

*PIGEONS MAY NOT REMEMBER THE STIMULI
THAT REINFORCED THEIR RECENT BEHAVIOR*

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In two experiments the conditioned reinforcing and delayed discriminative stimulus functions of stimuli that signal delays to reinforcement were studied. Pigeons' pecks to a center key produced delayed-matching-to-sample trials according to a variable-interval 60-s (or 30-s in 1 pigeon) schedule (Experiment 1) or a multiple variable-interval 20-s variable-interval 120-s schedule (Experiment 2). The trials consisted of a 2-s illumination of one of two sample key colors followed by delays ranging across phases from 0.1 to 27.0 s followed in turn by the presentation of matching and nonmatching comparison stimuli on the side keys. Pecks to the key color that matched the sample were reinforced with 4-s access to grain. Under some conditions of Experiment 1, pecks to nonmatching comparison stimuli produced a 4-s blackout and the start of the next interval. Under other conditions of Experiment 1 and each condition of Experiment 2, pecks to nonmatching stimuli had no effect and trials ended only when pigeons pecked the other, matching stimulus and received food. The functions relating pretrial response rates to delays differed markedly from those relating matching-to-sample accuracy to delays. Specifically, response rates remained relatively high until the longest delays (15.0 to 27.0 s) were arranged, at which point they fell to low levels. Matching accuracy was high at short delays, but fell to chance at delays between 3.0 and 9.0 s. In Experiment 2, both matching accuracy and response rates remained high over a wider range of delays in the variable-interval 120-s component relative to the variable-interval 20-s component. The difference in matching accuracy between the components was not due to an increased tendency in the variable-interval 20-s component toward proactive interference following short intervals. Thus, under these experimental conditions the conditioned reinforcing and the delayed discriminative functions of the sample stimulus depended on the same variables (delay and variable-interval value), but were nevertheless dissociated.

Key words: delayed matching to sample, conditioned reinforcement, variable-interval schedules, pigeons, key peck

A stimulus may have both reinforcing and discriminative functions in its effect on behavior (Keller & Schoenfeld, 1950). Wixted (1989) explored the relation between conditioned reinforcement and the remembering of recently presented stimuli typically studied using delayed matching-to-sample (DMTS) procedures. Specifically, he sought to assess the degree to which delay-reduction theory formed the basis for quantitative descriptions of short-term memory phenomena. Delay-reduction theory, based on the results of studies of choice employing concurrent-chains schedules, states that stimuli that signal delays to reinforcement that are short *relative to* the average time between reinforcers will be more effective conditioned reinforcers than stimuli that signal longer relative delays to re-

inforcement (Fantino, 1969; Squires & Fantino, 1971). Wixted assumed that the memorability of a stimulus over a brief interval would be related to its conditioned reinforcing efficacy. He amended delay-reduction theory by adding a variable that expresses the retention interval, that is, the time between sample offset and the onset of the comparison stimuli. So amended, delay-reduction theory adequately describes some of the more interesting results from DMTS experiments. Perhaps most important, the amended delay-reduction theory predicts the reliable finding that remembering in DMTS is a function of the retention interval relative to the intertrial interval (ITI) (e.g., Maki, Moe, & Bierly, 1977; Roberts, 1980; Roberts & Kraemer, 1982; White, 1985).

In concurrent-chains schedules, the conditioned reinforcing effects of stimuli that signal the onset of terminal links of chains are assessed by relative response rates in initial links (i.e., a choice procedure). The conditioned reinforcing effects of stimuli that signal delays to reinforcement have also been

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investigated using single-operant procedures (Lattal, 1984; Schaal & Branch, 1988). In a series of experiments (Schaal & Branch, 1988, 1990; Schaal, Schuh, & Branch, 1992) 0.5-s key-color changes that signaled delays to reinforcement maintained response rates of pigeons near those maintained with immediate reinforcement over a limited range of delays. Schaal and Branch (1988) found that high rates of pecking were maintained on a variable-interval (VI) 60-s schedule of briefly signaled delays to reinforcement ranging from 1.0 to 9.0 s, but that rates fell to low levels (near those maintained when delays were not signaled) when the delay was 27 s. Rates could be maintained at near-immediate-reinforcement levels with 27-s delays, however, if the entire delay was signaled with a distinct key color. Thus, it was apparent from this initial study that the conditioned reinforcing function of brief delay signals was limited temporally. In a subsequent study (Schaal & Branch, 1990) lengthening the delay signal while holding the delay constant at 27 s increased pre-delay response rates. Finally, Schaal *et al.* (1992) showed that the ability of brief delay signals to maintain near-baseline rates of pecking depended on the delay relative to the average time between food presentations. Specifically, briefly signaled delays of 10 to 20 s resulted in low response rates when presented according to a VI 20-s schedule, but maintained near-baseline rates when presented according to a VI 120-s schedule.

It appears, then, that both the conditioned reinforcing function of brief delay signals in the work of Schaal *et al.* (1992) and the delayed discriminative function of sample stimuli in DMTS procedures are determined by the delay between these stimuli and reinforcement relative to the interreinforcement (or intertrial) interval. Schaal *et al.* suggested the possibility that the conditioned reinforcing function of brief delay signals depends on its memorability across a delay. Specifically, brief delay signals may be conditioned reinforcers at a given delay only if pigeons can remember the signal when the food is presented; delay signals may cease to be reinforcers if, when food is presented, pigeons can no longer remember the signal. Such an explanation would be supported by data showing that high levels of accuracy are obtained in the DMTS procedure at delays that

maintain high pre-trial response rates, and that chance accuracy is obtained when response rates have fallen to low levels. The goal of the present studies, therefore, was to determine how similar the function relating delay to pre-delay response rates is to the function relating delay to DMTS accuracy.

The present experiments examined the delayed discriminative and conditioned reinforcing effects of brief delay signals by using the brief signals as sample stimuli in DMTS trials. Pigeons pecked a center key that, according to VI schedules, produced one of two brief (2-s) changes in key color. After a delay, during which the center key was lit as it had been during the VI, the center key was turned off and the two side keys were lit. Pecks to the side key with the matching color were reinforced with food. The variable intervals in this procedure were intended to be analogous to the ITI in a DMTS procedure, and the delays were intended to be analogous to the retention interval. Thus, pre-delay (or pre-trial) response rates provided an index of the conditioned reinforcing function of the brief signal (or sample), and accuracy on the DMTS trials provided an index of the memorability of the signal. If the same temporal relations are responsible for both functions of the brief signal, then the functions relating these two dependent measures to the delay should approximate each other.

