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DELAYED REINFORCEMENT AND DELAYED CHOICE IN SYMBOLIC MATCHING TO SAMPLE: EFFECTS ON STIMULUS DISCRIMINABILITY

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Six pigeons were trained to peck a red side key when the brighter of two white lights (S_1) had been presented on the center key, and to peck a green side key when the dimmer of two white lights (S_2) had been presented on the center key. Equal frequencies of reinforcers were provided for the two types of correct choice. Incorrect choices, red side-key pecks following S_2 presentations and green side-key pecks following S_1 presentations, resulted in blackout. With 0-s delay between choice and reinforcement, the delay between sample presentation and choice was varied from 0 to 20 s. Then, with 0-s delay between sample presentation and choice, the delay between choice and reinforcement was varied from 0 to 20 s. Both types of delay resulted in decreased discriminability (defined in terms of a signal-detection analysis) of the center-key stimuli, but delayed choice had more effect on discriminability than did delayed reinforcement. These data are consistent with the view that the two kinds of delay operate differently. The effect of a sample-choice delay may result from a degradation of the conditional discriminative stimuli during the delay; the effect of a choice-reinforcer delay may result from a decrement in control by differential reinforcement.

Key words: behavioral-detection theory, short-term memory, stimulus discriminability, sample-choice delay, choice-reinforcer delay, hyperbolic-decay function, response bias, key peck, pigeons

Remembering in pigeons is typically studied within a delayed conditional-discrimination paradigm such as a delayed-symbolic-matching-to-sample (DSMTS) task (e.g., Jans & Catania, 1980; Maki, Moe, & Bierley, 1977; Wilkie, Summers, & Spetch, 1981) or a delayed signal-detection task (e.g., Harnett, McCarthy, & Davison, 1984; White & McKenzie, 1982). These procedures impose a delay between the to-be-remembered sample stimulus and the availability of the choice alternatives. Increasing the delay between sample offset and choice onset decreases the accuracy of control by the sample stimulus (e.g., Harnett et al., 1984; Jans & Catania, 1980; White & McKenzie, 1982; Wilkie, 1978).

Recent research has interpreted this decrease in differential control by the sample as a decrease in stimulus discriminability, where discriminability is defined within a signal-detection framework (e.g., Harnett et al., 1984; White & McKenzie, 1982). In quantitative terms, discriminability, so defined, appears better described as a decreasing rectangular-hyperbolic function (Harnett et al.) than as a negative-exponential function (White & McKenzie), of the sample-choice delay. Matching-to-sample accuracy also has been shown to decrease with increasing delays between choice and reinforcers (Cox & D'Amato, 1977; D'Amato & Cox, 1976; Wilkie & Spetch, 1978).

One study, with monkeys as subjects (D'Amato & Cox, 1976), allowed a comparison of the effects of these two kinds of delay: sample to choice, and choice to reinforcer. Although accurate differential control by the sample was obtained on a visual discrimination task with sample-choice delays as long as about 120 s, good differential control was not maintained with choice-reinforcer delays longer than about 60 s. Apparently, of the two types of delay, that between choice and reinforcer was the more disruptive of stimulus control by the sample.

The present experiment was undertaken to assess, with pigeons, the functions relating discriminability to the two kinds of delay. This

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	RESPONSE red	RESPONSE green
STIMULI bright (S_1)	W RFT	X EXT
STIMULI dull (S_2)	Y EXT	Z RFT

Fig. 1. The matrix of stimulus and response events in the present experiments. S_1 and S_2 denote the two discriminative stimuli, and red and green the two choice alternatives. *W, X, Y,* and *Z* tally the numbers of events (responses emitted, reinforcers obtained) in each cell of the matrix. RFT and EXT denote reinforcement and extinction, respectively.

assessment of the sample-choice delay function constituted a replication of the study by Harnett et al. (1984). The assessment of the choice-reinforcer delay function constituted an extension of Wilkie and Spetch's (1978) study. The performance of each pigeon was studied under both kinds of delay, and identical sets of delay values were used with both delay procedures so that the functions could be directly compared. The implications of this comparison will be developed in the Discussion section.

For each pigeon in a symbolic-matching-to-sample (SMTS) experiment, pecking a red side key produced food when the brighter (S_1) of two white lights had been presented on the center key, and pecking a green side key produced food when the dimmer (S_2) of two white lights had been presented on the center key. Equal frequencies of reinforcers were provided for the two correct choices. This SMTS procedure is experimentally analogous to the human discrete-trials Yes-No detection task. The matrix of events in this task is illustrated in Figure 1. Red-key pecks were correct (denoted B_w) and intermittently reinforced (R_w) when S_1 was presented, and green-key pecks were correct (B_z) and intermittently reinforced (R_z) when S_2 was presented. Incorrect responses were red-key pecks following S_2 presentations (B_y), and green-key pecks following S_1 presentations (B_x). In different experimental conditions, either delays between stimulus presentation and choice (delayed choice) or between choice and reinforcement (delayed reinforcement) were arranged. When delay of choice was varied, there was no delay between choice and reinforcement, and vice versa for the delay of reinforcement conditions. Delays of choice or reinforcement were varied from 0 s to 20 s in steps of 5 s in the first part of the experiment. Then, after exposure to some experimental conditions not reported here, replications of some of the delayed-reinforcement conditions were arranged.

