

# Control of delayed matching-to-sample performance using directed forgetting techniques

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Pigeons acquired a successive delayed matching-to-sample task at a delay interval of 4 sec. Instructional stimuli were interpolated in the delay interval signaling the occurrence (R-cue) or nonoccurrence (F-cue) of comparison stimuli, a procedure modeled after the directed forgetting techniques commonly used in human memory studies. Accuracy on probe trials (in which comparison stimuli were presented following F-cues) was reduced relative to performance on standard training trials in which R-cues signaling the occurrence of comparison stimuli appeared in the same temporal location. The extent of the reduction in accuracy depended on the temporal location of the F-cues, the reduction being greater when the cue was more remote from the comparison stimuli. Examination of retention interval keypecking revealed a strong correlation between matching performance and retention interval responding.

Animal short-term memory has frequently been investigated using the delayed matching-to-sample (DMTS) procedure in which sample and comparison stimuli are separated by a delay interval during which neither stimulus is present. A response to a comparison stimulus is reinforced if the stimulus matches the preceding sample stimulus. Recent modifications to this procedure, in an attempt to devise a procedure analogous to the directed forgetting techniques commonly used in human memory studies (Bjork, 1972), have opened the way to the study of stimulus control of forgetting in animal short-term memory (Grant, 1981; Maki & Hegvik, 1980; Maki, Olson, & Rego, 1981; Olton, 1978; Kendrick, Rilling, & Stonebraker, Note 1).

The present experiment was stimulated by a series of experiments carried out by Maki and his students in which cancellation of the comparison stimulus emerged as a variable that produces forgetting. Maki, Gillund, Hauge, and Siders (1977) found that when comparison stimuli in a matching-to-sample paradigm are omitted from some trials, matching accuracy is reduced to chance levels on trials when the usual comparison stimuli are presented. Maki and Hegvik (1980) extended the research on comparison omission by introducing postsample instructional stimuli within the delay interval. A remember cue (R-cue) signaled the usual comparison stimuli, while a forget cue (F-cue) signaled cancellation of the com-

parison stimuli. The postsample stimuli were presented early in the delay interval, 1.5 sec after the sample stimuli. Occasional probe trials demonstrated that matching accuracy was substantially lower following the F-cue than following the R-cue. Maki and Hegvik hypothesized that F-cues terminated an active maintenance or rehearsal process during the delay interval, resulting in a decrement in matching accuracy. An alternative interpretation of the decrement in matching performance on F-cued trials, which trivializes the findings of Maki and Hegvik, is that the occurrence of comparison stimuli following a cue predicting the nonoccurrence of those same stimuli was a novel event (i.e., an event that was inconsistent with prior training). The reduced matching accuracy shown on probe trials may be due merely to a generalization decrement produced by a novel pairing of an F-cue and comparison stimuli on probe trials.

Maki and Hegvik (1980) held the temporal location of the cues constant in relation to sample stimuli. In the present experiment, the temporal location of the cues within the retention interval was manipulated. The temporal location of the cues is relevant to the disruption account. If poor matching performance on F-cue probe trials is the result of the presentation of comparison stimuli that are contrary to training, delaying the F-cue within the delay interval should produce a reduction in matching accuracy equal to or greater than that found with the cue presented at the beginning of the delay interval. The presentation of comparison stimuli immediately or shortly after an F-cue on probe trials produces a situation that is at least as novel (if not more novel) than the presentation of comparison stimuli after

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an F-cue that is more remote from these stimuli. Opposite predictions would be made if the processes involved in delayed matching tasks involved rehearsal.

Maki and Hegvik did manipulate the interval between the cue and the presentation of comparison stimuli, and their results were in a direction opposite to the predictions of a disruption account and thus favored a rehearsal account. They found that matching performance was worse when a long delay separated the cues from the comparison stimuli than when a short delay was used. However, their results in this instance showed an asymmetrical sample dependence; the cuing effect was obtained when the sample was food (a presentation of grain) but not when the sample was no food. In addition, there was a confound with retention interval length: short postcue delays occurred in short retention intervals, and long postcue delays occurred in long retention intervals. In the present experiment, the location of the cues was manipulated in constant-length retention intervals in a further attempt to reject the disruption account of the directed forgetting effect demonstrated by Maki and others. If, as Maki and Hegvik propose, F-cues disrupt ongoing processes during the retention interval, matching performance should be a function of the point of interpolation of those cues. Delaying the cues within the retention interval should result in improved matching performance.