This possibility was assessed in two experiments. In the first experiment, a single VI 60-s schedule controlled access to DMTS trials. Delays ranging from 0.1 to 27.0 s were arranged across phases. Under some conditions the rate of food reinforcement was allowed to vary with variations in DMTS accuracy, but in other conditions a peck to the correct key was required to end each trial in food reinforcement. In Experiment 2, identical DMTS trials were arranged according to a VI 20-s schedule in one component of a multiple schedule and a VI 120-s schedule in the other component. The delay was changed across phases, but was always the same in both components of the multiple schedule. The goal of this experiment was to determine how the conditioned reinforcing function and the memorability of delay signals were affected by different relative delays to reinforcement.

EXPERIMENT 1

METHOD

Subjects

Four adult male White Carneau pigeons (*Columba livia*), with prior experimental experience pecking for food under VI schedules with and without delays to reinforcement, 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 individually housed in a temperature-controlled colony where they were allowed free access to water and digestive grit. Sessions were conducted during the light portion of a 12:12 hr light/dark cycle.

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, white, or amber lights. The side keys could be lit with white or amber lights. The keys 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. 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. Extraneous noise was masked by white noise and ventilation fans. Contingencies were programmed and data were collected by an MS-DOS-based 80386 microcomputer, programmed under MED-STATE notation (MED Associates, Inc. & Tatham, 1991) software.

Procedure

Experimental sessions were conducted 6 or 7 days per week at approximately the same time each day. Sessions were terminated after 40 reinforcers were delivered. Initially subjects were exposed to a VI 60-s schedule of food reinforcement with the center key illuminated green. The intervals for the VIs were

chosen without replacement from a list of 20 generated using the BASIC program of M. Perone (Lattal, 1991, p. 99) based on the method described by Fleshler and Hoffman (1962). Then the procedure was changed such that the first peck after an interval elapsed produced a 2-s change in key color that served as the sample presentation. Sample colors were amber and white and were selected with a probability of .5 with no restrictions. Sample presentation was followed by a delay, which in the first phase was 0.1 s, during which the center key returned to the VI-associated color, green. At the end of the delay the center key was extinguished and the side keys were illuminated with the matching and nonmatching key colors. The location of the correct comparison varied unpredictably from trial to trial. A single peck to the matching key color produced 4-s access to the hopper. Pecks to nonmatching keys produced a 4-s blackout followed by the start of the next interval. At this point, the VI schedule for Pigeon P4 was changed to VI 30 s to increase its low response rates. The schedule for the other pigeons remained VI 60 s.

When response rates and matching accuracies had stabilized, as judged visually, the delay was increased to 1 s. Subsequently, across phases, delays of 3, 9, and 27 s were arranged in that order. Phases were changed when response rates and matching accuracies were stable.

To determine whether the reduction in rates of reinforcement that resulted from reductions in matching accuracy contributed to the results obtained, a correction procedure was arranged for Pigeons P409 and P712. Instead of a 4-s blackout following pecks to nonmatching keys, both sample keys remained lit until a peck to the matching key occurred and food was delivered. Pecks to nonmatching keys were counted but had no other consequence. Under these conditions, only the first peck to comparison stimuli was included in the computation of matching accuracy. This procedure was arranged at some of the delays, as indicated in Table 1. Time constraints prevented the testing of the correction procedure with the other 2 pigeons.

RESULTS

Figure 1 shows response rates (pecks per minute) and percentage correct for each pi-

Table 1

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

Delay (s)	Condition	Pigeon			
		P409	P712	P829	P4 ^a
0.1	BO ^b	54	35	47	111
1.0	BO	56	54	100	69
3.0	BO	40	54	78	101
9.0	BO	26	41	92	85
27.0	BO	26	32	120	52
0.1	BO	23	27	33	74
0.1	C ^c	89			
1.0	C	33			
3.0	C	40			
9.0	C	47	59		
27.0	C	26	29		
0.1	C	104	26		

^a The schedule of trial presentation for this pigeon was VI 30 s.

^b BO indicates that a 3.0-s blackout occurred after pecks to nonmatching comparisons.

^c C indicates that a correction procedure operated, during which comparisons remained illuminated until a peck to a matching comparison occurred and was reinforced.

geon under each condition. Both measures decreased as the delay to comparison presentation was increased. Accuracy declined in 3 of the pigeons when delays of 1 and 3 s were arranged, and then fell to near-chance levels at the 9-s delay for each pigeon. Pecks per minute were largely unchanged from the 0.1-s delay condition across delays of 1, 3, and 9 s, but declined when 27-s delays were arranged. Response rates and percentage correct were similar during both the correction and the noncorrection procedures for Pigeons P409 and P712. Accuracy at the 9-s delay for Pigeon P409 was slightly higher during the correction procedure (65% vs. 51%), but response rate was slightly higher during the noncorrection procedure (45 vs. 34 pecks per minute).

DISCUSSION

The ability of the 2-s delay signal to maintain high response rates across a range of delays was similar to that observed in previous experiments (Schaal & Branch, 1988). Response rates near baseline levels were maintained with delays as long as 9 s, but decreased when the delay was increased to 27 s. Accuracy in DMTS trials, however, decreased slightly at the 3-s delay and fell to chance

when the delay was increased to 9 s. Thus, accuracy fell at shorter delays than those required to reduce predelay response rates.

A notable feature of these results is the apparent lack of an effect on predelay response rates of large reductions in rates of food reinforcement in the noncorrection conditions, in which reinforcement rates were allowed to vary with DMTS accuracy. During the condition with 9.0-s delays, accuracy fell to chance levels, thus cutting in half the rate of food presentation and reducing to .5 the probability of food given a delay signal. Nevertheless, response rates were all but unchanged from immediate-reinforcement levels under this delay. Furthermore, neither response rates nor matching accuracies at a given delay were altered by employing the correction procedure, which insured reinforcement rates near the maximal programmed levels and a 1.0 probability of food given a delay signal.

Although the lack of an effect of this variation in reinforcement rates and probabilities may seem surprising, it is less so in the light of certain findings. First, as indicated in the work of Catania and Reynolds (1968), this range of reinforcement rates often produces similar response rates in single-key procedures. Furthermore, higher rates of pecking keylight conditioned stimuli (CS) in auto-shaping procedures have been obtained with probabilities of food presentation given CS presentation as low as .1 relative to rates obtained when the probability is 1.0 (Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980). Thus, it may seem that response rates under the no-correction procedure would be affected by both the programmed delay and the resulting changes in reinforcement rates and probabilities, but there is reason to believe that the latter variables are relatively less important.