The data obtained in the present experiment can be analyzed according to a recent extension of the Davison-Tustin (1978) behavioral detection model (Harnett et al., 1984; McCarthy, 1981). Assuming that the ratio of choices occasioned by each of the two stimuli was a power function of the ratio of reinforcers produced by those choices (Baum, 1974) and was a function of the extent to which the two brightness levels of the center-keylight were discriminable, Davison and Tustin proposed the following two equations to describe performance in the presence of each stimulus in the standard (i.e., no sample-choice delay) detection task:

On S_1 trials:

$$\log\left(\frac{B_w}{B_x}\right) = a_{r1}\log\left(\frac{R_w}{R_z}\right) + \log c + \log d, \qquad (1)$$

and on S_2 trials:

$$\log\left(\frac{B_y}{B_z}\right) = a_{r2}\log\left(\frac{R_w}{R_z}\right) + \log c - \log d, \qquad (2)$$

where *B* and *R* denote number of responses emitted and number of reinforcers obtained, respectively, and, for convenience, *w, x, y,* and *z* refer to the cells of the matrix (Figure 1). The obtained reinforcer ratio, $\log(R_w/R_z)$, quantifies a reinforcer-frequency bias (McCarthy & Davison, 1981a, 1984), and the parameters a_{r1} and a_{r2} measure the sensitivity of the choice ratios to changes in the reinforcer-frequency bias. Log *c* is inherent bias, a constant preference across changes in reinforcer bias. (See McCarthy & Davison, 1981a, 1981b, and McCarthy & White, 1986, for reviews of this model in both psychophysical and memory paradigms.)

The parameter log d is interpreted as measuring the discriminability of the two sample stimuli. Since a_{r1} typically equals a_{r2} (e.g., Harnett et al., 1984; McCarthy & Davison, 1980, 1984), the parameter log d can be defined as independent of reinforcer-frequency bias and inherent bias by subtracting Equation 2 from Equation 1. With some rearrangement, this gives:

$$\log d = 0.5 \log\left(\frac{B_w B_z}{B_x B_y}\right). \quad (3)$$

Within the typical delay-of-choice procedure, Harnett et al. (1984) found that stimulus discriminability (i.e., log d) decreased according to a rectangular-hyperbolic function of time, as follows:

$$\log d_t = \left(\frac{h}{h + t}\right) \log d_0. \quad (4)$$

In Equation 4, log d_t represents the discriminability of the stimuli at time t since the end of their presentation, log d_0 is the discriminability of the stimuli at time $t = 0$ s (i.e., a zero-second delay between sample and choice), and t is the delay between sample presentation and choice-key availability. The parameter h represents the half life, or time t at which discriminability falls to one half its initial (log d_0) value. With discriminability represented as a rectangular-hyperbolic function of time, discriminability at the end of a sample-choice delay becomes (from Equation 3):

$$\log d_t = 0.5 \log\left(\frac{B_w B_z}{B_x B_y}\right) = \left(\frac{h}{h + t}\right) \log d_0. \quad (5)$$

Further, a point estimate of response bias (i.e., choice-key bias due to reinforcer asymmetries and to constant inherent biases between the choice keys), independent of stimulus discriminability, is obtained by adding Equation 2 to Equation 1. With some rearrangement, and again assuming that $a_{r1} = a_{r2} = a_r$, this gives:

$$0.5 \log\left(\frac{B_w B_y}{B_x B_z}\right) = a_r \log\left(\frac{R_w}{R_z}\right) + \log c. \quad (6)$$

Thus, response bias (as measured by the left side of Equation 6) is a power function of reinforcer-frequency bias. In psychophysical studies, the value of the power ranges from 0.4 to 0.8 (e.g., McCarthy & Davison, 1979, 1980, 1984), and in recall experiments it ranges from about 0.4 to 0.7 (e.g., Harnett et al., 1984). That is, response bias typically undermatches reinforcer-frequency bias (McCarthy & Davison, 1981a, 1984).

Consistent with the findings of Harnett et al. (1984) and White and McKenzie (1982), we expected stimulus discriminability (log d_t) to decrease as the sample-choice delay (t_c) was increased. Further, we expected this decay function to be well described by a rectangular-hyperbolic function, Equation 4 (Harnett et al., 1984; McCarthy & White, 1986). Given the findings of Wilkie and Spetch (1978), we also expected discriminability to decrease with increasing choice-reinforcer delays (t_r). The major question posed was whether discriminability was a similarly decreasing function of delay under sample-choice and choice-reinforcer delay procedures (cf. D'Amato & Cox, 1976).