In the present experiment, a successive procedure was used in place of the choice procedure utilized by Maki and Hegvik. Successive DMTS is different from two-choice DMTS in several respects (Wasserman, 1976). Sample and comparison stimuli (in this case, red and green keylights) are presented on the same response key. Responses following matching trials (red-red and green-green) are reinforced, whereas responses following nonmatching trials (red-green and green-red) are not reinforced. Rather than being percentage correct, the dependent variable in successive DMTS is a discrimination ratio, derived from the rates of responding to comparison stimuli that occur during matching and non-matching trials. Use of the successive DMTS procedure allows a determination of the extent to which Maki and Hegvik's cuing effect is generalizable across different procedures used to assess short-term memory.

Finally, in the present experiment, delay interval behavior (keypecking) was recorded; such observations are not now available from other studies on directed forgetting in animals (e.g., Grant, 1981; Maki & Hegvik, 1980). This behavior may be an important variable in directed forgetting. Recent work in our lab (Tranberg & Rilling, 1980) has suggested that, in some situations, birds may peck during the retention interval as a self-maintained "instruction to remember." In a retroactive interference study using successive matching-to-sample,

Tranberg and Rilling found that certain relationships between delay interval and intertrial interval illumination interfered with delay interval keypecking. When keypecking was not present, matching performance suffered. It is quite likely that, in the present procedure, keypecking will come under the control of the R- and F-cues. Of special interest was whether the F-cue terminates delay interval responding. In the Tranberg and Rilling study, it was also evident that the retention interval keypecking was not sample-specific mediating behavior, since the rate of response during the delay was independent of the sample. A similar analysis was made of the delay interval response rates in the present experiment.

## METHOD

### Subjects

Three adult experimentally naive White Carneaux pigeons were used. Birds were maintained at  $80\% \pm 15$  g of their free-feeding weights. Birds were housed individually in a temperature-controlled and constantly illuminated room and had free access to water and grit.

### Apparatus

A standard Lehigh Valley Electronics three-key conditioning chamber was used. Interior dimensions were  $35 \times 35 \times 30$  cm. Only the center 2.5-cm response key, which required a force of .15 N for activation, was used. The response key was transilluminated with either a red (606 nm) or green (555 nm) stimulus from an IEE projector (Model 10-3723-757-L). White horizontal and vertical lines on a black background,  $.3 \times 2.5$  cm, were also presented. The key was located above the  $5 \times 6$  cm magazine opening. Above the key was a 28-V houselight (CM 1820). Also located on the intelligence panel was a circular speaker grill. During reinforcement, a 28-V light (Sylvania 28 PBS) within the magazine enclosure was illuminated. Activation of a Lehigh Valley Electronics photoelectronic relay initiated the reinforcement timer. An exhaust fan, located on the wall opposite to the response panel, partially masked extraneous noises.

### Procedure

All birds were trained to approach and eat mixed grain from the magazine. Birds were placed in the lighted test chamber, with the magazine elevated and lighted and food easily visible. A photoelectric beam was broken when the bird ate from the magazine, and 2.5 sec later the magazine was lowered out of reach. Thirty presentations of food occurred on a variable-time schedule of 45 sec. Throughout the entire experiment reinforcement consisted of the same 2.5-sec access to mixed grain. For the next three sessions birds were autoshaped. Each autoshaping session consisted of 50 trials during which a 6-sec stimulus presentation of either a red or green keylight was immediately followed by reinforcement. The mean interstimulus interval was 45 sec. After three autoshaping sessions all birds were reliably pecking both red and green stimuli.

