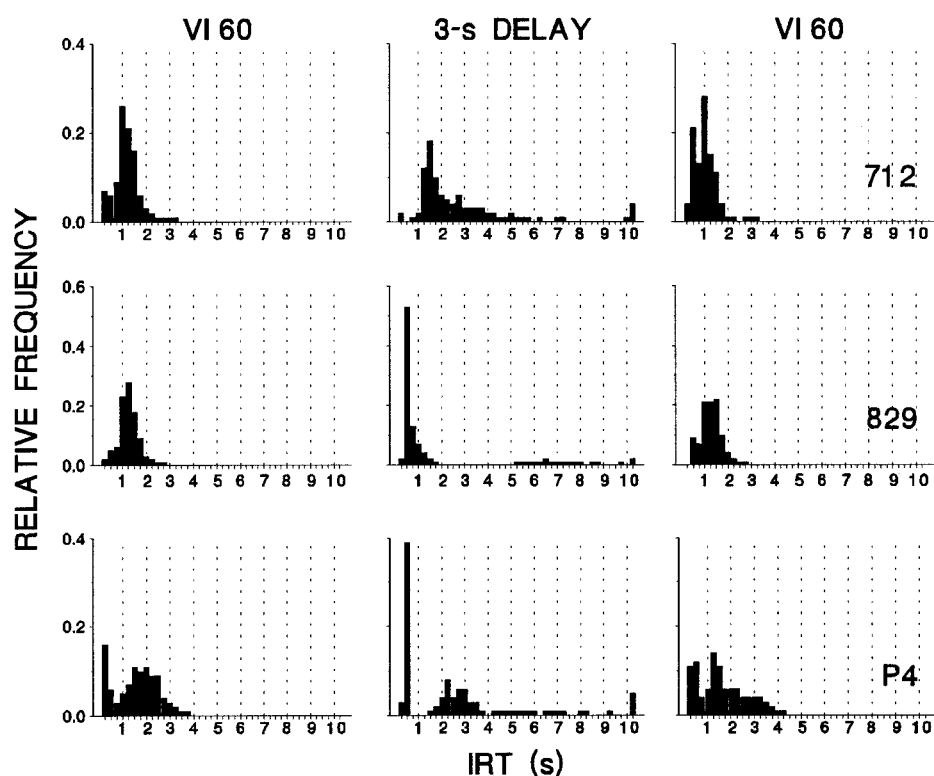


Fig. 8. Relative IRT distributions, constructed by distributing IRTs into 40 0.25-bins (and a >10-s dump bin) and dividing the number in each bin by the total number of IRTs. Distributions were obtained from three sessions for each pigeon; the left panels show data from the final session of the initial VI 60-s condition, the middle panels show data from the final session of the condition with 3-s unsignaled delayed reinforcement, and the right panels show data from the final session of the return to the VI 60-s condition in Experiment 3.

response rates. Third, Richards (1981) obtained response-rate reductions in pigeons with unsignaled delayed reinforcement even though hopper durations were timed from the pigeon's entry into the hopper, and thus were controlled (latencies were not present-ed). The importance of the disruption in eating times is that it suggests a disruption of discriminative control over hopper approach by hopper-correlated stimuli when reinforcement is delayed.

As suspected from the observation that the precision of reinforcement delivery required for IRT differentiation is sacrificed during conditions with unsignaled delayed reinforcement, IRT distributions were reliably altered by delayed reinforcement in this study (Figure 8). Such an effect has been observed in previous experiments (Arbuckle & Lattal, 1988). The significance of this finding is not clear, but there is some reason to believe that it is

important. In particular, Arbuckle and Lattal (1988; see also Lattal & Zeigler, 1982; Sizemore & Lattal, 1978) showed that 0.5-s unsignaled nonresetting delays reliably altered IRT distributions so that short (less than 0.5 s) IRTs predominated. Also, an *increase* in overall response rates was occasionally obtained. When a 5-s unsignaled delay was arranged, however, response rates were low and IRTs were spread out and generally lengthened. Thus, an initial effect of unsignaled delays to reinforcement may be a disruption in the IRT distribution. At short delays, bursts of short IRTs may be immediately reinforced and lead to increases in response rates, but at longer delays no particular pattern of IRTs is more likely to be reinforced, and rates generally decrease, as in the present study. Additional research is required to determine the contribution of changes in IRT distributions early in conditions with delayed reinforcement to the

bumpy transition to low response rates observed under these conditions.