Although Experiment 1 demonstrated a dissociation of the conditioned reinforcing and delayed discriminative functions of sample presentation, several variables that may illuminate more completely the multiple functions of sample presentations in this procedure were not examined. In particular, measures of (a) pecking during obtained delays (i.e., the actual intervals from pecks to comparison presentation) and (b) rates of pecking, which may also reflect delayed dis-

criminative stimulus effects of sample presentation, were not collected. In previous experiments in which the conditioned reinforcing function of brief delay signals was assessed (Schaal & Branch, 1988, 1990; Schaal et al., 1992), intradelay behavior varied considerably across subjects, with some pigeons pecking at a high rate during the delay and others pecking at near-zero rates. In general, however, when delays were relatively short and the brief delay signal maintained high pre-delay response rates, rates of pecking during the delay were different (sometimes higher, sometimes lower) than pre-delay rates. At longer delays, when pre-delay rates fell to low levels, pre-delay and intradelay pecking were less distinguishable. Thus, intradelay pecking seemed to reflect a lingering effect of the recent presentation of the delay signal when the delay signal maintained high pre-delay response rates. A closer examination of intradelay behavior under the present procedure may also reveal a delayed discriminative effect of the samples that is no longer reflected in accurate matching. This possibility is one reason why Experiment 2 was conducted.

EXPERIMENT 2

In Experiment 2, two VI schedules of DMTS-trial presentation, VI 20 s and VI 120 s, alternated. These schedules were employed in a previous study of the conditioned reinforcing effects of brief delay signals (Schaal et al., 1992). In that study 0.5-s key-color changes signaled the onset of delays to reinforcement. Pre-delay pecking rates in the VI 20-s component fell to low levels as the delay was increased across phases to 10 and 20 s, but remained near immediate-reinforcement levels at the same delays in the VI 120-s component. Thus, the conditioned reinforcing function of brief delay signals depended on the delay relative to the interreinforcement intervals. Similar relative delay effects have been noted in research on autoshaping (Kaplan, 1984; Lucas, Deich, & Wasserman, 1981) and DMTS (Roberts, 1980; Roberts & Kraemer, 1982; White, 1985). The second goal of Experiment 2, then, was to examine this relative delay effect using a procedure in which conditioned reinforcing and delayed discriminative effects could be observed simultaneously.

METHOD

Subjects and Apparatus

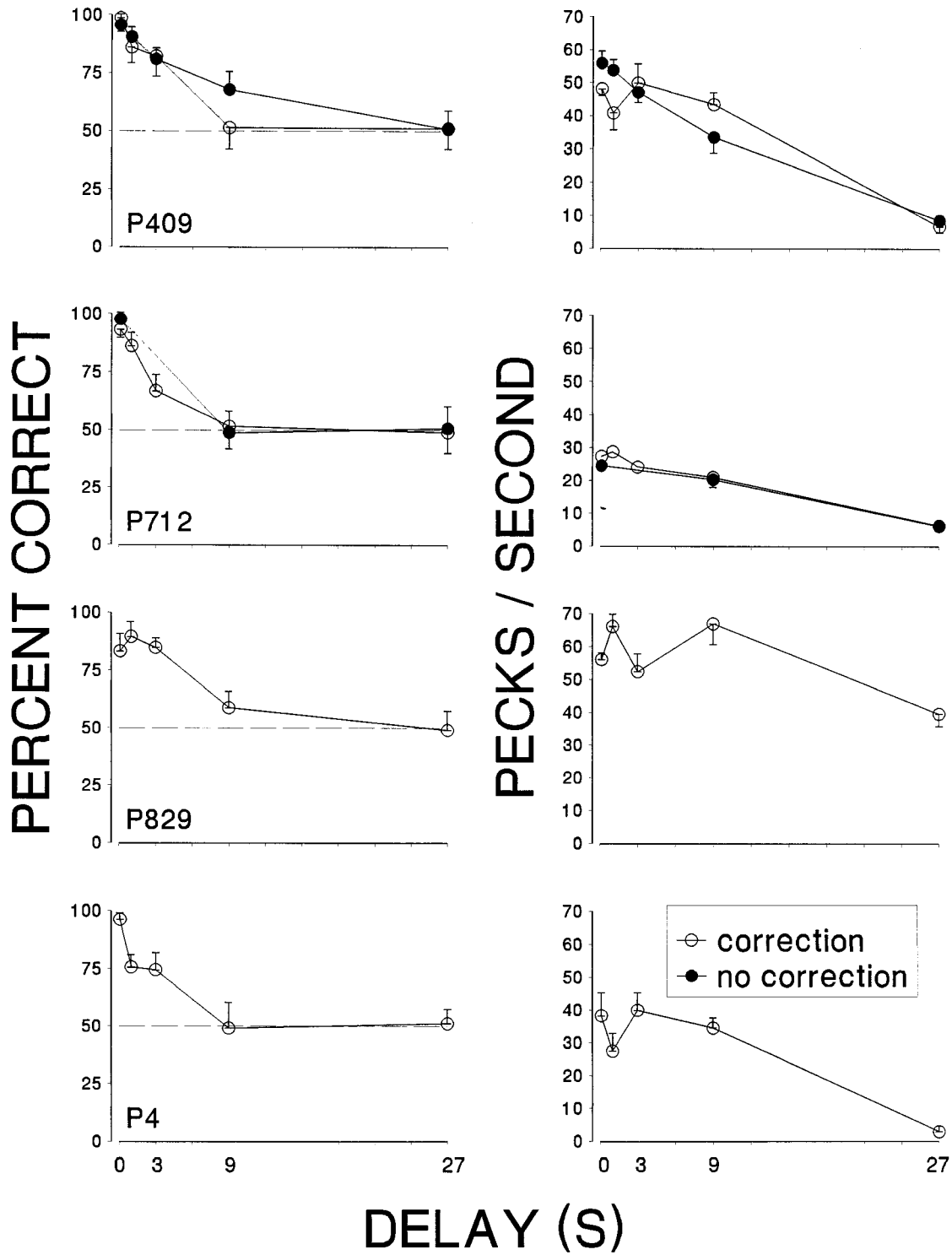
The subjects were 4 adult male White Carneaux pigeons. Three pigeons, P4, P712, and P829, had served in Experiment 1, and the 4th pigeon, P149, had a history of responding under a variety of schedules of food delivery. In this study Pigeon P4 was maintained at 75% of its free-feeding weight but the other pigeons were maintained at 80% of free-feeding weights. Other conditions of the pigeons' care were identical to Experiment 1.

