

CHARACTERISTICS OF FORGETTING FUNCTIONS IN DELAYED MATCHING TO SAMPLE

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Performance of pigeons in delayed matching-to-sample procedures was measured in terms of an index of discriminability derived from the difference between logarithms of ratios of choice responses to comparison stimuli following the different sample stimuli. Forgetting functions that plotted discriminability as a function of delay-interval duration were well described by a simple negative exponential function with two parameters, one describing initial discriminability of sample stimuli at zero delay ($\log d_0$) and the other describing rate of decrement in discriminability with increasing delay-interval duration (b). With the difference between wavelength values of the comparison stimuli held constant, a large difference between wavelengths of the sample stimuli resulted in a higher $\log d_0$ value than that for a small difference between sample stimuli, without changing the rate of decrement in discriminability, b . An increase in the fixed-ratio requirement for sample-key responding produced an increase in $\log d_0$ without affecting b , and interpolation of ambient illumination in the delay interval increased b without influencing $\log d_0$. Both parameters changed when intertrial-interval duration was varied. The result of variation in the point of interpolation of ambient illumination in the delay interval indicated that levels of discriminability at longer delays were independent of discriminability levels at earlier delays, consistent with the properties of the exponential function. Functions relating performance to delay-interval duration were suggested to have two characteristics: discriminability of the sample stimuli in the absence of a delay between the stimuli and the behavior they occasion, and rate of attenuation in discriminability with increasing delay-interval duration.

Key words: remembering, discriminability, delay-interval functions, delayed matching to sample, key peck, pigeon

Remembering is discriminative behavior under delayed stimulus control. It is studied in procedures that include a delay between presentation of discriminative stimuli and the behavior they occasion. But apart from the delay, remembering procedures do not differ in principle from those used to study other discrimination processes, as Branch (1977), D'Amato (1973), and Catania (1984) have noted. The

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main effect of the delay is to attenuate stimulus control, an effect commonly referred to as "forgetting." As the delay lengthens, the extent of attenuation increases. The main point of the present paper is that the function relating behavior under delayed stimulus control to the length of the delay has two characteristics. One is the extent of stimulus control with no delay between the stimuli and the behavior they occasion. The other is the rate at which stimulus control is attenuated as the delay lengthens. In the present study it is asked whether these characteristics are related and whether they are influenced differentially by variables typically used to study remembering.

The delayed matching-to-sample procedure has been the focus of an extensive empirical and theoretical literature largely concerned with cognitive processes in animal memory (Grant, 1981; Honig & Thompson, 1982;

Roberts & Grant, 1976). The procedure involves the center-key presentation of one of two sample stimuli, S_1 or S_2 , on each trial. Following a delay interval, two comparison stimuli, C_1 and C_2 , are presented on side keys. In delayed matching to sample, C_1 is identical to S_1 and C_2 is identical to S_2 . Responses on comparison stimuli that match the most recently presented sample are reinforced. The matching relation may be arbitrary, or "symbolic," in which case C_1 and C_2 differ from S_1 and S_2 . A response on C_1 is reinforced if the sample was S_1 and a response on C_2 is reinforced if the sample was S_2 .

Delayed matching to sample involves a conditional discrimination between S_1 and S_2 . The stimulus control exerted by S_1 and S_2 can therefore be measured by the accuracy of the matching performance. White and McKenzie (1982) employed an index of stimulus control that explicitly measured how well S_1 and S_2 could be discriminated, given that the discriminative behavior was emitted in the absence of the stimuli. This index, called $\log d$, was derived from Davison and Tustin's (1978) analysis of signal-detection performance. The index is directly analogous to d' of signal-detection theory but has an empirical basis in the generalized matching law (Baum, 1974), rather than a theoretical basis in the assumptions of signal-detection theory. The $\log d$ measure is also the same as the discriminability measure proposed by Nevin (Nevin, 1970, 1981; Nevin, Jenkins, Whittaker, & Yarensky, 1982). For the present purpose, the main advantage of $\log d$ is that it is a measure of the discriminability of the sample stimuli *at the time* the discriminative behavior is emitted. It also has the advantage that it is free of the biasing effects of the reinforcer differential by which the stimulus control is established, whereas the more usual measure of performance in delayed matching to sample, percentage correct, is not (McCarthy, 1983; McCarthy & White, in press; Wright, 1974).

In order to compute $\log d$ it is necessary to know the frequencies of choice responses on comparison stimuli following each sample. If responses on the two comparisons are P_{11} and P_{12} following S_1 , and P_{21} and P_{22} following S_2 , "correct" responses would be P_{11} and P_{22} . The

index of discriminability between S_1 and S_2 is

$$\log d = \frac{1}{2} [\log (P_{11}/P_{12}) - \log (P_{21}/P_{22})]. \quad (1)$$

The relative difficulty with which S_1 and S_2 are discriminated will depend on a variety of conditions, including the delay since their presentation (McCarthy & White, in press; White & McKenzie, 1982). A question of theoretical interest is whether the rate at which discriminability decreases with increasing delay interval depends on discriminability of the sample stimuli at zero delay. In other words, does the extent of "forgetting" depend on initial discriminability of the samples? For example, in relation to their "context model" for delayed matching, Reynolds and Medin (1981) suggested the possibility that "stimulus and context attributes may become less distinctive with time" (p. 346), and Roitblat (1983) has assumed that as the delay interval increases, similar "codes" representing the sample stimuli "would be more likely to be confused than are less similar codes" (p. 173).

Another suggestion pertaining to the discriminability of the sample stimuli was made by Nelson and Wasserman (1978). In order that D'Amato's (1973) temporal-discrimination hypothesis could account for the fact that longer sample-presentation durations improve matching accuracy (Grant, 1981), they suggested modifying it to include the assumption that the discriminability of sample stimuli is enhanced by longer sample durations. Such enhancement may result in an overall improvement in performance rather than a change in the rate at which discriminability diminishes with increasing delays.

EXPERIMENT 1

Experiment 1 examined whether the rate of decrease in discriminability of the sample stimuli with increasing delay-interval duration depends on initial discriminability of the sample stimuli. This was done by comparing performances with small and large differences between the wavelength values of sample stimuli, while keeping the wavelength values of comparison stimuli constant. In an earlier experiment by Roberts (1972), accuracy of de-

layed matching appeared to decrease with increasing delay-interval duration at a faster rate for similar sample stimuli. But because Roberts' delayed-matching procedure involved identical colors for sample and comparison stimuli, difficulty of discriminating samples was confounded with difficulty of discriminating comparison stimuli. This confounding may be important in that matching performance in the conditional discrimination may be predicted on the basis of the simple (sample or comparison) discriminations (Carter & Eckerman, 1975). Holding comparison-stimuli values constant in the present experiment avoided this problem.

METHOD

Subjects

Five adult homing pigeons with extensive experience in delayed symbolic matching-to-sample procedures (White & McKenzie, 1982) were maintained at 80% of their free-feeding weights. Daily sessions for each bird were conducted only if the bird's weight was within $\pm 5\%$ of the prescribed weight, which was maintained by supplementary feeding of mixed grain. Water and grit were always available in the living cages.

Apparatus

A sound-attenuating experimental chamber with internal dimensions of 31 by 34 by 33 cm contained a three-key intelligence panel. The interior was painted matte black. A houselight on a side wall was normally unlit, but when illuminated it had a brightness of 286 cd/m^2 as measured by a Pentax Spotmeter. The hopper opening was beneath the center key. An exhaust fan provided general masking noise. The three translucent response keys were 2.5 cm in diameter and 10 cm apart, center to center. Closure of microswitches mounted behind the keys required pressures of 0.15 N for the center key and 0.20 N for the side keys.

In-line projectors (IEE with 24-V #1820 lamps) were mounted behind the keys. Sample and comparison stimuli presented on the center and side keys were 0.8-cm discs of color produced by Kodak Wratten filters 65, 74, 73, and 72B with peak transmission wavelengths of 501 nm, 538 nm, 576 nm, and 606 nm, re-

spectively. Kodak neutral density filters were added to the Wratten filters in order to equate brightness of all color stimuli on all three keys at 0.2 cd/m^2 as measured by a Pentax Spotmeter.

Delay intervals were timed by a solid-state time base and decade counters, and trial sequences and other events were controlled and recorded by a tape reader, solid-state and relay circuitry, and digital counters, all located in an adjacent room.