#### GENERAL DISCUSSION

Delayed reinforcement is similar to response-independent reinforcement because, in both cases, an experimenter relinquishes control over the behavior that is occurring at the moment of reinforcement. It has been suggested that superstitious behavior may develop under both conditions; in the case of un signaled delayed reinforcement, this superstitious behavior may compete with the experimenter-specified behavior and reduce its rate. The point of the present experiments has been to assess the utility of an alternative conception. By this view the competing response is hopper-observing behavior that is shaped and maintained by a dependent relation between it and eating from the hopper (or between it and occasional contact with hopper stimuli that are correlated with eating). In Experiment 1 an analogue to this observing behavior increased in rate (and VI-key pecking decreased in rate) when VI-key pecks no longer produced stimuli correlated with the hopper. In Experiment 2 key pecking was maintained under conditions with response-independent reinforcement when pecks produced stimuli correlated with impending hopper delivery. Finally, Experiment 3 showed that latencies to eat from the hopper increased when an un signaled delay to reinforcement was introduced. As rates of key pecking fell to low levels, eating times gradually increased. This increase in eating times may reflect the development of hopper observing, which alternated with low-rate key pecking.

The procedure of Experiment 2 differs little from procedures that are commonly used to study observing (cf. Wyckoff, 1952). Most often observing procedures arrange mixed schedules of reinforcement in which two or more components differ in rate of reinforcement. Other responses (e.g., treadle pressing, key pecking, moving to one side of a chamber) change the mixed schedule into a multiple schedule for some amount of time, thus presenting stimuli correlated with the different reinforcement conditions. In general, subjects make observing responses when the multiple-schedule stimuli are correlated with

positive reinforcement (see Dinsmoor, 1983, for a review), and, when there are two observing responses available, the response that produces stimuli more favorably correlated with reinforcement will predominate (e.g., Browne & Dinsmoor, 1974). This general finding supports the basic conception proposed here because it shows that behavior may be reinforced by the presentation of reinforcer-correlated stimuli even when that behavior does not produce the reinforcer itself. Further, Dinsmoor, Bowe, Green, and Hanson (1988) showed that pigeons observed schedule-correlated stimuli even when the positive reinforcement schedule was a response-independent VT schedule (see also Badia, Ryan, & Harsh, 1981). These authors noted that "the function of [observing behavior] is to bring the subject into contact with the relevant stimuli, rather than to produce the ultimate reinforcer" (Dinsmoor et al., 1988, p. 229). The same can be said of the function of hopper observing under conditions with delayed reinforcement. The procedure of Experiment 2 could, therefore, be conceived of as an observing procedure in which pecks change the schedule from a tandem VT FT to a chained VT FT schedule. The procedure of Experiment 1 could also be conceived of as an observing procedure, although the conception is less clear because food-key pecks were required both to detect whether the hopper was available and to raise the hopper.

In a paper by Royalty, Williams, and Fantino (1987), it was shown that un signaled delays to *conditioned* reinforcement, in that experiment consisting of key-color changes associated with progression through a three-link chained VI 33-s VI 33-s VI 33-s schedule, reliably reduced response rates in the link for which the upcoming link was delayed (arranged, e.g., by changing the first VI 33-s link to a tandem VI 30-s FT 3-s schedule). In fact, rates of pecking when reinforcement was delayed in the third link, for which the delayed reinforcer was the hopper presentation, were actually higher for 2 of 6 birds than under immediate-food conditions (see Figure 5, Royalty et al., 1987). These findings pose two problems for the current interpretation. First, un signaled delays to conditioned reinforcement, in which no hopper-searching behavior should take place, effectively reduced re-

response rates. The second problem is how to account for the lack of a rate-decreasing effect of delayed hopper presentation in 2 of the birds in the Royalty et al. experiment.