METHOD

Subjects

Six homing pigeons, numbered 51 to 56, served. Each bird was maintained at 85% ± 15 g of its free-feeding body weight by supplementary feeding with mixed grain in the home cage after each experimental session. Water and grit were freely available in the home cage. The birds were not experimentally naive. All had served in a previous DSMTS recall experiment with the same equipment (Harnett et al., 1984).

Apparatus

Conventional solid-state control equipment was situated remotely from the standard sound- and light-attenuating chamber. The chamber was fitted with an exhaust fan to mask external noise, and it contained three response keys 2 cm in diameter, 6 cm apart, and 26 cm above the grid floor. The two outer keys could be transilluminated red or green, and the center key was transilluminated by white light. The white light could be varied between two different luminances by varying the voltage across the Fairmont E-10 0.05 amp, 24-V, 1.2-W incandescent pilot lamp. Luminance levels were measured using an ASAHI Pentax Spotmeter V®. The more intense luminance (S_1) was 1.84 cd/m^2, and the less intense luminance (S_2) was 0.87 cd/m^2. These luminance values were slightly lower than those used by Harnett et al. (1984). Both

Table 1

The sequence of experimental conditions and the number of training sessions given in each. t_c denotes the duration of the sample-choice delay, and t_r denotes the choice-reinforcer delay, both in seconds. The reinforcer schedules were dependent concurrent VI 30 s VI 30 s in all conditions. In the conditions for which data are not reported, some intermediate values of choice-reinforcer delays, and some reinforcer-frequency manipulations, were carried out.

Condition	t_c	t_r	Sessions
1	0	0	30
2	0	5	30
3	5	0	24
4	0	10	24
5	10	0	22
6	15	0	26
7	0	15	20
8	20	0	21
9	0	20	25
12	0	15	22
16	0	20	22
22	0	10	24
23	0	15	24

of these intensities remained constant throughout the experiment, and each was presented equally often on the center key during each training session. When illuminated, each key could be operated by a peck with force exceeding 0.1 N. Pecks on darkened keys had no scheduled consequences. A food magazine was situated beneath the center key, and 10 cm above the grid floor. Reinforcement was 3-s access to wheat, during which the magazine light was illuminated and the magazine was raised. The key and magazine lights provided the only sources of illumination in the chamber.

Procedure

Because the birds had previously served in a DSMTS task (Harnett et al., 1984), no shaping of key pecking was required, and they were placed directly on the first experimental condition. The sequence of experimental conditions, and the number of training sessions given in each, are shown in Table 1.

In all conditions, a trial began with the illumination by white light of the center key. The two side keys were initially darkened, and pecks on these darkened keys had no scheduled consequences. The luminance of the white center-keylight was either 1.84 cd/m^2 (S$_1$) or 0.87 cd/m^2 (S$_2$), and each of these intensities occurred equally often on the center key. One peck on the center key extinguished the white light and initiated the sample-choice delay interval of t_c s during which time all keylights were extinguished, and responses were ineffective. In Conditions 1, 3, 5, 6, and 8, the duration of the sample-choice delay (t_c) was 0, 5, 10, 15, and 20 s, and the choice-reinforcer delay was zero (Table 1). These conditions constitute a partial replication of Experiment 1 of Harnett et al.

On completion of the sample-choice delay, t_c, the two side keys were lit either red (left) and green (right), or green (left) and red (right). The occurrence of red or green on the left or right key was randomized ($p = .5$) across trials. A correct choice (or recall response) was either a single peck on the red side key following presentation of the more intense luminance (S$_1$) on the center key, or a single peck on the green side key following presentation of the less intense luminance (S$_2$) on the center key.

Correct red- and green-key choices were intermittently reinforced t_r s after side-key offset. In Conditions 2, 4, 7, and 9, the choice-reinforcer delay (t_r) was 5, 10, 15 and 20 s, respectively, and t_c was zero. During the choice-reinforcer delay the keylights were darkened. Condition 1 ($t_c = t_r = 0$ s) also contributed to the set of delayed-reinforcer conditions. Condition 22 was a replication of Condition 4 ($t_r = 10$ s), Conditions 12 and 23 were replications of Condition 7 ($t_r = 15$ s), and Condition 16 was a replication of Condition 9 ($t_r = 20$ s). As noted above, t_r was 0 s in Conditions 1, 3, 5, 6, and 8.

Reinforcement was 3-s access to wheat, arranged according to a concurrent VI 30-s (red) VI 30-s (green) schedule. In order to equalize the frequency of reinforcers for red- and green-key responses, the VI schedules were arranged dependently (Stubbs, 1976; Stubbs & Pliskoff, 1969) on the red and green side keys, as follows: The schedules ran continuously except during reinforcement. For example, if a reinforcer was set up by the green-key schedule, both VI timers stopped and a reinforcer was unavailable for a correct-red choice until the green-correct response had been emitted. This is a controlled reinforcer-ratio procedure that minimizes the development of extreme response biases at low discriminability levels (McCarthy, 1983; McCarthy & Davison, 1984). When a correct red or green side-key choice had been emitted but a food reinforcer had not been set up by either VI timer, the magazine light alone was presented for 3 s after the delay interval (t_r) had elapsed.