Following autoshaping, birds were trained on the successive delayed matching-to-sample task using red and green keylights as both sample and comparison stimuli. The stimulus parameters followed Nelson and Wasserman (1978) to obtain maximum matching performance. During DMTS training sample stimuli were presented (either red or green) and were terminated with the first keypeck after 12 sec had elapsed. Retention intervals, during which no stimuli appeared on the key, followed the samples and were in turn followed by comparison stimuli. Comparison stimuli on matching trials (red-red and green-green) were

presented for a minimum of 5 sec. A single peck after 5 sec terminated the keylight and resulted in reinforcement. Reinforced responses to comparison stimuli were excluded from the data analysis. Comparison stimuli on nonmatching trials (red-green and green-red) terminated automatically after 5 sec, and responses to these stimuli were not reinforced. The intertrial interval was 30 sec. The houselight remained on during the 72 trial sessions. Each of the four trial types was presented an equal number of times per session and was pseudorandomized such that the same stimulus event occurred no more than twice in succession.

From the response rates to matching and nonmatching comparison stimuli, discrimination ratios were calculated as a measure of matching accuracy. This ratio was calculated by dividing the responses during matching comparison stimuli by the total number of responses during comparison stimuli, both matching and nonmatching, and multiplying by 100. A discrimination ratio of 100% indicates perfect matching performance, with responding during comparison stimuli occurring exclusively on matching trials. A ratio of 50% indicates chance levels of matching performance, with equal levels of responding occurring on matching and nonmatching trials.

During training, the duration of the retention interval was initially set at 1 sec. This interval was maintained until a bird performed above an 80% discrimination ratio for two consecutive sessions. Retention intervals were increased in 1-sec increments each time the criterion was met until the terminal value of 4 sec was reached. Once this level of performance was met and maintained, discriminative stimuli predicting the occurrence (R-cue) or nonoccurrence (F-cue) of comparison stimuli were gradually introduced. Vertical lines presented on the key served as R-cues, while horizontal lines served as F-cues. The cues were gradually introduced in several stages. R-cues were included in 12, then 24, and finally 36 trials; F-cues were then included in 4, 8, 12, 20, 28, and finally 36 trials. At each stage, conditions were held constant until the two-session 80% criterion was met. On F-cued trials, the comparison stimuli were not presented and retention intervals were followed immediately by the intertrial interval. (Other than for the R- and F-cues, the stimulus conditions during the two intervals were identical.) All cues were presented immediately after the termination of the sample stimulus and were of a .5-sec duration. The key remained dark for the remainder of the retention interval.

Once all 72 trials contained cues (36 F-cues and 36 R-cues, presented pseudorandomly) and an 80% discrimination ratio on R-cued trials had been achieved, a 40-msec 1,000-Hz tone of approximately 80 dB was added to the procedure. This tone occurred at the onset of the comparison stimulus as an additional cue indicating the presence of that stimulus. The tone was an important part of F-cue probe trials, because the birds often turned away from the key after an F-cue, and it was thus necessary to signal the presence of the comparison stimulus on those trials.

Birds were trained with full cues and the tone for a minimum of 10 sessions. In addition, birds were required to perform above 80% for five consecutive sessions before probe sessions began. Probe sessions consisted of 68 baseline and 4 randomly located probe trials, one of each of the four trial types (red-red, red-green, green-green, green-red). On probe trials, horizontal lines (F-cues) were followed by the presentation of comparison stimuli. On probe trials, responses terminating comparison stimuli on matching trials were reinforced, while nonmatching comparison stimuli terminated automatically after 5 sec and pecks to these stimuli did not result in reinforcement. This contingency was identical to that of R-cued trials. Probe sessions in which a 75% discrimination ratio on baseline (R-cued) trials was not maintained were eliminated from the final analysis. Probe sessions were alternated with as many training sessions as were necessary to maintain the 80% discrimination ratio until data on five probe sessions had been collected.