The apparatus was the same as in Experiment 1. In addition, the center key could be lit from behind with blue or red light.

Procedure

All pigeons had extensive previous experience, so little pretraining was necessary. During the first few sessions, the variable intervals were shorter than the terminal values, but otherwise the procedure was the same as during the remainder of the experiment. Each daily session began with the center key lit blue and a VI 20-s schedule of matching-to-sample trials in effect. After eight reinforcers, a 30-s blackout was followed by the next component. The key was lit red, and a VI 120-s schedule of matching-to-sample trials was in effect for eight food deliveries. The components alternated in this manner until 24 reinforcers had been delivered in each. The intervals for the VIs were chosen without replacement from a list of 24 generated using the BASIC program of Perone (Lattal, 1991, p. 99) based on the method described by Fleshler and Hoffman (1962).

The same sample colors were used for the two components. In both, the first peck after the programmed interval elapsed started the 2-s presentation of the sample. The color (amber or white) was chosen randomly with a .5 probability of each. The response-independent sample offset was followed by a delay during which the key was lit the same color as during the VI portion of the trial. Following the delay, the center key was extinguished and the side keys were lit, one amber and one white (i.e., the comparisons were presented). The position of each color was randomly determined with a .5 probability of each arrangement. Pecks to the key lit the same color as the sample produced 2.5-s access to



food, during which the key and houselights were extinguished and the hopper aperture was lit white. Pecks to the key lit a different color than the sample were recorded as incorrect, but had no other programmed effect. The trial was not terminated until the bird pecked the matching key color and received food. This procedure insured that the interfood interval was similar to that programmed even if percentage correct varied considerably.

Across conditions, the delay between sample offset and presentation of the comparisons increased. The delays investigated were 0.1, 3, 6, 9, 15, 21, and 27 s, in that order. Each delay was in effect for at least 20 sessions and until several stability requirements were met. Mean rates of key pecking during the VI portion of trials, calculated for the VI 20-s and the VI 120-s components separately for each session, could show no increasing or decreasing trends or unusual variability (as determined by visual inspection of daily plots of the data), over the last 10 sessions. The same criteria applied to the percentage of trials on which the comparison chosen matched the sample (i.e., percentage correct), calculated for each component separately. When response rates and percentage correct for both components met the criteria, the delay increased. Table 2 gives the number of sessions each pigeon completed at each delay.

Response rates prior to trials and during delays, percentage correct, and obtained delays (i.e., the interval between food presentation and the last peck prior to food presentation) were collected daily. In addition, matching accuracy as a function of the obtained ITI was collected.

RESULTS

Figure 2 shows percentage correct as a function of delay in both VI components. Data points throughout this section indicate means of the final 10 sessions of each condition (± 1 SD). Matching accuracy was high-

Table 2

Total number of sessions at each delay for each pigeon in Experiment 2.

Pigeon	Delay (s)						
	0.1	3	6	9	15	21	27
P829	77	39	29	27	43	21	20
P712	51	29	21	56	22	20	22
P149	21	54	37	20	24	24	20
P4	64	26	26	43	24	20	23

est at the 0.1-s delay, and was slightly higher for the VI 120-s component at this shortest delay. Accuracy fell to near 50% when delays were increased from 3 to 9 s in the VI 20-s component. Accuracy remained higher in the VI 120-s component, however, approaching chance only when delays reached 9 s or greater.

Response rates prior to trial presentation are depicted in Figure 3, both as absolute rates and as a proportion of the rates obtained at the 0.1-s delay (i.e., baseline). Absolute response rates were lower in the VI 120-s component than in the VI 20-s component at the shortest delays. As delays became longer, response rates in the VI 20-s component fell to low levels by the 9- to 15-s delays for each bird. For 3 of the birds, response rates in the VI 120-s component remained nearer baseline levels across a wider range of delays. This effect is most apparent when rates are plotted as a proportion of baseline. For these 3 birds, rates did not decrease below baseline during the VI 120-s component until the 15-s (P829), 21-s (P149), or 27-s (P712) delays were arranged. Rates for Pigeon P4 were particularly low in the VI 120-s component, and the effects of increasing delays deviated from those in the other 3 birds. Observation of this pigeon revealed that it pecked just off the key at a fairly high rate during this component, which may have contributed to the unusual effect of delays to comparison presentation in the VI 120-s com-

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Fig. 1. Left panels show percentage correct as a function of the programmed delay between sample offset and comparison presentation for each pigeon in Experiment 1. The dashed horizontal line shows performance at chance levels. Right panels show pecks per second prior to trials as a function of the programmed delay. Open circles depict data obtained from conditions with a noncorrection procedure; filled circles depict data obtained from conditions with a correction procedure. Points represent the mean of the last 10 sessions at each delay duration. Vertical bars show one standard deviation above or below means.

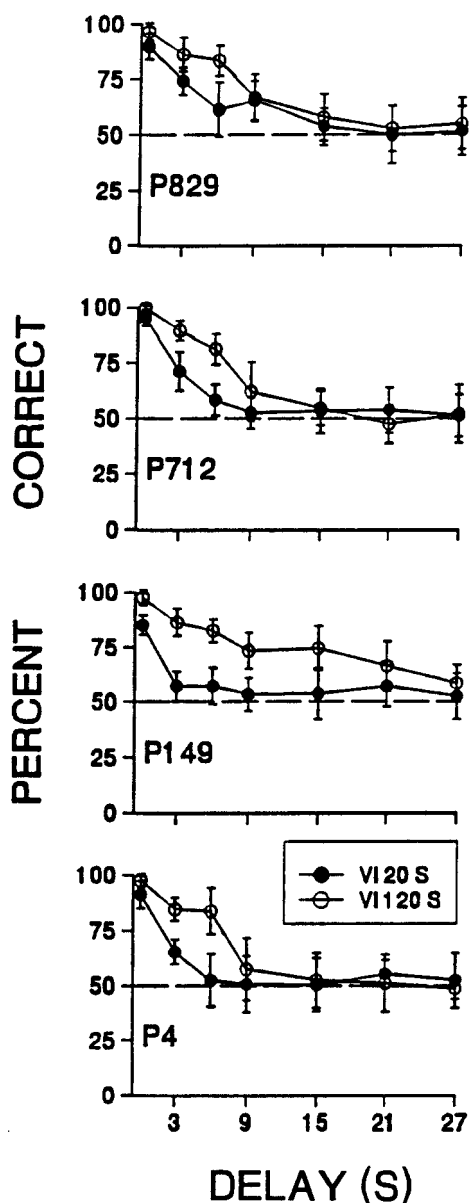


Fig. 2. Percentage correct during the component with the VI 20-s schedule (filled circles) and the component with the VI 120-s schedule (open circles) as a function of the programmed delay between sample offset and comparison presentation for each pigeon in Experiment 2. Points represent the mean of the last 10 sessions at each delay duration. Vertical bars show one standard deviation above and below means. The dashed horizontal line shows performance at chance levels.

ponent. Rates in the VI 20-s component for this bird were similar to those obtained from the other pigeons across all delays.