An incorrect choice was either a single red-key peck following S_2 presentation or a single green-key peck following S_1 presentation. Each incorrect choice produced the delay interval (t_r) that terminated in a 3-s blackout. Thus, after an incorrect response, the keylights were extinguished for (t_r + 3) s, during which time responses had no scheduled consequences.

A new trial (i.e., presentation of the white center-keylight) began after either food, magazine light, or blackout had been produced. A noncorrection procedure was in effect throughout the experiment: Presentations of S_1 and S_2 on the center key on a given trial were independent of both the stimulus and the accuracy of choice on the previous trial.

Experimental sessions were conducted 7 days per week. Each training session ended in blackout either when 200 trials had been completed or when approximately 40 min had elapsed, whichever occurred first. The data collected were the numbers of responses emitted on, and the numbers of food reinforcers produced by responses on, the red and green side keys following both S_1 and S_2 presentations. Experimental conditions were not changed until each of the 6 birds had met a stability criterion: Following a minimum of nine training sessions, the median discriminability estimates (Equation 3) were calculated across successive blocks of three consecutive sessions. The criterion required no monotonic trend in discriminability. In this manner, stability could not be attained in fewer than 18 training sessions. The mean number of training sessions conducted, averaged across the 13 experimental conditions, was 24 (Table 1).

RESULTS

The appendix shows the number of responses emitted on, and the number of food reinforcers produced by responses on, the red and green keys following both S_1 and S_2 presentations. The data shown in the appendix were summed over the final five sessions of each experimental condition. These data show that with increases in the duration of both the delay from sample offset to choice-key onset, and in the delay from choice to reinforcement, all birds emitted fewer correct choices (red/S_1 & green/S_2) and emitted more errors (red/S_2 & green/S_1). That is, accuracy decreased as the sample-choice delay (t_c) increased, as reported by Jans and Catania (1980) and by Wilkie (1978), and as the choice-reinforcement delay increased as reported by D'Amato and Cox (1976) and by Wilkie and Spetch (1978).

Delay of Choice

Point estimates of stimulus discriminability at each sample-choice delay t_c (i.e., log d_t) were calculated using Equation 3 with the data shown in the appendix. Assuming that pigeons can discriminate perfectly between red and green choice alternatives (Charman & Davison, 1983), the values of log d_t reported here are interpreted as the discriminability of the two light intensities. Figure 2 shows the estimate of stimulus discriminability plotted as a function of the sample-choice delay, t_c (measured in seconds), for each of the 6 birds. Plotted with open-square symbols, this shows that log d_t decreased as the sample-choice delay increased, which is consistent with the findings of Harnett et al. (1984) and White and McKenzie (1982).

The rectangular-hyperbolic decay function (Equation 4) was fitted to the delay of choice data shown for each bird using parametric least-squares curve fits (PARAFIT; Ruckdeschel, 1981). The predicted values of initial discriminability, log d_0 (discriminability at time $t_c = 0$ s), the half life, h (time t_c at which discriminability fell to one half its initial value), and the percentage of data variance accounted for (VAC) by the rectangular-hyperbolic model, are shown in Figure 2 for each bird.

Predicted values of log d_0 ranged from 0.73 (Bird 51) to 1.96 (Bird 53), and were very close to the values actually obtained in Condition 1 in which t_c was zero. The half life h ranged from 0.23 s (Birds 54 & 55) to 2.54 s (Bird 52). Consistent with the results of Harnett et al. (1984), who used the same birds as subjects, for Bird 55 discriminability of the sample stimuli was zero at delays longer than $t_c = 0$ s. For this bird, the value of h probably was overestimated because no delays between 0 and 5 s were arranged. The variance accounted for by these rectangular-hyperbolic fits ranged from 97% (Bird 52) to 100% (Birds