With respect to the first problem, there are two ways of reconciling Royalty et al.'s (1987) data with the current interpretation of the effects of unsignaled delayed reinforcement. First, recall that unsignaled delays to conditioned reinforcement eliminate the IRT-differentiation property of VI schedules, and thus would be expected to alter key pecking in some fashion. Second, it may have been the case that lower response rates were maintained by delayed presentation of conditioned reinforcers because behavior that allowed pigeons to *see the changes in key color* competed with key pecking. The effect of observing reinforcer-correlated stimuli on rates of typical operants has been studied in rats by Henton and Iversen (1978) and Iversen (1981). Iversen showed that, for rats whose lever pressing was reinforced initially according to a VI 60-s schedule, a 2-s signaled delay of reinforcement decreased rates of pre-delay lever pressing slightly and increased rates of looking at the light above the lever, which flashed during delays. Also, during the delays, lever pressing was completely suppressed while the rat initially observed the signal and then stuck its snout in the food tray. Thus, the observation of stimulus changes that serve as conditioned reinforcers can compete with other behaviors. Although the effects of unsignaled delays have not been studied frequently with rats pressing levers, there is some evidence that these variables would operate similarly (Burgess & Wearden, 1981).

The second problem posed by Royalty et al.'s (1987) data is the less-than-reliable rate reduction in the link leading to food. The lack of a reduction in rates is consistent with findings from several pigeons in our laboratory that indicate that, when delays to reinforcement are signaled, high rates of key pecking during the delay are sometimes obtained. For example, Pigeon 269 in Schaal and Branch (1988) pecked the key during the delay at over seven pecks per second. Two of the pigeons in Experiment 2 (Pigeons 159 and 41) also pecked the food-correlated stimulus at very high rates. Under signaled delayed reinforcement conditions that are favorable for the maintenance of high pre-delay response

rates, some pigeons do not peck the key at all during the delay and some peck at high rates (Schaal & Branch, 1988, 1990). It is possible that the conditions with signaled delays and the chain schedule of Royalty et al. (1987) pit the usual effects of unsignaled delayed reinforcement against the favorable associative relations between stimulus changes and food. These stimulus changes are the delay signals in Schaal and Branch (1988) and the onset of the key color associated with the third link of the chain schedule in Royalty et al. (1987). This may result in high-rate autoshaped pecking that eliminates the effects of unsignaled delayed reinforcement. Higher-than-immediate-reinforcement rates of pecking under these conditions may result from the combination of autoshaped pecking with the elimination of long-IRT differentiation due to the unsignaled delay.

Throughout this paper, the posited competing behavior has been called hopper-observing behavior, as opposed to superstitious behavior (Skinner, 1948), in order to make the point that a dependent relation between eating and hopper detection exists even when hopper presentations are response independent. The behavior that emerges and persists is not specified by the experimenter, however, so idiosyncratic movements across pigeons, and modification of those movements in individual pigeons across time, are likely to occur. Some of these changes in behavior may be attributed to adventitious reinforcement in the sense in which Skinner (1948) intended the term. Others have suggested (Staddon & Simmelhag, 1971; Timberlake & Lucas, 1985) that these responses are *elicited* by the periodic presentation of food and therefore are species specific (the authors noted similarities between behavior produced by response-independent food and both begging for food in young squab and begging for food by female pigeons in courtship). Future studies may be aimed at parceling out the relative contributions of hopper-observing behavior, superstitious behavior, and species-specific behavior to the reduction in rates of key pecking produced by unsignaled delayed reinforcement. For now, we think the current experiments make it clear that dependent relations between behavior and eating (and between behavior and reinforcer-correlated stimuli) remain even when food reinforce-

ment is delivered freely, and that these relations play an important role in the effects of unsigned delayed reinforcement.

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