Matching accuracy was collected individually for different classes of obtained variable intervals (i.e., the VI value plus the latency to peck after the interval elapsed) ranging from the shortest to the longest intervals. Data obtained from the last 10 sessions of each condition were combined in this analysis. The first interval of the session and the intervals that followed each component change were omitted; thus, 21 intervals per session were included. Obtained intervals were grouped into 10-s bins, ranging from 0 to 10 s up to over 500 s. The number of correct choices for a bin duration was divided by the number of intervals in that bin and multiplied by 100% to yield a percentage correct measure for each obtained interval. Data from bin durations with only one interval were not included in this analysis. Accuracy was plotted as a function of the log of the obtained intervals for both components in Figure 4 across the 3-s to 9-s delays, conditions during which differences across components were most apparent. Matching accuracy was not obviously dependent on the obtained interval in either component; birds were nearly as accurate after short variable intervals as they were after longer ones. It is important to note, though, that matching accuracy was higher in the VI 120-s component at the shorter obtained intervals, which overlapped with the short intervals arranged in the VI 20-s component. This effect was most apparent at the 6-s delay, in which overall matching accuracy was most clearly separated across components.

Figures 5 and 6 depict different measures of performance during delays (i.e., after samples were withdrawn and before comparisons were presented). These measures are thought to indicate a delayed discriminative stimulus effect of sample presentation that is not captured by matching accuracy. Obtained delays (i.e., the actual time between the last center key peck and comparison presentation, as distinct from the programmed delay) are shown in Figure 5. As programmed delays increased, obtained delays in both components deviated from the programmed delay. Obtained delays remained nearer programmed delays in the VI 120-s component than in the VI 20-s component for 3 of 4 pigeons (P829, P149, and

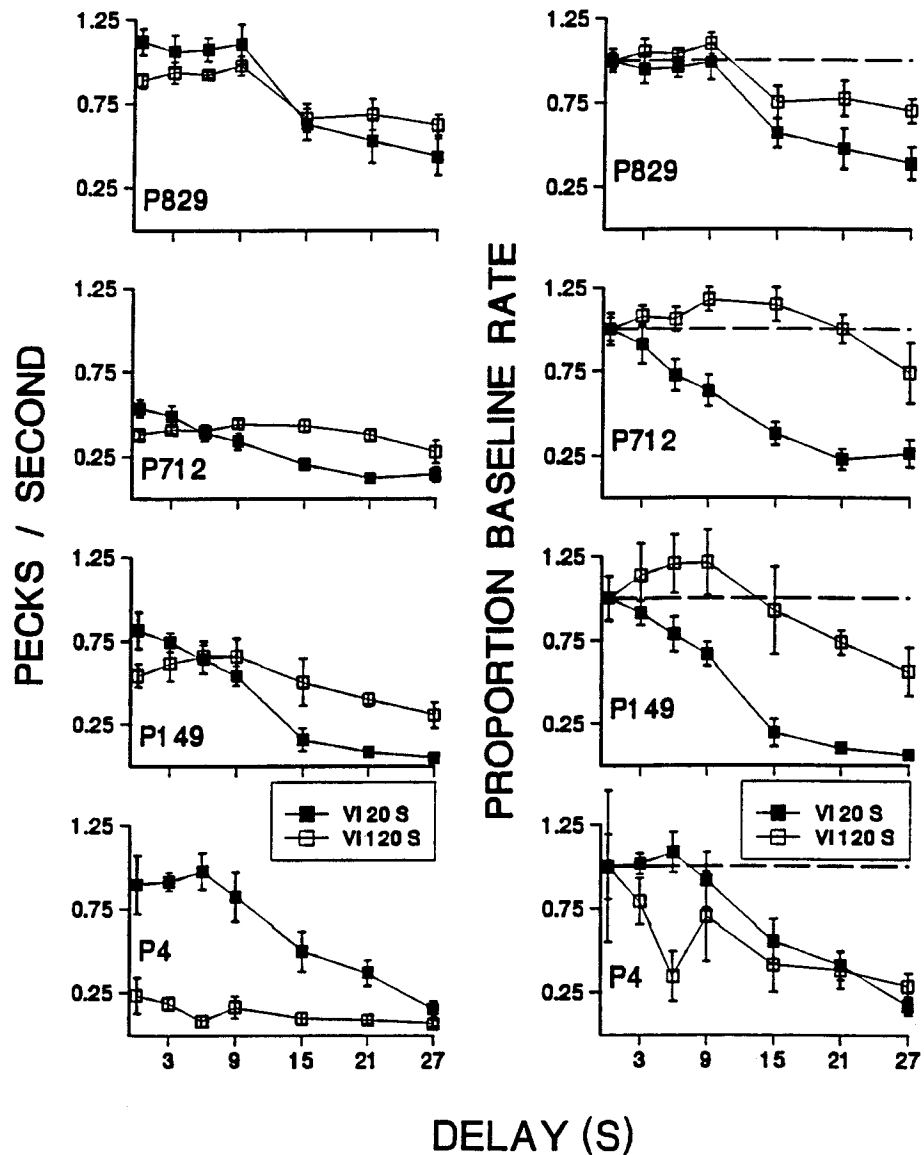


Fig. 3. Left panels show pecks per second prior to trials during the VI 20-s component (filled squares) and the VI 120-s component (open squares) as a function of the programmed delay between sample offset and comparison presentation for each pigeon in Experiment 2. Right panels show the proportion of baseline rate (i.e., rate obtained during the condition with 0.1-s delays) for both components. The dashed horizontal lines show no change from baseline rates. Points represent the mean of the last 10 sessions at each delay duration. Vertical bars show one standard deviation above and below means.