Procedure

Owing to their extensive prior training in the present and similar procedures, the birds did not require preliminary training and were introduced directly to the first experimental condition. (Experiment 1 was actually conducted after Experiment 2, but is reported first in the interest of organizational clarity.) The standard procedure was as follows. Each trial began with the presentation of the center key illuminated by a sample-stimulus wavelength of 576 nm (S_1) or 538 nm (S_2). The fifth peck (FR 5) darkened the center key and initiated a delay interval that lasted for 0.5, 2, 4, 8, or 20 s. During the delay interval, the chamber was dark and responses were ineffective. The order of S_1 and S_2 sample stimuli was randomized in blocks of 10 trials within each session, with the constraint that the same sample could occur on no more than three successive trials. The order of delay intervals was randomized within blocks of five trials within each session. The delay interval terminated with onset of side-key comparison stimuli, one with the 576-nm wavelength (C_1) and the other with the 538-nm wavelength (C_2), randomly located on left or right side keys over trials. Correct side-key responses were defined as a peck on C_1 if the prior sample was S_1 , or a peck on C_2 if the prior sample was S_2 . A single correct response darkened both keys and produced 2-s access to grain and a dark 20-s intertrial interval. A single incorrect side-key response darkened both keys and initiated the dark 20-s intertrial interval. Each daily session comprised 80 trials, with eight S_1 and eight S_2 trials for each of the five delay intervals.

Two replications of two conditions were

Table 1

Correct choices at each delay summed over the last 10 sessions of each of two repetitions per condition and over repetitions for individual birds.

Bird	Delay (s)									
	Sample S_1					Sample S_2				
	0.5	2	4	8	20	0.5	2	4	8	20
<i>A. 538 nm vs. 576 nm samples with 538 nm vs. 576 nm comparisons</i>										
T1	154	152	118	124	93	152	136	116	96	83
T2	144	132	136	121	88	142	146	135	117	90
T3	145	141	126	122	98	148	133	134	104	99
T4	159	153	147	136	112	156	148	149	129	123
T5	157	146	142	120	89	157	145	131	127	100
<i>B. 501 nm vs. 606 nm samples with 538 nm vs. 576 nm comparisons</i>										
T1	159	155	138	137	95	153	148	138	114	93
T2	146	149	147	129	97	150	144	153	131	94
T3	158	150	146	129	116	154	147	140	112	105
T4	159	157	150	151	116	159	157	148	124	130
T5	160	159	149	145	92	158	157	151	120	105

conducted, following 32 sessions in the above procedure. In Condition A, sample stimuli were wavelengths of 538 nm and 576 nm and the comparison stimuli presented on the side keys were also 538-nm and 576-nm wavelengths. In Condition B, sample stimuli were 501-nm and 606-nm wavelengths and comparison stimuli were 538-nm and 576-nm wavelengths. Correct responses were defined as pecks on the 538-nm key following the 538-nm sample in Condition A or the 501-nm sample in Condition B, and pecks on the 576-nm key following the 576-nm sample in Condition A or the 606-nm sample in Condition B. There were 19 sessions (17 for Bird T2) and 23 sessions for each bird in the two repetitions of Condition A, and 27 sessions (26 for Birds T1 and T3) and 20 sessions in the two repetitions of Condition B. That is, a total of at least 42 sessions were conducted in each condition.

RESULTS AND DISCUSSION

Correct responses made on the comparison keys following S_1 or S_2 samples were summed over the last 10 sessions of each replication and over the two replications per condition. Frequencies of correct responses are given in Table 1, where maximum per entry is 160. The data in Table 1 show that the pattern of responding was very similar for individual birds within each condition and exhibited no

systematic or large response bias (also see below) with regard to changes in responding either over delay intervals or between conditions.

Proportions of correct responses at each delay interval were derived from the frequencies of correct choices in Table 1. The arithmetic means of the proportions of correct responses for the 5 birds are plotted in Figure 1 as a function of delay for Conditions A and B. Overall, the mean proportion correct was higher for Condition B than for Condition A, $F(1, 4) = 25.36$, $p < .01$, and it decreased systematically with increasing delay interval, $F(4, 16) = 89.03$, $p < .01$. The interaction between condition and delay interval was not statistically significant. The greater wavelength difference between sample stimuli therefore resulted in overall higher accuracy in matching performance. These conclusions are confirmed by the data for individual birds in Table 1. That is, for each bird, mean frequency correct was higher in Condition B than in Condition A and decreased systematically with increasing duration of the delay.

For each bird, measures of discriminability at each delay interval, $\log d$, were calculated according to Equation 1 by halving the difference between log ratios of responses made to the comparison stimuli following S_1 and S_2 samples. Arithmetic means of the $\log d$ values averaged over the 5 birds are plotted in Figure 2 as a function of delay interval. The discrim-

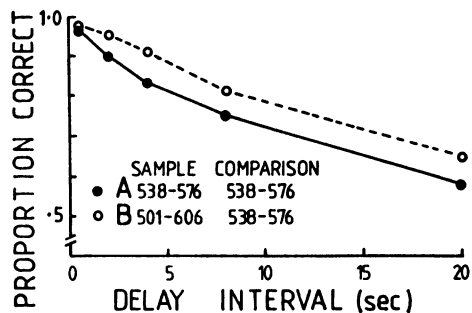


Fig. 1. Mean proportion correct as a function of delay for conditions where: (A) sample stimuli and corresponding comparison stimuli were of identical wavelengths; and (B) the same comparison stimuli were used, but the sample stimuli differed from their corresponding comparison stimuli by approximately equal amounts (30 nm and 37 nm, respectively).

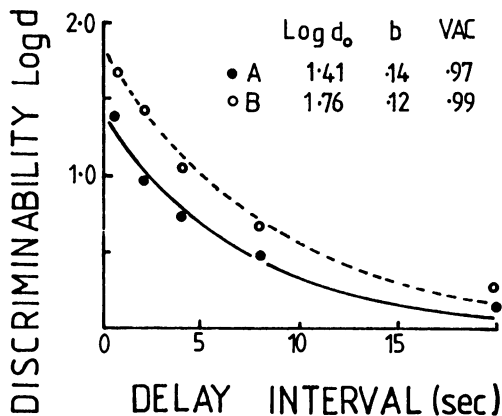


Fig. 2. Mean discriminability as a function of delay between sample and comparison stimuli for large and small wavelength differences between sample stimuli. Parameter values for best fitting exponential functions (dashed and smooth curves) are given for the two conditions.

inability measures in Figure 2 reflect the differences shown in Figure 1 in terms of proportion correct, with $\log d$ decreasing systematically with increasing delay and being overall higher for Condition B where the sample-stimulus difference was larger than for Condition A where sample-stimulus separation was small. That is, discriminability of the sample stimuli at different delays since their presentation was overall higher for the larger difference between wavelength values of the sample stimuli. The rationale for the smooth functions fitted to the data points in Figure 2 is explained in the following section.

Davison and Tustin (1978) proposed a measure of response bias analogous to the discriminability measure in Equation 1:

$$\log \text{bias} = \frac{1}{2} [\log(P_{11}/P_{12}) + \log(P_{21}/P_{22})]. \quad (2)$$

Log response-bias measures were obtained for each bird in the present study and are plotted in Figure 3 as a function of delay interval. There were no obvious differences between conditions or over delay intervals in the extent of response bias exhibited by each bird. McCarthy (1983) showed that fluctuations in bias were large for a brightness-detection procedure in which the relative frequencies of reinforcers for correct responses could covary with relative frequencies of correct responses. In an alternative procedure, however, where relative reinforcer frequency was "controlled" using an unconventional scheduling arrangement, Mc-

Carthy found relatively small deviations from zero in response bias. In McCarthy's terms, relative reinforcers in the present procedure were "uncontrolled." Yet the fluctuations in response bias shown here in Figure 3 are well within those for the controlled procedure in McCarthy's study. It can therefore be concluded that response bias in the present study was practically absent, and in particular did not change systematically as discriminations became more difficult with increasing duration of the delay interval. The probable reason for the absence of bias in the present data is that short delays, where discriminability was high, were mixed with longer delays where discriminability was low, within each session.