After birds completed the fifth probe session with immediate cues (0-sec delay between sample and cue, as depicted in line A

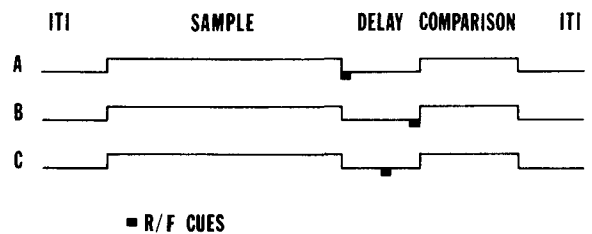


Figure 1. Pictorial representations of temporal location of cues within the delay interval. Comparison stimuli followed all R-cues and only F-cues on probe trials. F-cues normally were followed immediately by the initiation of the intertrial interval (not shown in figure).

of Figure 1), they were trained with 3.5-sec delays between the sample and the cue. In other words, the .5-sec cues occurred as late as possible within the 4-sec retention intervals (see line B in Figure 1). Both R- and F-cues were delayed on all trials. Once birds performed above 80% for five consecutive sessions, probing began, following the procedure used with immediate cues. When probing with 3.5-sec delays was completed, the cue location was changed to the middle of the delay interval, after 2.0-sec cue delays (line C in Figure 1), and the procedure was repeated.

## RESULTS

Table 1 shows the response rates for each bird under the various conditions. From these response rates, the percentage responses to matching comparison stimuli (discrimination ratios), displayed in Figure 2, were calculated. Under the 0-sec sample-cue interval condition, Birds 1162, 1067, and 924 had matching accuracies of 91%, 86%, and 93%, respectively, on R-cued trials, while matching performance on F-cued trials was greatly reduced to 58%, 54%, and 64%, respectively. When the sample-cue interval was 2 sec, the respective matching accuracies were 92%, 87%, and 86% on R-cued trials and 80%, 62%, and 71% on F-cued trials. In Condition B, in which the sample-cue interval was 3.5 sec, the respective accuracies for individual birds were 91%, 93%, and 93% on R-cued trials and 96%, 82%, and 85% on F-cued trials. The top panel of Figure 2 presents matching accuracies combined across birds. As the presentation of the cues was delayed within the 4-sec retention interval, the matching performance on F-cued trials improved.

Observing the behavior of the birds during the retention interval revealed that they ordinarily remained oriented toward the key until the presentation of the cue. Following an R-cue, they continued to orient toward the dark key, while, following an F-cue, they terminated key orientation. In addition to orienting toward the key, the birds usually pecked the darkened key during the retention interval. The mean frequencies of this responding by individual birds are presented in Table 2, while the combined averages, converted to responses per minute, are presented in the lower panel of Figure 2. As can be

Table 1  
Responses per Minute During Comparison Stimuli Following Remember (R) and Forget (F) Cues During 4-Sec Retention Intervals With Various Cue Delays (in Seconds)

Cue Delay	R Cued				F Cued			
	RR	GG	RG	GR	RR	GG	RG	GR
	Bird 1067							
.0	173.6	174.7	30.4	25.6	160.8	151.2	117.6	151.2
2.0	221.9	220.0	47.7	17.1	237.6	204.0	81.6	187.2
3.5	250.4	221.7	15.2	21.9	276.0	201.6	31.2	74.4
	Bird 1162							
.0	170.4	161.1	11.5	22.4	158.4	132.0	79.2	127.2
2.0	126.7	99.5	9.6	10.7	158.4	98.4	43.2	19.2
3.5	148.8	132.0	11.2	16.3	136.8	124.8	2.4	7.2
	Bird 924							
.0	508.8	487.2	50.7	19.2	360.0	427.2	199.2	235.2
2.0	405.9	401.3	46.7	87.2	441.6	477.6	276.0	86.4
3.5	542.7	402.7	30.7	42.7	585.6	568.8	88.8	120.0

Note—Trial types are red-red (RR), green-green (GG), red-green (RG), and green-red (GR).

seen in both the table and the figure, keypecks during R-cued intervals consistently exceeded keypecks in F-cued intervals, with the difference most pronounced at 0 sec and decreasing as a function of the temporal location of the cue.

Informal observation failed to identify any sample-specific delay interval behavior. This observation is supported by the means in Table 2: Keypecking for Birds 1067 and 1162 was essentially identical following red and green samples; for Bird 924, the differences were inconsistent.