P4). Obtained delays were shorter in the VI 20-s component than in the VI 120-s component when delays reached 15 to 21 s.

The obtained delays provide an indication of levels of pecking during delays. In the case of Experiment 2, they may be viewed as an indication of discriminative stimulus control by sample presentation (if samples are seen

as discriminative stimuli for “not pecking”). Another measure of the discriminative stimulus function of sample presentation is the response rate during the sample relative to the rate before the sample. Differences between these rates are depicted in Figure 6 as ratios. Response rates prior to sample presentation were divided by the sum of rates prior

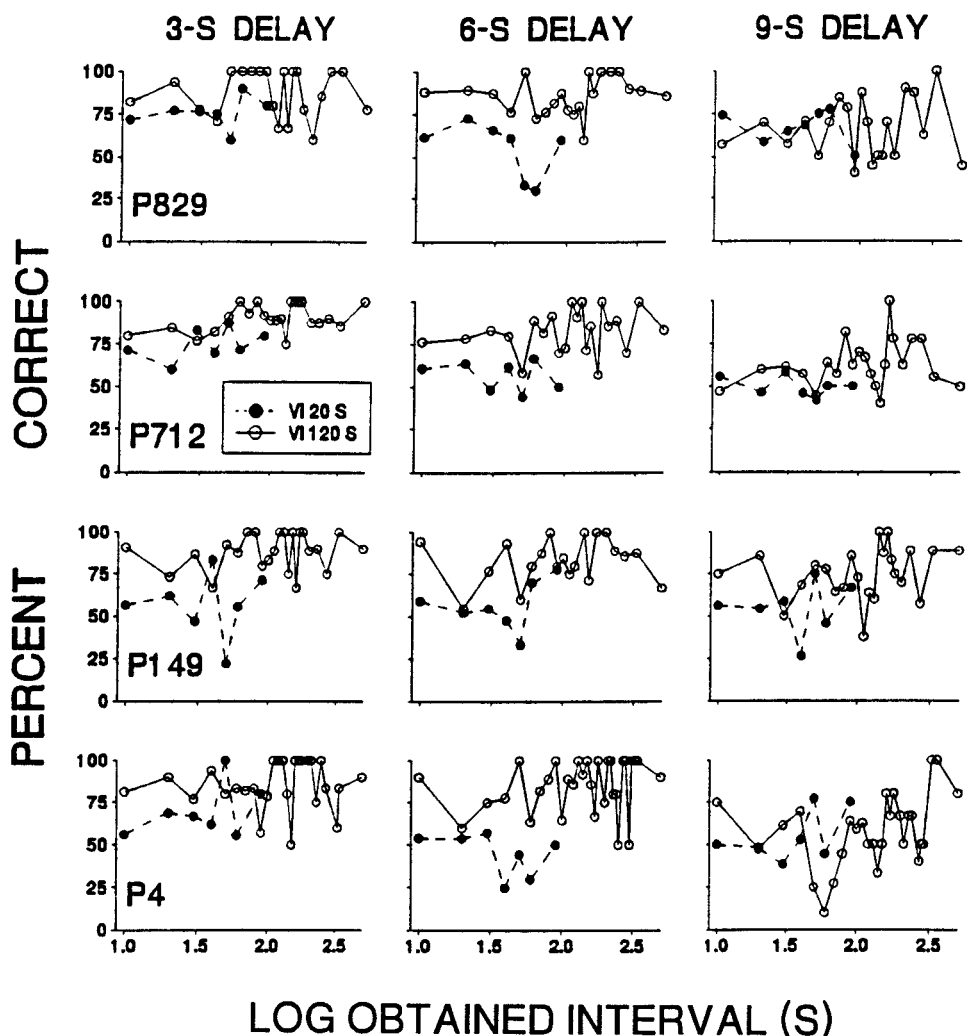


Fig. 4. Percentage correct as a function of the logarithm of the obtained ITI during the VI 20-s (filled circles) and VI 120-s (open circles) components at the 3-s delay (left panels), the 6-s delay (middle panels), and the 9-s delay (right panels) for each pigeon in Experiment 2. See text for details.

to samples and after samples. This discrimination ratio could range from 1.0 (if no pecks occurred during delays) to .5 (if an equal number of pecks occurred before and during delays), and theoretically to 0 (if all pecking occurred during delays). Figure 6 shows that response rates remained differentiated across a wider range of delays in the VI 120-s component than in the VI 20-s component for each pigeon, although the shortest delay at which this difference was apparent differed across pigeons. Changes in this measure of discriminative control by the sample stimulus

tracked pretrial response rates more closely than did matching accuracy.

DISCUSSION

Experiment 2 replicated the main findings of Experiment 1: Pretrial response rates and matching accuracy were a decreasing function of delays, and response rates were more resistant to the disruptive effects of delays than was matching accuracy. In addition, Experiment 2 showed that these effects were dependent on the time between trials, as arranged using VI 20-s and VI 120-s schedules.

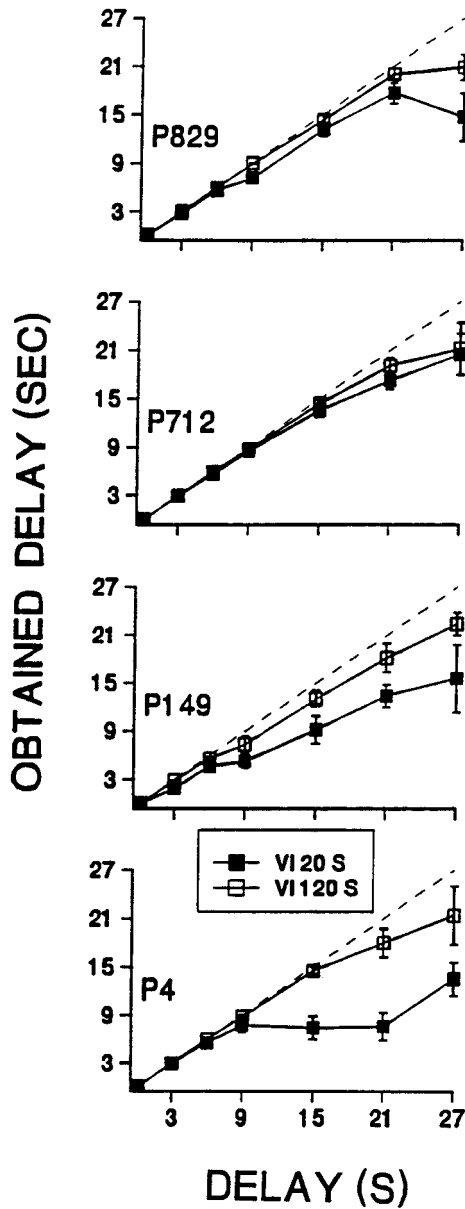


Fig. 5. Mean obtained delays between a center key peck and presentation of the comparison stimuli during the VI 20-s component (filled squares) and the VI 120-s component (open squares) as a function of the programmed delay from sample offset to comparison presentation for each pigeon in Experiment 2. The dashed horizontal lines show no change from the programmed delay. Points represent the mean of the last 10 sessions at each delay duration. Vertical bars show one standard deviation above and below means.