Exponential Decrement in Discriminability

Quantification of delayed stimulus control in terms of a specific function relating discriminability to duration of the delay allows specification of discriminability at zero delay and of the rate at which discriminability decreases with increasing duration of delay. White and McKenzie (1982) suggested that the effect of the delay is to attenuate discriminability as a negative exponential function of delay duration (t). That is,

$$\log d = \log d_0 \cdot \exp(-bt), \quad (3)$$

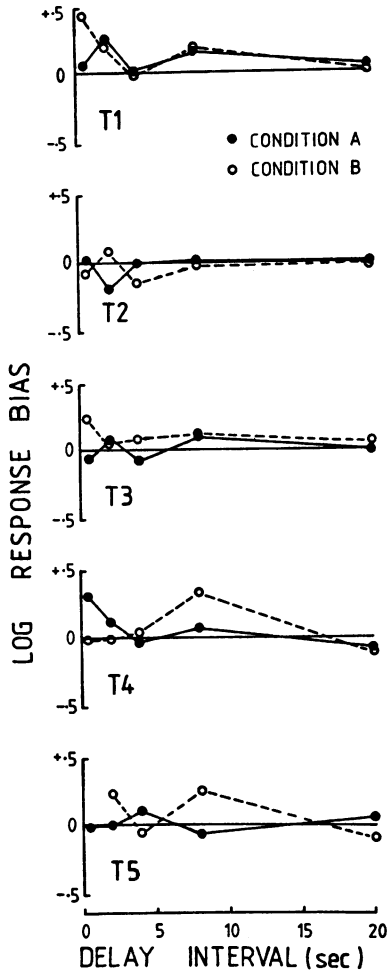


Fig. 3. Log response bias for individual subjects as a function of delay between sample and comparison stimuli in Experiment 1.

where $\log d_0$ is discriminability at zero delay and b is the rate of decrement in discriminability. In effect, b is a time constant with dimensions of t^{-1} .

The negative exponential function given by Equation 3 follows from a treatment of remembering as a discrimination between sample stimuli, the influence of which is weakened owing to the delay, as follows. White and McKenzie (1982) supposed that presenting a stimulus some time before the behavior it occasions has the effect of degrading stimulus discriminability. Therefore, a small increase in time, Δt , reduces $\log d$ by a small amount, $\Delta(\log d)$, which is proportional to $\log d$ at time

t . That is,

$$\Delta(\log d) = -b \cdot \log d \cdot \Delta t, \quad (4)$$

where b is the proportionality constant. The value of $\log d$ can be specified for any value of t . Thus the extent of decrement $\Delta(\log d)$ depends only on the level of $\log d$ from which the decrement occurs and is independent of $\log d$ at earlier times. This assumption deals with the criticism that Gibson (1979) and Turvey (1977) leveled at any theory of "indirect" remembering based on the "storage metaphor" (Roediger, 1980)—namely, that it is logically impossible to identify the point at which "perceiving stops and remembering begins" (Gibson, 1979, p. 253). The present view does not distinguish "perceiving" from "remembering" in that the temporal distance of a stimulus may attenuate discriminability in the same way that spatial distance does, as suggested by Equation 4 (also see Branch, 1982; Catania, 1984). Equation 3 can be rewritten and integrated with respect to t :

$$\int \frac{\Delta(\log d)}{\log d} = \int -b \Delta t$$

to yield

$$\text{Ln}(\log d) = -bt + C. \quad (5)$$

The constant of integration, C , can be replaced by $\log d_0$ since at $t = 0$, $\log d = \log d_0$. Rewriting Equation 5 in exponential rather than logarithmic terms gives the exponential function used by White and McKenzie (1982):

$$\log d = \log d_0 \cdot \exp(-bt). \quad (3)$$

This is Equation 3 above, which followed from the single main assumption expressed in Equation 4—namely, that the reduction in $\log d$ during a given time interval is proportional to the level of $\log d$ at the beginning of the interval.

Equation 3 was fitted to the mean $\log d$ values in Figure 2 for Conditions A and B using a nonlinear least-squares method. Estimates for the parameters, $\log d_0$ and b , for the best fitting exponential functions are given in Figure 2. Measures of variance in the data accounted for by the best fitting functions (VAC) given in Figure 2 indicate that fits of Equation 3

Table 2

Parameter values for exponential functions best fitting log *d* values for individual birds.

Bird	log <i>d</i> ₀	<i>b</i>	VAC	MS _e
A. 538 nm vs. 576 nm samples with 538 nm vs.				
576 nm comparisons				
T1	1.509	.233	.953	.010
T2	1.014	.097	.985	.001
T3	1.039	.113	.962	.003
T4	1.781	.110	.873	.031
T5	1.734	.185	.932	.018
B. 501 nm vs. 606 nm samples with 538 nm vs.				
576 nm comparisons				
T1	1.859	.172	.971	.009
T2	1.262	.076	.863	.020
T3	1.645	.138	.912	.019
T4	2.162	.111	.902	.035
T5	2.637	.170	.971	.012

to the data were very satisfactory. Equation 2 was also fitted to the log *d* values for each bird. Table 2 presents the parameter estimates, log *d*₀ and *b*, for the functions best fitting the individual data. The data for each bird were well fitted by Equation 3 as indicated by the high proportions of variance accounted for and low values for the mean squared error (MS_e) given in Table 2. In particular, the analyses for individual birds are entirely consistent with the treatment of group mean data in Figure 2. For each of the 5 birds, log *d*₀ was higher in Condition B than in Condition A, $F(1, 4) = 18.09, p < .05$.

In conclusion, the data from Experiment 1 demonstrated that increasing the wavelength difference between sample stimuli increased their discriminability at zero delay (log *d*₀), but did not affect the rate (*b*) at which discriminability was attenuated by increases in the duration of the delay. In this regard, rate of decrement was independent of initial discriminability of the sample stimuli. The conclusion from the present data is consistent with the conclusion that can be drawn from the study by White and McKenzie (1982). In their study, choices following different delays since stimulus presentation were simply responses on left or right side keys. In their first experiment, log *d*₀ was smaller for a difficult discrimination between the stimulus relations of "same" and "different" than for an easier discrimination be-

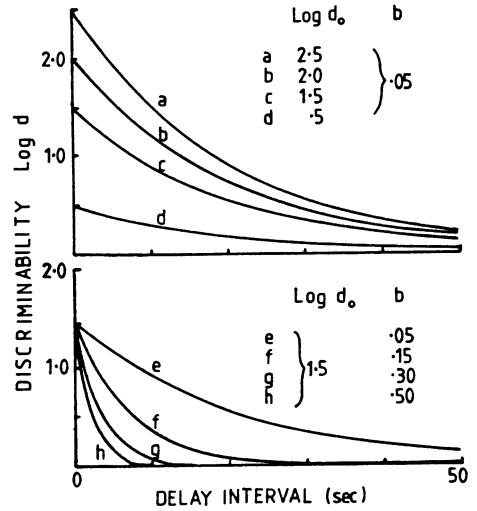


Fig. 4. Negative exponential functions predicted by Equation 3 for different values of log *d*₀ (discriminability at zero delay) and the same rate of decrement, *b* (top panel) and for different values of *b* and the same log *d*₀ (bottom panel).

tween sample stimuli with very different wavelengths. In their second experiment, log *d*₀ was smaller for a difficult discrimination between sample stimuli with similar wavelengths than for an easier discrimination between samples with widely separated wavelengths, as in the present study. In both experiments, there was no systematic change in values of *b*. On the basis of the previous and present results, it can therefore be concluded that changing the discriminability of the sample stimuli at zero delay by changing their separation on some stimulus dimension does not affect the rate at which discriminability diminishes as the duration of the delay increases.

EXPERIMENT 2

It was argued above that negative exponential attenuation of discriminability with increasing delay is consistent with the notion that remembering is discriminative behavior under delayed control by the sample stimuli. The parameters of the negative exponential equation afford a means of quantifying two characteristics of delay-interval functions, initial discriminability and rate of decrement in discriminability. To illustrate the possible independence of these two characteristics, Figure 4

shows negative exponential functions defined by Equation 3 for instances where $\log d_0$ was varied and b remained constant (top panel) and for instances where b was varied and $\log d_0$ was held constant (bottom panel).

The aim of Experiment 2 was to examine in what ways the two characteristics illustrated in Figure 4 were sensitive to changes in some variables frequently manipulated in previous studies of delayed matching to sample. It should be noted that the data from the many previous experiments where percentage correct was the performance measure cannot be treated directly in terms of Equations 1 and 3. Rather, the present analysis requires the recording of response frequencies following S_1 and S_2 and manipulation of delay duration over at least four values.

The variables examined in Experiment 2 were the duration of the intertrial interval, the fixed-ratio requirement for sample-key responding, and inclusion of ambient illumination (from the houselight) during the normally dark delay interval. These variables address the main features of the delayed-matching procedure: sample-stimulus parameters, delay-interval conditions, and intertrial-interval conditions. In previous studies, proportion correct has been found to increase with increases in the fixed-ratio requirement for sample-key responding (Cohen, Looney, Brady, & Aucella, 1976; Roberts, 1972; Sacks, Kamil, & Mack, 1972) and with increases in the duration of the intertrial interval (Maki, Moe, & Bierley, 1977; Roberts, 1980; Roberts & Kraemer, 1982). Introduction of a houselight in a normally dark delay interval results in a decrease in the proportion of correct matching responses (Cook, 1980; D'Amato, 1973; Grant & Roberts, 1976; Maki, Moe, & Bierley, 1977; Roberts & Grant, 1978; Tranberg & Rilling, 1980; Zentall, 1973). In the present experiment, it was asked whether these variables would differentially influence initial discriminability, $\log d_0$, and the rate of decrement in discriminability with increasing delay duration, b .