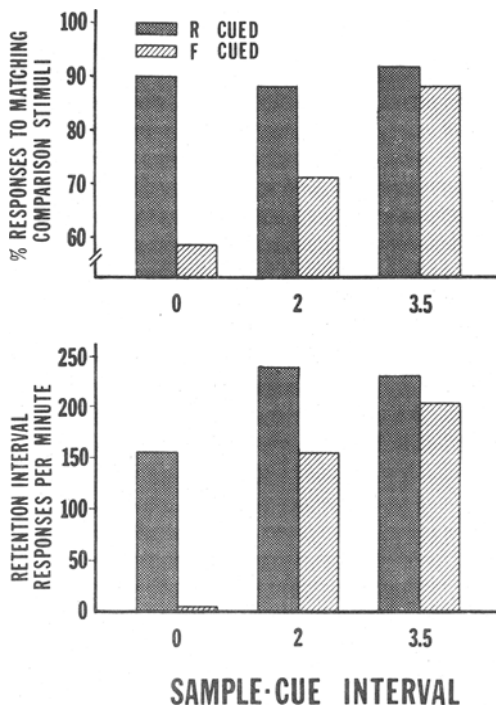


Figure 2. Average matching accuracies (top panel) and retention interval response rates (lower panel) for each of the three sample-cue intervals. Percent responses to matching comparison stimuli were calculated from probe trials (F-cued) and all of the R-cued trials during probe sessions (R-cued). Retention interval response rates were calculated from all retention intervals during the five-session baseline trials.

## DISCUSSION

The results of the present experiment demonstrate that, in successive delayed matching-to-sample, accuracy on probe trials after an instructional stimulus (F-cue) signaling nonoccurrence of comparison stimuli was reduced relative to performance on standard training trials in which a different instructional stimulus (R-cue) appeared in the same temporal location and was followed by comparison stimuli. The extent of the reduction in accuracy depended on the temporal location of the F-cues, the reduction being greater when the cue was at the beginning of the retention interval. The data presented indicated that, in general, reduced matching performance on F-cued trials was the result of increased responding to nonmatching comparison stimuli, rather than decreased responding to matching comparison stimuli. It is reasonable to assume that there is a response bias to the food-associated keys. When a hungry pigeon is presented with a comparison stimulus and has forgotten the preceding sample stimulus on which a respond/inhibit decision is made, the bias is to peck the lit key. Equal response rates on matching and nonmatching comparison stimuli are taken as an indication of forgetting, regardless of the absolute response rate.

One possible criticism of the present research is that all birds received the same order of conditions: 0-sec sample-cue interval, followed by 3.5 sec, fol-

Table 2  
Mean Keypeck Responses During the 4-Sec Delay Interval  
for Conditions A, C, and B

Delay After	Bird 1067		Bird 1162		Bird 924	
	R Cued	F Cued	R Cued	F Cued	R Cued	F Cued
0-Sec Cue Delay (Condition A)						
Red	14.7	.2	10.2	.7	6.0	3.0
Green	14.1	.5	10.8	.4	7.6	2.1
2-Sec Cue Delay (Condition C)						
Red	12.6	7.7	10.8	7.5	29.7	18.6
Green	12.6	7.2	10.9	7.9	21.3	14.1
3.5-Sec Cue Delay (Condition B)						
Red	15.9	14.0	13.1	12.2	18.4	15.5
Green	15.5	14.2	13.7	13.0	15.6	13.2

Note—See Figure 1. R = remember, F = forget.

lowed by 2 sec. It is highly unlikely that the present results are a product of the order of presentation, given that the order of results was, in sequence, minimum matching performance on F-cued probes, maximum matching, and a medium value of matching performance. Matching accuracy on F-cued probe trials varied incrementally as a function of sample-cue interval, but not as a function of order of conditions. In addition, Grant (1981) has obtained similar results using a different technique (cue placement varied session to session) and various orders.<sup>1</sup>