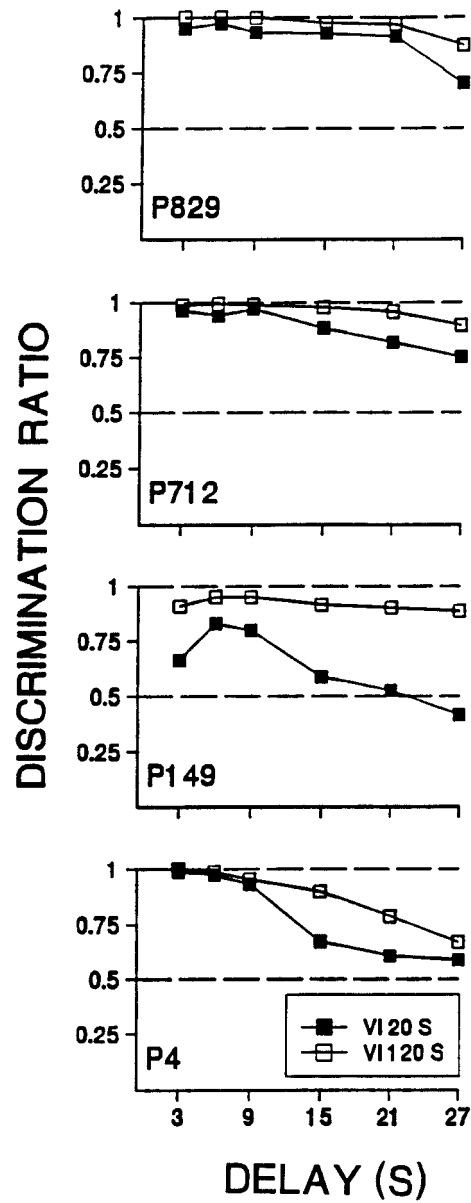


Fig. 6. Discrimination ratio (response rate prior to trials divided by response rate prior to trials plus response rate during delay from sample offset to comparison presentation) for each pigeon in Experiment 2. Filled squares depict data from the VI 20-s component, and open squares depict data from the VI 120-s component. Dashed lines at $y = 1.0$ indicate perfect discrimination (i.e., response rates near zero during the delay); the dashed lines at $y = 0.5$ indicate no discrimination (i.e., response rates equal prior to and during delays).

All measures of performance were less likely to be altered as delays were increased in the VI 120-s component than in the VI 20-s component.

The results of Experiment 2 replicate and are related to results from several areas of behavioral research. First, the effects on pretrial response rates of increasing delays to comparison presentation in the current experiment replicate almost exactly the effects of delays to food presentation found by Schaal *et al.* (1992). In that experiment, a similar multiple VI 20-s VI 120-s schedule was arranged. The consequence of pecking under the schedules was not the presentation of matching-to-sample trials, however. Rather, 0.5-s key-color changes signaled delays to reinforcement ranging from 5 to 20 s. As in the present study, response rates fell in the VI 20-s component at 10- to 20-s delays, but were largely unaffected by the same delays in the VI 120-s component. The slightly higher response rates in the VI 120-s component at some of the short delays for 3 of the birds in the present study have also been observed before (Schaal & Branch, 1988; Schaal *et al.*, 1992). Increases in response rates relative to baseline with short delays are not always obtained in these procedures, and it is not clear what is responsible for them.

The greater resistance of matching accuracy to the effects of increasing delays in the VI 120-s component compared to the VI 20-s component reflects the reliable effect of longer ITIs in conventional DMTS procedures (Maki *et al.*, 1977; Roberts & Kraemer, 1982; White, 1985). This "relative-delay effect" is also consistent with the "trial-spacing effect" in classical conditioning, specifically auto-shaping (Jenkins, Barnes, & Barrera, 1981). Using a trace conditioning procedure, for example, Lucas *et al.* (1981) showed that acquisition and maintenance of autoshaped pecking were enhanced across a range of trace intervals when trials were separated by 480 s compared to when they were separated by 160 s. Thus, several functions of stimuli associated, after a delay, with reinforcement have been shown to depend on the delay to reinforcement relative to the overall time between reinforcers.

The effect of VI duration on matching accuracy is particularly interesting given that the range and variability of ITIs, controlled

in this study by the VI schedule, were considerably greater than that typically arranged in DMTS procedures (Roberts & Kraemer, 1982). Specifically, the constant-probability VI schedules allowed a great deal of overlap between obtained ITIs, in particular in the range of the shortest intervals. Figure 4 shows that, when matching accuracy differed appreciably between components, it did so across the entire range of obtained ITIs; high levels of matching accuracy were obtained in the VI 120-s component even at short intervals that produced lower accuracy in the VI 20-s component. This effect addresses an important question raised by Wixted (1989) in his review of the DMTS literature. The utility of the analysis of DMTS performance based on the important quantities of the delay-reduction theory depends, in part, on the functional importance of the mean ITI independent of the individual ITIs of which the schedule is composed. In the present study, accuracy did depend on the *mean* ITIs regardless of the specific intervals arranged by the two VI schedules. Differential accuracy in the two components did not result from a greater tendency in the VI 20-s component toward proactive interference due to the preponderance of short intervals. A similar result was obtained by Roberts and Kraemer (1982) using a more conventional DMTS procedure. In their Experiment 1, ITIs ranged from 4 to 32 s, and only one ITI operated during a session. Accuracy was higher across a range of delays at the longer ITIs. In their Experiment 4, identical mean ITIs were arranged across conditions, but the range of variation in individual ITIs was varied. Long mean ITIs (e.g., 24 s) resulted in higher accuracy across the range of delays even when the individual ITIs ranged from very short (e.g., 8 s) to very long (e.g., 40 s). Thus, as in the present study, short ITIs resulted in accurate matching when they appeared in a context with longer ITIs.