Experiment 2 also included conditions in which the houselight was turned on at two different points in the delay interval. The purpose

Table 3

Sessions per condition for each bird in Experiment 2.

Condition	T1	T2	T3	T4	T5
1. 20-s intertrial interval FR 5 sample requirement Dark delay interval	16	15	16	16	16
2. 5-s intertrial interval	15	15	15	15	15
3. Same as 1	15	15	15	15	15
4. FR 1 sample requirement	16	16	15	16	16
5. Same as 1	16	16	15	16	16
6. Houselight in delay interval	23	20	22	22	21
7. Houselight from 2 s into delay	18	15	18	18	17
8. Houselight from 4 s into delay	14	15	14	15	15

of these conditions was to test an important property of the negative exponential function—namely, that the extent of decrement in $\log d$ from a given (nonzero) time depends only on the level of $\log d$ at that time and not on discriminability at earlier times.

METHOD

The same subjects, apparatus, and general procedure were used as in Experiment 1. Experiment 2 was actually run before Experiment 1, and the 5 birds were previously trained in symbolic matching to sample (White & McKenzie, 1982) and in conditions similar to those in the present Experiment 2 (White, Harvey, & Lees, 1981). The only apparatus difference from Experiment 1 was that the brightness of the sample stimuli on the center key (576 nm [S_1] and 538 nm [S_2] wavelengths) was 5.0 cd/m², and comparison stimuli on the side keys were 2.5-cm discs of green and red with peak transmission at wavelengths of 555 nm and 606 nm, respectively. Correct responses were defined as pecking the red comparison key following S_1 and the green comparison key following S_2 .

Eight conditions were conducted, each lasting for at least 15 sessions. Table 3 gives the numbers of sessions conducted in each condition in the order of conduct. Sessions per condition often differed from 15 because condition changes were made for all birds at the same time and some birds were not run on some days during the condition if they were overweight. Otherwise they were run daily.

Conditions 1, 3, and 5 were identical. Each

Table 4
Correct Choices at Each Delay Summed over the Last 10 Sessions per Condition for Individual Birds

Bird	Delay (s)									
	Sample S ₁					Sample S ₂				
	0.5	2	4	8	20	0.5	2	4	8	20
<i>1. 20-s intertrial interval</i>										
T1	80	74	69	68	54	80	74	72	60	59
T2	77	73	78	68	50	76	80	72	64	53
T3	74	67	70	60	58	72	75	61	54	43
T4	78	77	74	54	34	80	78	70	63	56
T5	77	76	69	64	45	79	76	74	56	50
<i>2. 5-s intertrial interval</i>										
T1	62	60	52	49	45	72	59	45	46	43
T2	68	59	59	47	32	68	62	53	46	54
T3	63	54	46	55	50	66	46	36	38	30
T4	76	52	36	48	39	67	66	54	51	56
T5	75	67	66	59	47	80	72	61	52	50
<i>3. FR 5 sample requirement</i>										
T1	74	71	66	59	50	78	75	70	56	48
T2	73	75	76	64	59	76	78	66	68	59
T3	77	77	69	65	53	76	73	69	52	50
T4	78	78	68	61	40	79	78	75	56	66
T5	79	77	68	62	41	80	77	74	59	46
<i>4. FR 1 sample requirement</i>										
T1	69	66	54	56	38	73	61	64	48	55
T2	69	63	72	61	50	69	68	69	60	53
T3	69	59	68	55	55	61	66	50	49	46
T4	77	72	56	56	29	76	75	68	60	63
T5	44	44	40	37	42	47	44	43	36	44
<i>5. Dark delay interval</i>										
T1	77	70	65	68	36	76	72	71	58	59
T2	74	73	73	71	68	77	79	79	71	67
T3	77	77	76	69	49	78	73	66	62	54
T4	79	80	75	66	37	79	76	78	65	63
T5	79	79	71	63	46	79	76	74	62	47
<i>6. Houselight in delay interval</i>										
T1	75	60	52	47	35	73	58	52	44	42
T2	73	42	37	39	42	75	48	49	43	37
T3	76	57	63	67	46	74	58	55	39	35
T4	75	71	65	57	35	80	70	71	50	46
T5	72	43	60	60	43	77	50	57	46	42
<i>7. Houselight from 2 s into delay</i>										
T1	74	70	68	43	42	73	75	50	43	37
T2	75	75	41	46	44	74	73	45	47	51
T3	79	79	49	54	47	78	70	50	42	42
T4	79	77	61	56	41	78	78	68	57	48
T5	76	74	52	64	43	77	79	54	52	43
<i>8. Houselight from 4 s into delay</i>										
T1	80	74	70	51	44	78	74	68	49	39
T2	79	78	73	48	39	77	77	73	41	39
T3	77	72	74	71	51	77	76	72	44	33
T4	77	73	74	65	33	80	78	78	62	57
T5	79	78	76	63	48	79	76	75	59	40

of these "standard" conditions included a 20-s intertrial interval, a ratio requirement of FR 5 for sample-key responding, and dark delay intervals of 0.5, 2, 4, 8 or 20 s within each ses-

sion. Orders of sample stimuli, comparison-stimulus positions on the side keys, and delay intervals were randomized over the 80 trials in each session. Each of the remaining conditions

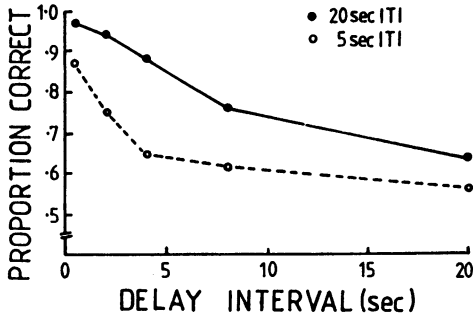


Fig. 5. Mean proportion correct as a function of delay for 20-s and 5-s intertrial intervals, averaged over 5 birds' data from the last 10 sessions on each condition.

involved a single variation in the standard procedure. In Condition 2, the intertrial interval was reduced to 5 s. In Condition 4, the sample-key ratio requirement was FR 1. In Condition 6, the houselight was turned on for the whole duration of each delay interval. Thus the effects of intertrial interval, FR requirement, and interpolation of ambient illumination in the delay interval were examined in three pairs of conditions.

Conditions 7 and 8 were the same as the standard procedure but included different conditions of delay-interval illumination. In Condition 7, the houselight was turned on 2 s after the beginning of the delay. That is, 0.5-s and 2-s delays in each session were dark and the first 2 s of the 4-s, 8-s, and 20-s delays were dark with the remainder illuminated by houselight. In Condition 8, the houselight was turned on 4 s after the beginning of the delay so that the first 4 s of each delay was dark and the remainder was illuminated.

RESULTS

Table 4 gives the correct responses made by each bird at each delay interval, summed over the last 10 sessions per condition. The maximum entry for each cell in Table 4 was 80. The data for individual birds in Table 4 consistently reflect the main features of the summary data presented below — namely, a reduction in correct responses with increasing delays and systematic differences between correct responses for pairs of experimental conditions. The data presented in Table 4 also indicate that there were no systematic or large changes

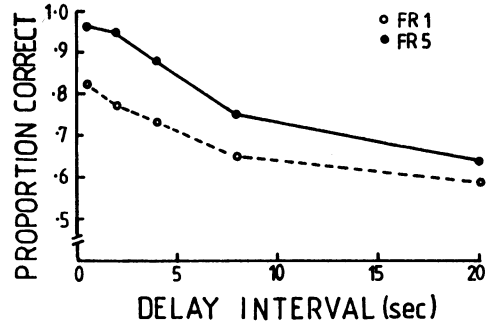


Fig. 6. Mean proportion correct as a function of delay for FR 5 and FR 1 sample-key ratio requirements, averaged over 5 birds' data from the last 10 sessions on each condition.

in response bias for any bird.