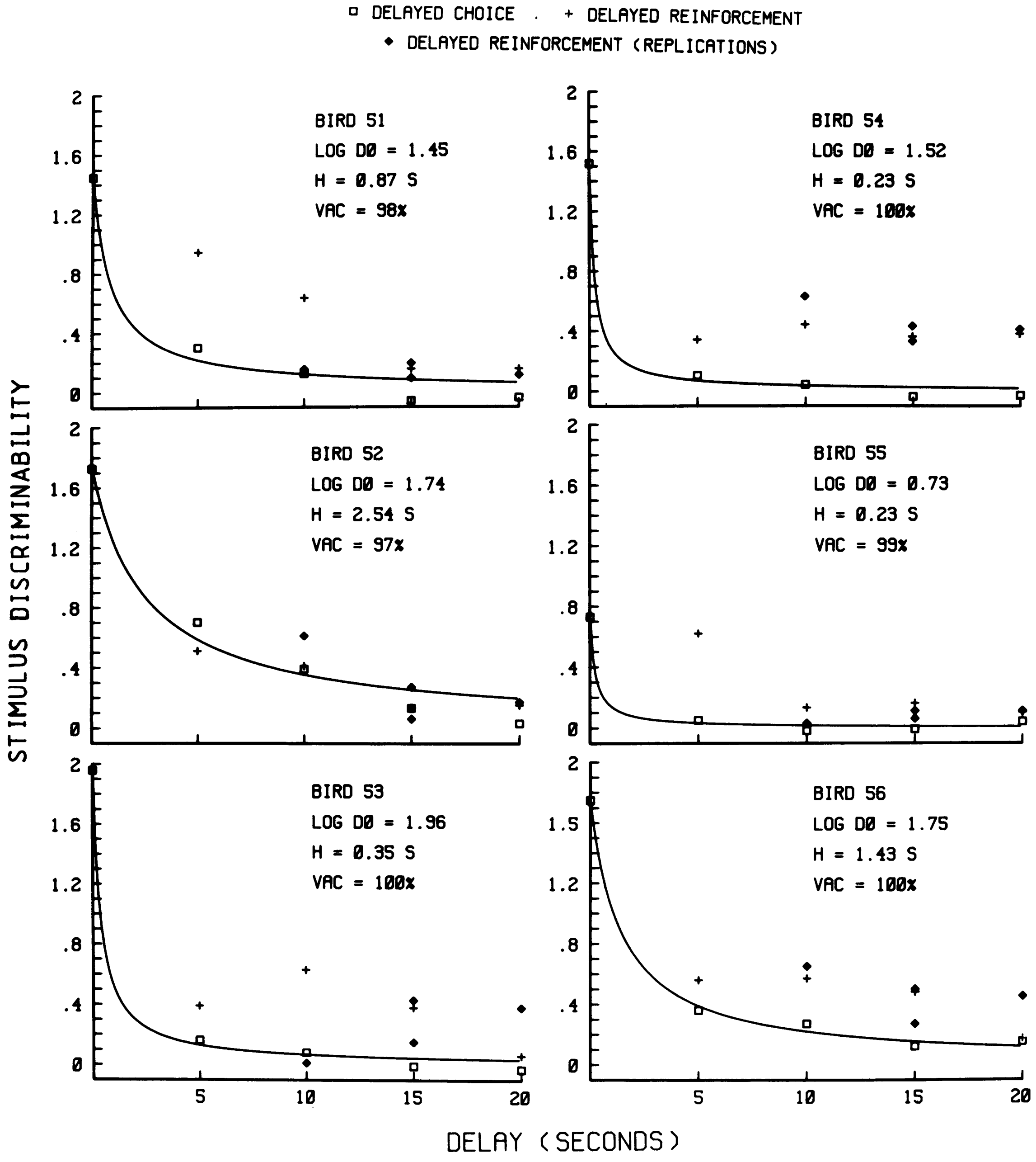

Fig. 2. Point estimates of stimulus discriminability (log d_t) as a function of the sample-choice delay (t_c, square symbols) and the choice-reinforcer delay (t_r, plus symbols), measured in seconds, for each bird. The data shown were averaged over the final five sessions of each experimental condition. Nonlinear least-squares fits of the rectangular-hyperbolic model (Equation 4) to the delay of choice data *only* are shown as continuous lines, and the values of the half life (h), the predicted values of initial discriminability (log d_0), and the percentage of data variance accounted for (VAC) by these fits are shown on each figure.

53, 54, & 56), with an average of 99% across all birds.

In a DSMTS task, when the relative distribution of reinforcers for correct choices was kept constant and equal between the choice alternatives, response bias remained constant as the sample-choice delay increased (Harnett et al., 1984). As the data in the appendix show, approximately equal numbers of food reinforcers were obtained from the red and green keys across all sample-choice delays in the present experiment (mean obtained $\log[R_w/R_z] = 0.01$, $SD = 0.03$). Accordingly, response bias (as measured by the expression to the left of the equality in Equation 6) should have remained constant and, in the absence of any inherent bias ($\log c$), close to zero, as the sample-choice delay increased.

To assess the constancy of response bias as a function of increasing t_c, point estimates of response bias were computed using Equation 6 with the data shown in the appendix. With the single exception of Bird 53 at $t_c = 0$ s, response-bias values were close to zero for all values of t_c. The standard deviation of response-bias measures over subjects and over sample-choice delay values (excluding Condition 1 for comparison purposes with delay of reinforcement data) was 0.05. A nonparametric trend test (Ferguson, 1965; $p > .05$) revealed that response bias did not change in any systematic way as the sample-choice delay increased, and hence, as discriminability decreased.