Pretrial response rates and measures of pecking during delays in both components were more resistant to the effects of increasing delays than was matching accuracy. The differential effects of delays to comparison presentation on pretrial response rates and matching accuracy may indicate that the conditioned reinforcing function of sample presentation was, in part at least, independent of

its delayed discriminative stimulus function. Measures of behavior during delays, however, indicate that sample presentations had delayed discriminative stimulus effects that were less susceptible to disruption than matching accuracy. In particular, at relatively short delays sample presentation controlled waiting or not pecking so that obtained delays were near the programmed delays (Figure 5) and intradelay rates of pecking were very low (as indicated by the discrimination ratios in Figure 6). It appears that the delayed discriminative stimulus control indicated by matching performance is not the only indication of delayed discriminative control by the sample presentations. The significance of this fact is addressed below.

GENERAL DISCUSSION

In these experiments, methods used to study the conditioned reinforcing function of brief delay signals were combined with the methods used to assess the memorability of a recently presented stimulus to determine how these stimulus functions are related to each other. Although the conditioned reinforcing function of sample presentation and the delayed discriminative function of samples both depended jointly on the delay to the presentation of the comparisons and on the time between trials, the memorability of sample stimuli was much more susceptible to the disruptive effects of increasing delays than was the conditioned reinforcing function of samples. In addition, other measures of delayed discriminative control by sample presentation (i.e., obtained delays and intradelay response rates) were more resistant to changes produced by increasing the delay than was matching accuracy.

Both stimulus functions measured in these experiments were weakened by increasing the delay to comparison presentation, and that weakening depended not on the absolute delay, but on that delay relative to the time between trial (or food) presentations. Thus, the central feature of delay-reduction theory applies to both stimulus functions in this study: The conditioned reinforcing effect *and* the memorability of the sample stimuli depended on the relative reduction in delay to reinforcement that they signaled (Wixted, 1989). The conditioned reinforcing and de-

layed discriminative effects of the sample stimuli clearly differed, however, as indicated by the large differences in the functions relating matching accuracy and predelay response rates to delay. In the rest of this discussion the reasons for this dissociation of conditioned reinforcement and memorability will be considered.

The ability of a brief delay signal to serve as a conditioned reinforcer in the current single-key procedure is indicated by the rate of responding prior to its presentation. One might say that conditioned reinforcing efficacy in this procedure ranges from "strong," as indicated by response rates near those maintained with immediate reinforcement, to "weak," as indicated by response rates near those maintained under conditions with unsignaled delayed reinforcement (Schaal & Branch, 1988; Schaal et al., 1992; Schaal, Shahan, Kovera, & Reilly, 1998). The ability of a brief delay signal to serve as a delayed discriminative stimulus in the DMTS procedure also ranges from strong to weak, with strong stimulus control indicated by accurate matching and weak stimulus control indicated by performance at the chance level. The question addressed by the current experiments was whether a strong conditioned reinforcer also produces strong delayed discriminative stimulus control. This question arose from our previous work with delays to reinforcement signaled with brief stimulus changes: Did the high response rates obtained with brief delay signals at some delays indicate that pigeons could remember the signal at the end of the delay; or, conversely, did the low response rates obtained at longer briefly signaled delays indicate that pigeons forgot the signal by the end of the delay?

A possible outcome was that the functions relating delays to predelay response rates and matching accuracy would fall on top of each other. This did not occur. At some relative delays the onset of the delay signal maintained near-immediate-reinforcement response rates, but pigeons did not peck the appropriate stimulus at the end of the delay. Thus, as expressed in the title of this paper, pigeons may not remember the stimuli that reinforced their recent behavior. This could mean that the two stimulus functions are separable, or dissociable; that is, the conditions

that lead to effective conditioned reinforcers are not those that lead to memorable stimuli.

For several reasons this conclusion should be rejected. The first has already been mentioned; although there were clear *quantitative* differences in the functions relating delay to matching accuracy and pre-delay response rates, they were *qualitatively* similar. That is, both stimulus functions were weakened by increasing the relative delay to reinforcement. Another reason to reject such a conclusion is that other measures of delayed discriminative stimulus control provided evidence of another kind of remembering. Pigeons usually stopped pecking when the sample was presented, provided the delays were sufficiently short. As a result, obtained delays approximated programmed delays across a wide range of programmed delays (Figure 5), and rates of pecking were markedly lower after the sample presentation than prior to it (Figure 6). In other words, it may be said that pigeons remembered that a stimulus had recently been presented, although they may not have remembered which stimulus had been presented. This suggests that the conditioned reinforcing function of sample presentation is independent of the specific sample presented, and matching accuracy depends critically on remembering the specific sample that was presented. As a result, it may be that the onset of a change in keylight color after a center-key peck reinforces behavior depending only on its temporal relation to food (or the opportunity to obtain food), regardless of its relation to to-be-remembered comparison stimuli. Of course, the same cannot be said of discriminative control over pecking the comparison stimuli.

The differences in conditioned reinforcing efficacy and memorability obtained in the current experiments may reflect more about the measures of these functions than the processes that underlie them. In particular, response rates under schedules of reinforcement in single-key procedures are notoriously insensitive to changes in important variables. Perhaps the clearest example of this is reinforcement rate (Catania & Reynolds, 1968), but the notion applies as well to reinforcer magnitude (Catania, 1963) and signaled reinforcement delay (Chung & Herrnstein, 1967). Each of these variables has been shown to yield large shifts in preference un-

der two-key concurrent schedules at values that have little effect on response rate in single-key procedures (see also Grace & Nevin, 1997). Relatively small changes in the conditioned reinforcing efficacy of brief delay signals may be observed more easily using concurrent or concurrent-chains schedules. Put another way, the conditioned reinforcing function of the sample stimulus in the current experiments may have varied greatly across the low-to-moderate delays, but that variation was not reflected in changes in pre-delay response rates. On the other hand, the delayed discriminative function of brief delay signals may be more robustly apparent over a longer range of intervals in single-key measures of intradelay behavior (Figures 5 and 6). In future research, methods could be employed that would yield a more precise correlation between conditioned reinforcing and delayed discriminative stimulus functions. The goal of the present study was simply to show whether or not pigeons remembered the stimulus that reinforced their recent behavior. The answer appears to be, "yes and no." Although pigeons' matching accuracy dropped at moderate delays, suggesting that they did not remember the sample stimulus, their rate of pecking during those same moderate delays suggested that they remembered that a sample had been presented.

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