In Figure 5, 6, and 7, the arithmetic means of proportions of correct responses averaged over birds for pairs of conditions (Conditions 1 vs. 2, 3 vs. 4, 5 vs. 6) are plotted as functions of delay interval. Figure 5 shows that with the 5-s intertrial interval, proportion correct was lower overall $F(1, 4) = 30.31$, $p < .01$, and that it decreased with increasing delay interval, $F(4, 16) = 98.42$, $p < .001$. There was also a significant interaction between intertrial interval and delay interval, $F(4, 16) = 10.19$, $p < .01$. When the ratio requirement for sample-key responding was varied (Figure 6), proportion correct was higher with the FR 5 than with the FR 1 requirement, $F(1, 4) = 7.48$, $p < .05$, and decreased with increasing delay interval, $F(4, 16) = 78.39$, $p < .001$. There was no interaction between FR condition and delay interval. When the houselight was illu-

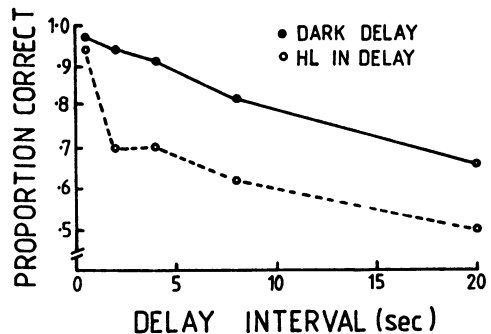


Fig. 7. Mean proportion correct as a function of delay with a dark delay or with houselight illumination interpolated in the delay, averaged over 5 birds' data from the last 10 sessions on each condition.

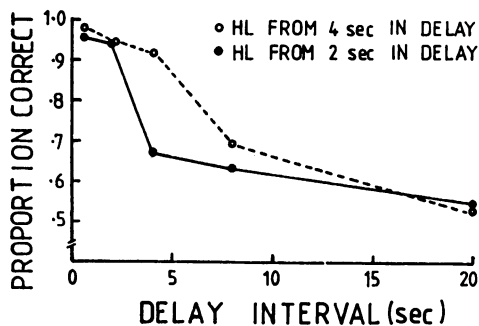


Fig. 8. Mean proportion correct as a function of delay for conditions where onset of houselight illumination was 2 s or 4 s into the delay interval.

minated during the delay interval (Figure 7), proportion correct decreased markedly, $F(1, 4) = 21.71, p < .01$, and also decreased with increasing delay interval, $F(4, 16) = 49.18, p < .001$. The reduction in proportion correct with increasing delay occurred at a greater rate with houselight in the delay than with the dark delay, $F(4, 16) = 6.02, p < .05$.

In Conditions 7 and 8 where the houselight was illuminated from different times during the delay interval, proportion of correct responses was high during the dark portions of the delay and low when the houselight was illuminated. Figure 8 shows mean proportions correct averaged over birds plotted as a function of delay interval. There was a general decrease in proportion correct with increasing delay, $F(4, 16) = 116.02, p < .01$, and proportion correct was overall higher in Condition 8 where the houselight was turned on 4 s into the delay, $F(1, 4) = 133.26, p < .01$. The different effects of introducing the houselight at 2 s and at 4 s are indicated by the significant interaction between conditions and delay interval, $F(4, 16) = 11.90, p < .01$.

For each bird, measures of discriminability at different delay intervals in each condition, $\log d$, were derived from the data in Table 4 according to Equation 1 by halving the difference between log ratios of responses made to the comparison stimuli following S_1 or S_2 samples. Exponential functions defined by Equation 3 were fitted to the $\log d$ values for the five delays for Conditions 1 to 6 for each bird, using a nonlinear least-squares fitting procedure. Table 5 gives values for the $\log d$ and b pa-

Table 5

Parameter estimates for exponential functions best fitting $\log d$ values for individual birds, for Conditions 1 to 6.

Bird	$\log d_0$	b	VAC	MS_e
1. 20-s intertrial interval				
T1	1.178	.066	.946	.004
T2	1.493	.082	.928	.014
T3	1.084	.104	.950	.005
T4	2.218	.201	.994	.002
T5	1.768	.156	.994	.002
2. 5-s intertrial interval				
T1	0.857	.308	.934	.004
T2	0.816	.212	.980	.001
T3	0.883	.702	.910	.004
T4	1.271	.499	.870	.014
T5	0.988	.112	.947	.003
3. FR 5 sample requirement				
T1	1.412	.147	.979	.004
T2	0.946	.013	.929	.000
T3	1.452	.129	.955	.008
T4	1.954	.157	.931	.023
T5	1.989	.180	.996	.001
4. FR 1 sample requirement				
T1	0.916	.160	.934	.005
T2	0.847	.055	.788	.010
T3	0.645	.071	.876	.003
T4	1.450	.179	.951	.009
T5	0.143	.308	.420	.001
5. Dark delay interval				
T1	1.297	.113	.943	.008
T2	1.441	.036	.726	.024
T3	1.527	.102	.991	.002
T4	2.048	.120	.978	.009
T5	2.092	.167	.991	.004
6. Houselight in delay interval				
T1	1.353	.468	.975	.004
T2	1.745	.983	.977	.004
T3	1.204	.278	.800	.030
T4	1.980	.280	.811	.023
T5	1.820	.903	.666	.054

rameters for the best fitting exponential functions. Measures of variance accounted for (VAC) by the best fitting exponential functions and the mean squared error (MS_e) indicate that in all cases the fits were excellent. In some cases (e.g., Bird T5, Condition 4), low VAC estimates simply reflected overall low $\log d$ values (a floor effect on the VAC measure) but were otherwise accompanied by acceptably small MS_e terms.

For each condition, discriminability measures at each delay interval, $\log d$, for individual birds were averaged over birds and plotted

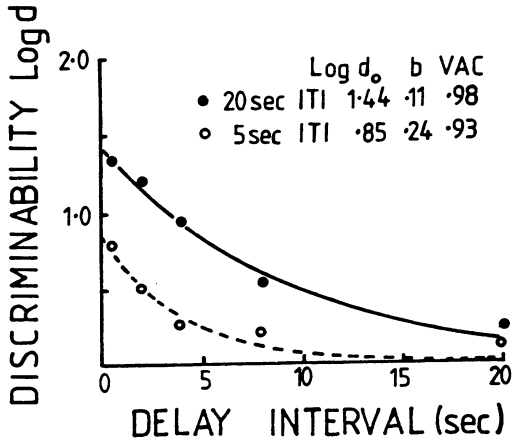


Fig. 9. Mean discriminability as a function of delay for 20-s and 5-s intertrial intervals. Parameter values for the best fitting exponentials (solid and dashed curves) are given for the two conditions. The data are based on performances of 5 birds, during the final 10 sessions on each condition.

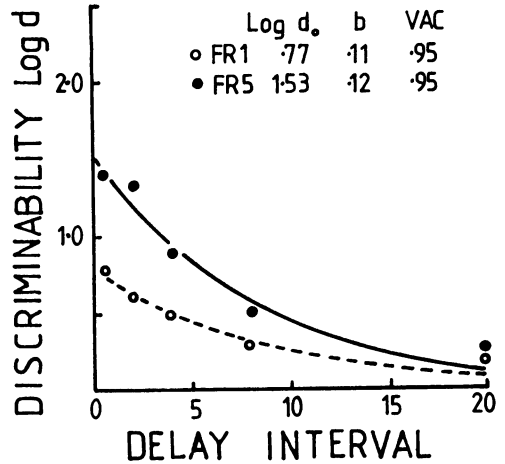


Fig. 10. Mean discriminability as a function of delay for FR 5 and FR 1 sample-key ratio requirements. Parameter values for the best fitting exponentials (solid and dashed curves) are given for the two conditions.

in Figures 9, 10, 11, and 12 as functions of delay interval. For Conditions 1 to 6, exponential functions (Equation 3) were fitted to the mean log d values in the same way as for the data from individual subjects. The parameter estimates for functions fitted to mean log d values closely corresponded to the mean of parameter estimates for functions fitted to individual data (Table 5). Differences between parameter values for pairs of conditions were evaluated in relation to the MS_e terms from separate repeated-measures analyses of variance conducted with the log d_0 and b values for Conditions 1 to 6 from Table 5, using Tukey's "allowance" measure based on Dunnett's statistic (Winer, 1971, pp. 202). The allowance measure required differences between log d_0 values of 0.49 and 0.62 at the .05 and .01 levels of significance, respectively, and differences between b values of 0.33 and 0.42 at the .05 and .01 significance levels, respectively.

Comparison of the two functions in Figure 9 shows that reducing the intertrial interval from 20 s to 5 s had a marked effect on discriminability. For both the functions fitted to the mean log d values (Figure 9) and functions for each of the 5 birds (Table 5), initial discriminability at zero delay (log d_0) was greater with the 20-s than with the 5-s intertrial interval ($p < .05$). Although rate of decrement (b) was greater for

the 5-s intertrial interval for both the group function and each of the individual functions, the difference was not significant ($p > .05$). In further, unpublished experiments, we have found similarly strong effects of intertrial-interval duration on log d_0 and also an increase in b with decreasing duration of the intertrial interval. The effect on b should therefore not be disregarded.