Although there were no consistent red/green response biases, it is possible that left/right position preferences were adopted by the animals. This possibility seems unlikely, however, because of results obtained from an equivalent procedure with the same subjects (Harnett et al., 1984). In that study, the relative frequency of reinforcers produced by correct choices was varied. The important result was that the sensitivity to changes in the red/green reinforcer ratio was the same at each of three different sample-choice delays, $t_c = 0.06$, 3.85, and 10.36 s (mean a_r in Equation 6 was 0.5). Thus, the trend toward zero discriminability with increasing sample-choice delay (Figure 2) probably was not accompanied by the development of left–right position preferences.

Delay of Reinforcement

Figure 2 also shows, for each subject, stimulus discriminability measures, plotted with plus symbols, as a function of choice-reinforcer delay. These $\log d_t$ values were obtained by applying Equation 3 to the data in the appendix. The rectangular-hyperbolic model was not fitted to these data because there was no a priori reason to assume that discriminability falls hyperbolically with delay of reinforcement, and indeed the data obtained from 3 of the 6 subjects did not show a clear monotonic decrease. Nevertheless, discriminability tended to decrease as a function of the choice-reinforcer delay. Further, discriminability values at a given choice-reinforcer delay were usually higher than those obtained under the equivalent sample-choice delay.

As the data in the appendix show, approximately equal numbers of food reinforcers were obtained from the red and green keys across all choice-reinforcer delays (mean obtained $\log[R_w/R_z] = 0$, $SD = 0.03$). Consistent with the data from sample-choice delay conditions, point estimates of response bias (computed by applying Equation 6 to the data given in the appendix) showed no significant ($p > .05$) trend as the choice-reinforcer delay increased. There were, however, large and apparently random fluctuations in response-bias measures across delay-of-reinforcement conditions (mean log bias = 0.01, $SD = 0.22$, range -0.58 to $+0.64$). Again, it is possible that left–right position preferences could have developed under delays of reinforcement as a concomitant to the discriminability decrease that occurred. We have no evidence to refute such a suggestion, but the development of position preferences would not change the conclusions of the present experiment.

DISCUSSION

The main result of the present experiment was the demonstration that, in a delayed-symbolic-matching-to-sample (DSMTS) task, instituting delays either between sample-stimulus presentation and choice, or between choice and reinforcement, decreased the control by the discriminative stimuli over choice, and hence caused a decrease in the discriminability measure, $\log d$. Nevertheless, the sample-choice delay tended to have a greater decremental effect on discriminability ($\log d_t$) than did the choice-reinforcer delay. For example, averaging over replications, $\log d_t$ values were lower under the sample-choice delays than under the equivalent choice-reinforcer delays in 23 of the 24 (6 subjects, 4 nonzero delays) comparisons. If each individual replication value is used in the comparison, delay-of-reinforcement discriminabilities were higher in 45 of 48 comparisons.

This result is opposite from that reported by D'Amato (1973) and by D'Amato and Cox

(1976). The reason for this difference may be in the subjects (D'Amato used capuchin monkeys), or in the procedure (D'Amato used a nonsymbolic matching task, in which sample and choice stimuli are identical, whereas we used a symbolic matching task, in which the sample and choice stimuli are related only through the procedures, and not through their physical characteristics. D'Amato (p. 265) proposed an explanation for the discriminability differences between delayed-choice and delayed-reinforcer conditions. He hypothesized that a delay of reinforcement was aversive, and that this aversiveness becomes correlated with the sample stimulus on a particular trial. Thus, in a nonsymbolic matching-to-sample task, when the sample stimulus is re-presented during the choice, the subject will be less likely to emit that response. Such an effect should be absent, presumably, in a symbolic task such as we used. The implications of D'Amato's suggestion for symbolic procedures are unclear. Certainly, discriminabilities under symbolic choice-reinforcer delays will be greater than under the equivalent nonsymbolic delays. Such an effect could lead to symbolic choice-reinforcer and stimulus-choice discriminabilities being equal. But there is no obvious basis for the greater choice-reinforcer discriminabilities than stimulus-choice discriminabilities that we found.

The present data are consistent with a recent model of detection and the effects on detection of differential reinforcement (Davison & Jenkins, 1985). When delay of choice is increased, the control by the discriminative stimuli over the choice response is decreased by the time between sample presentation and the availability of the choice alternatives. This could be thought of as a decrement purely in the current effectiveness of the sample as a discriminative stimulus for choice. That is, the stimulus differential between the samples is effectively reduced by increasing sample-choice delays. The effect of a reinforcer delay is interpreted differently. When the choice-reinforcer delay is zero, the effectiveness of differential reinforcement in establishing and maintaining control over choice should be maximal and constant over variations in sample-choice delays. When the choice-reinforcer delay is increased, the control by the subsequent reinforcer of the emission of red versus green responses during choice could be affected by the delay from emitting the choice response to reinforcement. Increasing delay of reinforcement is thus seen as degrading the reinforcement differential for preceding responses.