When the cues occurred immediately after the termination of the sample stimulus, the results were consistent with those of Maki and Hegvik (1980), that is, high matching accuracy on R-cued trials and greatly reduced matching accuracy on F-cued trials. Two possible explanations can be given for the results: Either F-cues reduced control by the sample stimulus over the animal's behavior during the comparison stimulus or the novel stimulus sequence on probe trials has resulted in general disruption of matching performance. If the reduced matching performance on probe trials were due to the novel pairing of an F-cue and comparison stimuli, delaying the F-cue should result in probes that are at least as disrupting if not more so. Reducing the interval between an F-cue and the novel presentation of a comparison should increase the novelty of those probe trials and subsequently increase any general disruption, resulting in equal or increased matching decrement. The results of the present experiment were in the direction exactly opposite to the predictions based on a disruption hypothesis. Delaying R- and F-cues in baseline resulted in F-cue probe trials in which the matching decrement was reduced. Delaying the cues until the end of the delay interval nearly eliminated the decrement in matching performance on F-cue probe trials. The results demonstrate that a simple disruption-by-novelty account is

not sufficient to explain Maki and Hegvik's data or the data presented here.

Maki and Hegvik (1980) interpreted their results in terms of a rehearsal process during the delay interval. This hypothesis holds that a representation of the sample stimulus is actively maintained until the presentation of the postsample cue. On R-cued trials, rehearsal may continue until the presentation of the comparison stimulus. On F-cued trials, rehearsal is terminated with the presentation of the F-cue, and forgetting of the sample stimulus occurs. The present results are consistent with the rehearsal interpretation given by Maki and Hegvik. If the pigeon rehearses until the presentation of an F-cue, which then terminates rehearsal, more forgetting should occur when the cue is presented at the beginning of the delay interval than at the end. Matching performance did vary as a function of the temporal location of the cue, with matching accuracy lower when cues were presented at the beginning of the delay interval.

The results show that, during the retention interval, pigeons typically keypecked. These data would not lead one to conclude that keypecking was the rehearsal process, however, in light of the fact that keypecking rate was generally nondifferential following red and green sample stimuli. Honig and Wasserman (in press) have also reported successive matching-to-sample results in which delay interval responding was not dependent on the sample stimulus. Rather than viewing keypecking as a sample-specific rehearsal process, it is more likely that keypecking is a collateral behavior occurring simultaneously with rehearsal. If this is the case, either rehearsal is a cognitive process or the bird is simultaneously engaging in two behaviors: one sample-specific and one nondifferential. Informal observation of the birds during the retention interval did not reveal any sample-specific mediating behaviors.

Birds stayed focused on the key (usually keypecking) for the entire retention interval on R-cued trials. On F-cued trials, birds stayed at the key only until the cue. When an F-cue was presented, birds not only stopped keypecking, but also left the key and began other behaviors. Matching performance is then directly proportional to the time spent keypecking during the retention interval. This correlation is clearly evident when one compares the top and bottom panels of Figure 2. One possible interpretation is that, during the time attention was focused on the key, a rehearsal process was occurring. Attention was focused on the key in order to reduce interference from other stimuli and events. As attention was focused on the key during rehearsal, the natural response of the pigeon was to peck the food-associated key, but that keypecking behavior was not itself the rehearsal process. Whether keypecking was necessary or whether focused attention

alone would have been sufficient for accurate matching is not clear. A similar account has been suggested by Tranberg and Rilling (1980). They hypothesized that keypecking during the retention interval may serve as an instruction to remember. Cessation of responding could then be taken as an indication of decreased attention to the mnemonic requirements of the matching task. Another possibility is that keypecking becomes part of the stimulus context necessary to perform accurately on the matching task. Rilling, Kendrick, and Stonebraker (in press) have argued that stimuli produced by delay interval behavior may be part of the context necessary for accurate performance in memory tests. In all of these interpretations, the termination of retention interval responding, as controlled by the F-cue, leads to forgetting of the sample stimulus, despite the fact that retention interval keypecking is not considered to be the rehearsal process.

#### REFERENCE NOTE

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#### NOTE

1. Grant (1981) has also reported a directed forgetting study in which the temporal location of cues was varied within a constant-length retention interval, also using the successive matching procedure. The reliability of the effects of sample-cue interval has thus been demonstrated by independent replications from different laboratories.

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