Figure 10 shows that the FR 5 sample-key response requirement resulted in a higher estimate of discriminability at zero delay, log d_0 , than did the FR 1 requirement ($p < .01$). Functions fitted to the data for each bird (Table 5) had higher log d_0 values for the FR 5 condition than for the FR 1 condition. The difference in FR requirements did not have a statistically significant effect on rate of decrement in discriminability with increasing delay, b ($p > .05$).

Figure 11 shows that interpolation of the houselight in the normally dark delay interval reduced discriminability at long delays but had little effect at the shortest delay. Interpolation of houselight in the delay had no effect on log d_0 ($p > .05$), but resulted in a large increase in b , the rate of decrement in discriminability ($p < .01$).

In Figure 12, discriminability measures for Conditions 7 and 8, where the houselight was

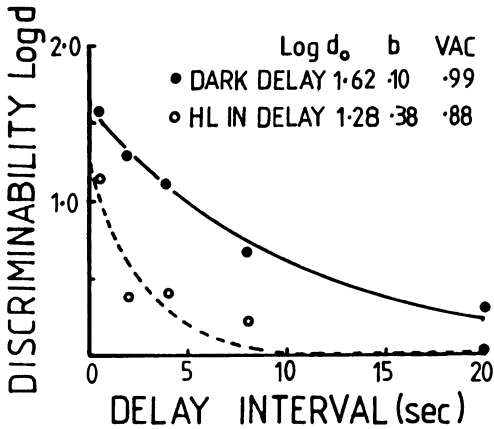


Fig. 11. Mean discriminability as a function of delay, for dark-delay and houselight-in-delay conditions. Parameter values for the best fitting exponentials are given for the two conditions.

turned on 2 s or 4 s into the delay, were compared to the data from Conditions 5 and 6. The squares are data points from Condition 6 in which the houselight was illuminated for the whole delay, and the smooth curve is the exponential function that best fitted the data points from Condition 5 where the delay was dark (the data points from Condition 5 are not plotted in Figure 12). The filled circles in Figure 12 are the data points for Condition 8 (top panel) and Condition 7 (bottom panel). Figure 12 shows that discriminability for the 0.5-s, 2-s, and 4-s delays in Condition 8 (top panel) and for the 0.5-s and 2-s delays in Condition 7 (bottom panel), all of which involved dark delay intervals, sat neatly on the exponential functions for Condition 5 where all delays were dark. That is, the data for dark delays in Conditions 7 and 8 replicated those for the same delays from Condition 5. For delays during which the first 2 s (Condition 7) or 4 s (Condition 8) were dark and for the rest of the delay the houselight was lit, discriminability dropped to the low levels obtained when the whole delay was illuminated (Condition 6), even though the first 2 s or 4 s of the delay was dark. These data clearly indicate that the levels of discriminability at the longer delays, given that the latter part of the delay was illuminated, were independent of whether the initial portion of the delay was dark or illuminated.

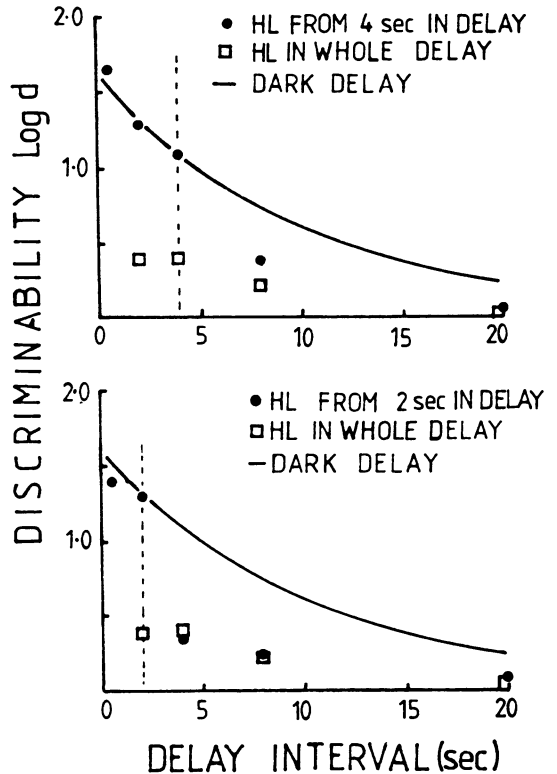


Fig. 12. Mean discriminability as a function of delay for conditions where houselight illumination was introduced 4 s into the delay interval (top panel) or 2 s into the delay interval (bottom panel). In both panels, the smooth curve is the exponential that best fit the data for completely dark delays in Condition 5, and unfilled squares are data points for 2-s, 4-s, 8-s, and 20-s delays in Experiment 2 where the houselight was on during the whole delay (Condition 6).

DISCUSSION

The results of Experiment 2 were consistent with those of previous studies, in that proportions of correct matching responses were overall lower with a short intertrial interval (Roberts & Kraemer, 1982), with a small fixed-ratio requirement for sample-key responding (Cohen et al., 1976; Roberts, 1972), and with houselight interpolation in the normally dark delay interval (Roberts & Grant, 1978; Tranberg & Rilling, 1980). In addition, the present analyses indicated that these variables had different effects on discriminability as a function of delay: The intertrial-interval duration and the sample-key fixed ratio affected discriminability at zero delay ($\log d_0$), and houselight illumination

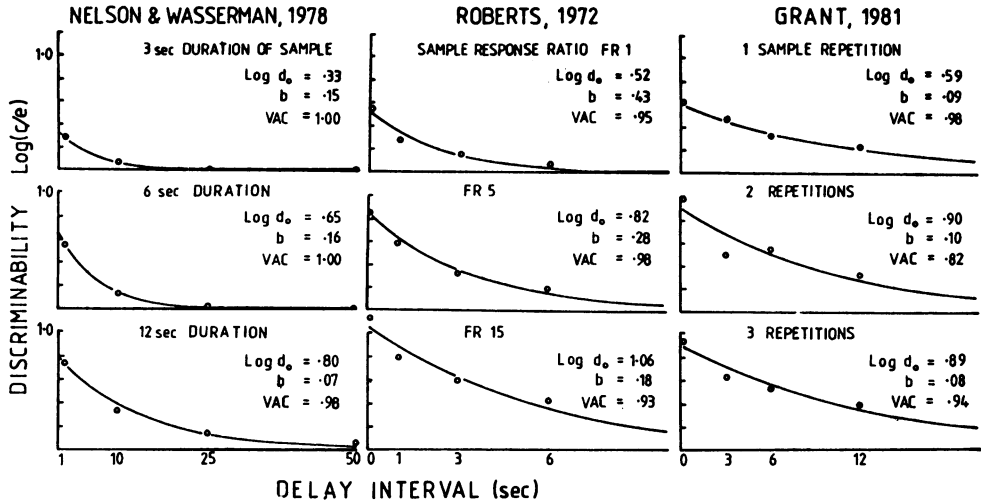


Fig. 13. Estimates of discriminability at different delays calculated from data of three previous studies in which aspects of sample stimuli were varied. Curves and parameter values for best fitting exponential functions are shown.

during the delay affected rate of decrement in discriminability (b). Intertrial interval may also have influenced the rate of decrement.

Reanalyses of data from several previous studies in which delay interval was varied over at least four values support the conclusions from the present data. In most cases, the reanalyses were based on the mean proportions of matching responses for groups because response frequencies for individual subjects were not reported. The measure of discriminability was therefore estimated by the logarithm of the ratio of correct and error responses, $\log(c/e)$ (McCarthy & White, in press; Wright, 1974). $\log d$ and $\log(c/e)$ are equal when there is no response bias, a relatively safe assumption when data are averaged over subjects within a group. Reanalyses are presented below for studies that examined the effects of sample-stimulus variables, delay-interval conditions, and intertrial-interval conditions.

Figure 13 shows the results of a reanalysis of data from three studies that manipulated different aspects of the sample stimulus. Nelson and Wasserman (1978) varied sample duration for four delay intervals in a successive matching-to-sample procedure. Log ratios of matching to nonmatching responses (from their Table 3) averaged over subjects were well fitted by the negative exponential function as shown in Figure 13. As sample duration in-

creased from 3 s to 12 s, $\log d_0$ increased from 0.33 to 0.80, whereas there appeared to be little systematic change in b . Consistent with this result, reanalysis of data from a delayed matching-to-sample procedure in which Grant (1976) manipulated sample-stimulus duration yielded $\log d_0$ values of 0.58, 1.01, 1.46, and 1.94, respectively, for 1-, 4-, 8-, and 14-s sample durations and corresponding b values of 0.05, 0.04, 0.05, and 0.06 (with VACs of .94 or greater).