If a reinforcer delay produced a failure of the differential reinforcement of correct responses, relative to incorrect responses, then the situation is conceptually similar to that which occurs when error responses, as well as correct responses, are reinforced in signal detection. Under such a procedure, measures of log *d* fall as the probability of error reinforcers is increased and, therefore, as differential reinforcement for correct responses is degraded (Davison & McCarthy, 1980; Nevin, Olson, Mandell, & Yarensky, 1975). Analogously, under delay of reinforcers, differential reinforcement for correct versus error responses might effectively decrease with increasing delays. Both sample-choice (stimulus differential) and choice-reinforcer (reinforcer differential) effects would be seen as decreasing measures of sample discriminability in the detection model used to analyze these data. Naturally, the decremental effects over time produced by the two kinds of delay may be quite different. These suggestions do not explain the difference between D'Amato and Cox's (1976) results and ours, but they do point to one area of investigation—the discriminability of the stimuli signaling the choices. Without doubt, this discriminability was lower in D'Amato and Cox's nonsymbolic task (giving a lower reinforcer differential) than it was in our symbolic task.

REFERENCES

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior,* **22,** 231–242.

Charman, L., & Davison, M. (1983). Undermatching and stimulus discrimination in multiple schedules. *Behaviour Analysis Letters,* **3,** 77–84.

Cox, J. K., & D'Amato, M. R. (1977). Disruption of overlearned discriminative behavior in monkeys (*Cebus apella*) by delay of reward. *Animal Learning & Behavior,* **5,** 93–98.

D'Amato, M. R. (1973). Delayed matching and short-term memory in monkeys. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 7, pp. 227–269). New York: Academic Press.

D'Amato, M. R., & Cox, J. K. (1976). Delay of consequences and short-term memory in monkeys. In D.

L. Medin, W. A. Roberts, & R. T. Davis (Eds.), *Processes of animal memory* (pp. 49-78). Hillsdale, NJ: Erlbaum.

Davison, M., & Jenkins, P. E. (1985). Stimulus discriminability, contingency discriminability, and schedule performance. *Animal Learning & Behavior,* **13,** 77-84.

Davison, M., & McCarthy, D. (1980). Reinforcement for errors in a signal-detection procedure. *Journal of the Experimental Analysis of Behavior,* **34,** 35-47.

Davison, M. C., & Tustin, R. D. (1978). The relation between the generalized matching law and signal-detection theory. *Journal of the Experimental Analysis of Behavior,* **29,** 331-336.

Ferguson, G. A. (1965). *Nonparametric trend analysis.* Montreal: McGill University Press.

Harnett, P., McCarthy, D., & Davison, M. (1984). Delayed signal detection, differential reinforcement, and short-term memory in the pigeon. *Journal of the Experimental Analysis of Behavior,* **42,** 87-111.

Jans, J. E., & Catania, A. C. (1980). Short-term remembering of discriminative stimuli in pigeons. *Journal of the Experimental Analysis of Behavior,* **34,** 177-183.

Maki, W. S., Jr., Moe, J. C., & Bierley, C. M. (1977). Short-term memory for stimuli, responses, and reinforcers. *Journal of Experimental Psychology: Animal Behavior Processes,* **3,** 156-177.

McCarthy, D. (1981). Toward a unification of psychophysical and behavioural research. *New Zealand Psychologist,* **10,** 2-14.

McCarthy, D. (1983). Measures of response bias at minimum-detectable luminance levels in the pigeon. *Journal of the Experimental Analysis of Behavior,* **39,** 87-106.

McCarthy, D., & Davison, M. (1979). Signal probability, reinforcement and signal detection. *Journal of the Experimental Analysis of Behavior,* **32,** 373-386.

McCarthy, D., & Davison, M. (1980). Independence of sensitivity to relative reinforcement rate and discriminability in signal detection. *Journal of the Experimental Analysis of Behavior,* **34,** 273-284.

McCarthy, D., & Davison, M. (1981a). Towards a behavioral theory of bias in signal detection. *Perception & Psychophysics,* **29,** 371-382.

McCarthy, D., & Davison, M. (1981b). Matching and signal detection. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 393-417). Cambridge, MA: Ballinger.

McCarthy, D., & Davison, M. (1984). Isobias and alloiobias functions in animal psychophysics. *Journal of Experimental Psychology: Animal Behavior Processes,* **10,** 390-409.

McCarthy, D., & White, K. G. (1986). Behavioral models of delayed detection and their application to the study of memory. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. C. Rachlin (eds.), *Quantitative analyses of behavior: Vol. 5. Effects of delay and of intervening events on reinforcement value* (pp. 29-54). Hillsdale, NJ: Erlbaum.