As in the present Experiment 2, Roberts (1972) varied sample-key fixed-ratio requirement. Figure 13 shows exponential functions fitted to $\log(c/e)$ measures estimated from the "high discriminability" condition (Roberts, 1972, Figure 2). Increasing the ratio requirement produced an increase in $\log d_0$ as in the present study. There was also a reduction in b , although it is not possible to evaluate how reliable this change was. A further variable that may bear a functional similarity to fixed-ratio requirement, particularly for the pigeon, is the number of times that sample is presented at the beginning of a trial. Data reported by Grant (1981) for conditions in which samples were presented one, two, or three times (called 1, 2, or 3 repetitions) were converted into $\log(c/e)$ measures. Figure 13 shows that Equation 3 fitted the discriminability estimates satisfactorily and indicates a general increase

in $\log d_0$ with increasing repetitions while b remained constant.

To summarize, the reanalyses presented in Figure 13, the data from Experiment 1 in the present study, and the data for the FR 1 versus FR 5 conditions in the present Experiment 2 all suggest that changing aspects of the sample stimulus results in a change in the initial discriminability of the samples ($\log d_0$), whereas rate of decrement in discriminability over the delay interval (b) most likely remains unaffected. Interestingly, it appears that it is also $\log d_0$ that changes during the acquisition of delayed matching-to-sample performance. Percentages of correct matching responses for six delay intervals reported by Berryman, Cumming, and Nevin (1963) over successive blocks of 12 sessions for Bird 171 were converted into $\log(c/e)$ discriminability measures. The procedural conditions in their study were very similar to those of the present study. Estimates of the $\log d_0$ parameter for exponentials best fitting data for five successive blocks of sessions (beginning with Session 1) were 0.67, 1.08, 1.55, 1.93, and 1.86, with corresponding b values of 0.57, 0.33, 0.49, and 0.37 (and VACs averaging .96). This single example indicates the importance of the discrimination between sample stimuli in the development of delayed-matching performance.

In the present study, interpolation of ambient illumination in the delay interval increased b without having a systematic effect on $\log d_0$. This effect was confirmed by reanalysis of data from two previous studies in which delay-interval conditions were altered. $\log(c/e)$ measures were estimated from the percentages of correct matching responses reported by Roberts and Grant (1978, Figure 1) for conditions in which the delay interval was dark or was illuminated by houselight. Additionally, $\log d$ measures were calculated from the conditional response probabilities given by Jans and Catania (1980, Table 1) for a standard training condition in which the delay interval was illuminated and for an "activity" condition in which the feeder was raised during the delay. The results of the reanalyses are plotted in Figure 14. In both studies, the change in delay-interval conditions had no obvious effect

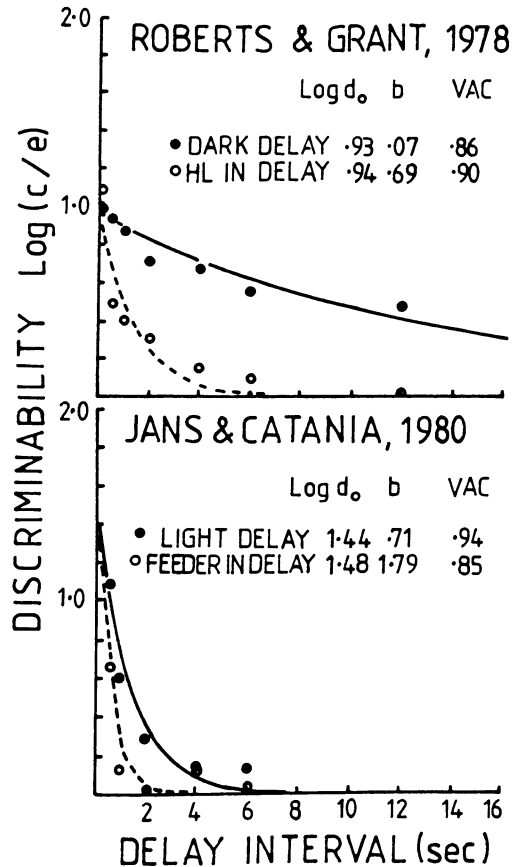


Fig. 14. Estimates of discriminability at different delays calculated from data of two previous studies in which delay-interval conditions were varied. Curves and parameter values for best fitting exponential functions are shown.

on the $\log d_0$ parameter for the best fitting exponential functions, but did alter the value of b . That is, inclusion of interfering events in the delay interval increased b , consistent with the result of delay-interval illumination in the present study. Reanalysis of two of the functions described by Shimp and Moffitt (1977, Figure 2) offered further confirmation. With a line-tilt in the delay or with a houselight plus line-tilt in the delay, $\log d_0$ values were, respectively, 1.25 and 1.27, and values for b were 0.68 and 1.10, with VACs of .93 and .97. It therefore appears that conditions during the delay interval, typically thought to generate "retroactive interference" (Grant & Roberts, 1976; Roberts & Grant, 1978), affect the rate at which discriminability decreases with increasing delay-interval duration, without affecting the initial

Table 6

Parameter estimates for exponential functions best fitting $\log(c/e)$ measures calculated from previous studies.

<i>Study and condition</i>	<i>log d₀</i>	<i>b</i>	<i>VAC</i>
<i>Robert & Kraemer (1982). Experiment 1, 8-s sample</i>			
4-s intertrial interval	0.75	.14	.89
8-s intertrial interval	0.85	.16	.99
16-s intertrial interval	0.95	.15	.91
32-s intertrial interval	1.02	.13	.97
<i>Roberts & Kraemer (1982). Experiment 2, FR 5 sample ratio</i>			
4-s intertrial interval	0.97	.25	.97
8-s intertrial interval	1.00	.18	.96
16-s intertrial interval	1.30	.24	.99
32-s intertrial interval	1.47	.26	.99
<i>Roberts (1980). Experiment 1, Random</i>			
1-s intertrial interval	0.54	.21	.93
20-s intertrial interval	0.71	.13	.98
<i>Roberts (1980). Experiment 1, Homogeneous</i>			
1-s intertrial interval	0.83	.03	.84
20-s intertrial interval	1.15	.05	.78
<i>Zentall & Hogan (1974). Experiment 3</i>			
No interfering stimulus	1.49	.21	.86
Pre-sample interfering stimulus	0.98	.38	.99
<i>Grant (1975). Experiment 1</i>			
No interfering trials	1.22	.22	.90
1 interfering trial	1.01	.58	.89
4 interfering trials	0.65	.95	.95
6 interfering trials	0.63	.57	.86
<i>Grant (1975). Experiment 4, No interfering trials</i>			
2-s intertrial interval	1.37	.15	.88
20-s intertrial interval	1.28	.15	.84
40-s intertrial interval	1.54	.19	.82
<i>Grant (1975). Experiment 4, Prior interfering trial</i>			
2-s intertrial interval	1.40	.52	.96
20-s intertrial interval	1.45	.22	.81
40-s intertrial interval	1.54	.21	.79

level of discriminability ($\log d_0$).

Variables used to study "proactive interference" seem to have more complex effects on $\log d_0$ and b . In the present study, increasing intertrial-interval duration increased $\log d_0$ and may have decreased b . Table 6 summarizes $\log d_0$ and b parameters for exponentials that best fitted estimates of discriminability, $\log(c/e)$, calculated from the data of several studies in which prior trial events were varied. In all studies four delays were arranged. Table 6 shows that lengthening the intertrial interval consistently resulted in an increase in $\log d_0$. In Experiments 1 and 2 of Roberts and Kraemer (1982), in the homogenous condition of Roberts (1980), and in the condition without prior interfering trials in Grant's (1975)

Experiment 4, values for b remained fairly constant over variations in intertrial interval. In Experiment 3 of Zentall and Hogan (1974) and Experiment 1 of Grant (1975), the result of presenting an interfering stimulus or interfering trials prior to sample presentation was to decrease $\log d_0$ and increase b . The pattern of results for the combined effects of intertrial interval and prior interfering events suggests the following tentative conclusion. Shortening the intertrial interval reduces $\log d_0$ but does not affect b . An increase in b results from the proactive effect on comparison-stimulus responding of events on a previous trial or preceding presentation of the sample as in the study by Zentall and Hogan. For example, in the homogeneous condition described by Roberts (1980), samples remained the same over trials and would not have interfered with subsequent matching responses, as reflected in the constancy of b with intertrial interval (Table 6). When, however, the intertrial interval is particularly short, as in Roberts' random condition, events related to the prior trial may affect comparison-stimulus responding and hence b . The reduction in $\log d_0$ together with an increase in b when the intertrial interval was shortened in the present study as well as in studies by Roberts (1980) and Grant (1975) may therefore represent two sources of influence—an effect of intertrial-interval duration on $\log d_0$ and an effect of prior-trial events on b .

In Conditions 7 and 8 of the present experiment, the houselight was turned on 4 s or 2 s into the delay and remained illuminated for the remainder of the delay interval. Discriminability when delays were completely dark—that is, at 0.5 s and 2 s in the 2-s condition, and at 0.5 s, 2 s and 4 s in the 4-s condition—replicated discriminability levels when all delay intervals were dark. More importantly, discriminability at longer delays, with the houselight illuminated from 2 s or 4 s into the delay, perfectly replicated discriminability levels obtained when the entire delay interval was dark. That is, discriminability at the longer delays remained the same whether the first 2 s or 4 s of the delay was dark or illuminated. In terms of the exponential function relating discriminability to the duration of the delay, dis-

criminability at the longer intervals was independent of the levels of discriminability at the earlier delays (up to 2 s or 4 s). Unfortunately, this conclusion is weakened by the possibility that the same levels of discriminability may have resulted from introducing the houselight at *any* stage in the delay interval. The conclusion would be strengthened if it could be shown that when the first part of the delay is illuminated with the later part dark, discriminability at longer delays is as high as discriminability obtained with completely dark delays.

GENERAL DISCUSSION

In the present study, delayed-matching performance was assessed in terms of a measure of discriminability ($\log d$) derived from the ratios of choice responses to the comparison stimuli. The decrement in discriminability with increasing time since presentation of prior sample stimuli was satisfactorily described by a simple negative exponential function (Equation 3). The parameters of the exponential function quantified two main characteristics of performance: the initial level of discriminability ($\log d_0$) and the rate of decrement in discriminability over the delay interval (b).

To measure these characteristics it is necessary to manipulate delay interval over several values (preferably at least five) to generate a "forgetting" function for which parameter values can be estimated. In the absence of a delay-interval manipulation, discriminability recorded at a single delay confounds a particular level of initial discriminability with a certain rate of decrement in discriminability. As an example, directed-forgetting procedures include stimuli that signal absence of the usual choice phase on a trial, with the result that matching accuracy decreases on test trials where the "forget" cue is presented but the usual choice is available (Kendrick, Rilling, & Stonebraker, 1981; Maki, 1981; Maki & Hegvik, 1980; Stonebraker & Rilling, 1981). Without manipulating delay interval over several values it cannot be established whether the reduction in accuracy reflects a change in $\log d_0$ or in b .

In the present study, estimates of discriminability at zero delay, $\log d_0$, were influenced by the wavelength difference between sample

stimuli (Experiment 1), duration of the intertrial interval, and the fixed-ratio requirement for sample-key responding (Experiment 2). Re-analyses of previous data also indicated that changes in various aspects of the sample stimulus affected $\log d_0$. These results support the interpretation of $\log d_0$ as a measure of the discriminability of the sample stimuli at zero delay. That is, $\log d_0$ places an upper limit on performance at all delay intervals. Changes in $\log d_0$ reflect changes in overall levels of performance independent of delay interval. For example, longer intertrial intervals increase $\log d_0$. Acquisition and maintenance of simultaneous matching to sample are also facilitated by longer intertrial intervals (Holt & Shafer, 1973). Although the reasons for this effect are unclear (Roberts, 1980), overshadowing or interference by prior-trial stimuli owing to weak temporal discrimination or similarity factors may contribute (D'Amato, 1973; Reynolds & Medin, 1981). But whatever the source for the effect of intertrial-interval duration on $\log d_0$, the processes affected have to do with discriminating sample stimuli rather than post-sample or "memorial" processes as might be assumed by trace-strength theory (Roberts & Grant, 1976) or a version of maintenance-rehearsal theory (Grant, 1981).

The marked increase in rate of decrement in discriminability (b) when ambient illumination was interpolated in the delay interval in Experiment 2 was consistent with reanalysis of data from previous studies designed to examine retroactive interference. The present analysis confirmed the conclusion that b is influenced by events that occur during the delay interval. Apart from the possibility of proactive effects from preceding trials, delay-interval conditions would not be expected to influence $\log d_0$ in at least the trivial sense that there is no delay at the time $\log d_0$ is measured. Empirically, $\log d_0$ was unaffected by delay-interval events. The parameter b measures the rate at which discriminability decreases over delays, or equivalently, rate of forgetting. The results of Experiment 2 indicated that b is sensitive to delay-interval conditions whereas $\log d_0$ depends on sample-stimulus characteristics.

Table 7

Parameter estimates for exponential functions best fitting $\log(c/e)$ measures derived from data reported by Roberts (1972, Figure 2).

Condition	$\log d_0$	b	VAC	MS _e
<i>FR 1</i>				
Easy	0.52	.43	.95	.001
Difficult	0.38	.88	.80	.003
<i>FR 5</i>				
Easy	0.82	.28	.98	.001
Difficult	0.46	.42	.86	.003
<i>FR 15</i>				
Easy	1.06	.18	.93	.005
Difficult	0.55	.21	.96	.001

Independence of Log d_0 and b ?

According to the present analysis, the delay-interval or forgetting function has two characteristics, discriminability at zero delay and rate of decrement in discriminability with increasing delay, and these characteristics may be quantified in terms of the parameters of a negative exponential function. An important implication is that the two characteristics are independent. In Experiment 1, changing the wavelength difference between sample stimuli changed $\log d_0$ without influencing b , and in Experiment 2, decreasing the FR requirement decreased $\log d_0$ without changing b . In addition, b was altered by introducing houselight during the delay, without a systematic effect on $\log d_0$. Furthermore, the result of introducing the houselight from 2 s or 4 s into the delay interval in Experiment 2 was interpreted as support for an important property of the exponential function—namely, that the change in discriminability from a given delay is independent of the levels of discriminability at earlier delays. But further work is needed to confirm or strengthen this interpretation.

The effect of intertrial-interval duration in Experiment 2 and reanalyses of data from various studies described earlier (Roberts, 1972, Figure 13; and studies listed in Table 3) suggest that changes in $\log d_0$ may not always be achieved without altering b . A clear example is provided by the reanalysis in Table 7 of data reported by Roberts (1972) for a standard delayed-matching-to-sample procedure in which samples were difficult or easy to discriminate

(also see Figure 13). For both difficult and easy discriminations, $\log d_0$ increased with increasing FR requirement for sample-key responding. But there was a concomitant decrease in b with increasing FR size, indicative of a negative correlation between $\log d_0$ and b values. However, the apparent relation between $\log d_0$ and b illustrated in Table 7 may not reflect their dependence. Rather, the relation may result from the way in which experimental procedures allow $\log d$ to vary at long delays. For example, when accuracy is overall very low, changes in discriminability at long delays suffer from a floor effect. In Table 7, the change in b with FR size for the difficult discrimination was about twice that for the easy discrimination. And in the reanalyses presented above where there tended to be a relation between $\log d_0$ and b , the overall level of discriminability tended to be very low.

In the literature on human memory, the flattening out of delay functions at longer delays has been taken as evidence for Jost's second law: "Given two associations of the same strength, but of different ages, the older falls off less rapidly in a given length of time" (Hovland, 1951; Woodworth & Schlosberg, 1954). Jost's law, if treated as a description of the data, is inconsistent with a negative exponential change in forgetting (Simon, 1966). The *change* in the rate of decrement in discriminability has been described in hyperbolic terms, both in early (Hovland, 1951) and recent (Staddon, 1983) formulations. Wickelgren (1972) modified his "trace strength" model (Wickelgren 1970; Wickelgren & Berian, 1971) to account for a *change* in the rate of forgetting (versus the *constant* rate required by the simple exponential) by assuming that traces have "resistance" as well as "strength." His exponential-power function copes nicely with his data and is a plausible alternative to a hyperbolic description of decrement in discriminability as a function of delay (McCarthy & White, in press; Staddon, 1983). The assumption of hyperbolic or exponential-power functions that the rate of decrement is not constant, however, stumbles on the problem of specifying the determinants of the changes in rate of decrement that may occur within any one de-

lay interval. In the absence of obvious changes in delay-interval conditions in the animal's environment, it becomes tempting to suppose that the source of the change is organismic, as in Wickelgren's (1972) account. Given the consistency of exponential decrement in discriminability with the premise that the discriminative stimuli occasioning remembering are the temporally distant sample stimuli, a useful strategy might be to start from the position that rate of decrement is constant and $\log d_0$ and b are independent, as argued here, and to search for the conditions of which changes in the rate of decrement in discriminability are a function.

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