Nevin, J. A., Olson, K., Mandell, C., & Yarensky, P. (1975). Differential reinforcement and signal detection. *Journal of the Experimental Analysis of Behavior,* **24,** 355-367.

Ruckdeschel, F. R. (1981). *Basic scientific subroutines.* Peterborough, NH: Byte/McGraw-Hill.

Stubbs, D. A. (1976). Response bias and the discrimination of stimulus duration. *Journal of the Experimental Analysis of Behavior,* **25,** 243-250.

Stubbs, D. A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior,* **12,** 887-895.

White, K. G., & McKenzie, J. (1982). Delayed stimulus control: Recall for single and relational stimuli. *Journal of the Experimental Analysis of Behavior,* **38,** 305-312.

Wilkie, D. M. (1978). Delayed symbolic matching to sample in the pigeon. *Psychological Record,* **28,** 463-469.

Wilkie, D. M., & Spetch, M. L. (1978). The effect of sample and comparison ratio schedules on delayed matching to sample in the pigeon. *Animal Learning & Behavior,* **6,** 273-278.

Wilkie, D. M., Summers, R. J., & Spetch, M. L. (1981). Effect of delay-interval stimuli on delayed symbolic matching to sample in the pigeon. *Journal of the Experimental Analysis of Behavior,* **35,** 153-160.

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APPENDIX

The number of responses emitted on, and the number of reinforcers produced by responses on, the red and green side keys following both S_1 and S_2 presentations. These data were summed over the final five sessions of each experimental condition. The durations of the sample-choice delay (t_c) and the choice-reinforcer delay (t_r) are in seconds.

				Responses					
				S_1		S_2		Reinforcers	
Condition	t_c	t_r	Bird	R	G	R	G	R	G
1	0	0	51	488	13	22	467	64	71
			52	512	6	13	447	65	60
			53	489	27	1	456	62	64
			54	488	10	21	463	61	62
			55	420	64	93	415	52	52
			56	480	12	6	484	61	57
2	0	5	51	353	16	86	289	123	115
			52	313	78	101	258	113	107
			53	170	132	54	249	85	83
			54	290	104	130	224	95	93
			55	260	94	54	342	115	117
			56	271	69	75	248	117	116
3	5	0	51	240	137	114	259	88	83
			52	328	65	60	296	123	120
			53	252	137	168	191	89	88
			54	200	171	157	212	83	85
			55	186	183	171	210	78	79
			56	268	107	121	250	98	95
4	0	10	51	211	22	67	127	69	63
			52	130	37	75	138	68	66
			53	181	59	37	224	92	83
			54	182	63	70	185	73	71
			55	145	123	92	139	61	56
			56	212	33	80	175	92	82
5	10	0	51	116	84	89	113	54	48
			52	180	79	67	174	86	81
			53	139	106	119	130	68	58
			54	129	115	122	132	58	55
			55	92	86	96	80	39	31
			56	179	70	106	145	72	64
6	15	0	51	66	75	85	74	34	34
			52	80	59	48	65	37	37
			53	29	32	36	38	16	17
			54	82	88	89	80	47	46
			55	84	97	79	89	40	38
			56	97	71	75	94	37	43
7	0	15	51	60	66	40	86	41	30
			52	34	15	29	23	19	16
			53	36	16	10	26	15	12
			54	136	36	73	101	57	51
			55	90	68	70	110	52	47
			56	43	55	9	103	27	28
8	20	0	51	38	53	57	66	22	25
			52	89	78	85	85	42	39
			53	33	33	35	31	14	14
			54	86	83	86	72	44	45
			55	93	78	90	89	41	40
			56	70	50	52	73	31	32
9	0	20	51	25	14	17	19	4	9
			52	63	13	66	27	19	18
			53	31	14	25	15	11	8

APPENDIX (*Continued*)

				Responses					
				S_1		S_2		Reinforcers	
Condition	t_c	t_r	Bird	R	G	R	G	R	G
			54	70	52	27	114	39	50
			55	75	81	57	99	47	45
			56	47	39	32	57	23	24
12	0	15	51	102	79	71	85	45	43
			52	53	58	55	78	26	32
			53	71	6	39	24	13	13
			54	89	71	41	149	58	57
			55	100	63	77	82	48	41
			56	97	70	50	124	44	48
16	0	20	51	79	69	52	74	44	41
			52	73	32	58	55	27	27
			53	89	19	50	62	43	39
			54	128	54	44	122	59	64
			55	89	77	75	107	51	56
			56	86	24	34	75	43	39
22	0	10	51	87	84	66	130	42	40
			52	187	67	36	210	97	94
			53	56	67	55	69	32	34
			54	188	68	32	212	91	86
			55	117	128	112	143	55	55
			56	197	54	38	211	90	90
23	0	15	51	99	78	64	121	56	53
			52	91	77	42	126	50	49
			53	47	36	29	44	24	18
			54	162	80	56	202	86	79
			55	93	120	70	117	54	44
			56	147	35	51	122	71	57