Directed forgetting in pigeons: Analysis of cue functions

WILLIAM S. MAKI, DEBORAH OLSON, and SUSAN REGO
North Dakota State University, Fargo, North Dakota 58105

In delayed matching-to-sample with pigeons, brief postsample cues signaled different trial outcomes. The normal comparison stimuli followed the cue to remember (R cue). In the comparison-omission procedure, comparison stimuli and reinforcement were omitted following the cue to forget (F cue). In the comparison-substitution procedure, comparison stimuli were replaced by a single stimulus and reinforcement for a single response following the F cue. Infrequent probe trials revealed that F cues disrupted matching, with the amount of accuracy loss dependent on the length of the cue-comparison delay. These results, however, were found only with the comparison-omission procedure (Experiment 1). Replacing the comparison stimuli with another simultaneous (unconditional) discrimination revealed no accuracy loss in F-cue probes (Experiment 2), even though choice latencies were again lengthened by F cues. These results suggest that, while the F cue interferes with performance at the time of a retention test by slowing choices, it also interferes with sample retention. Alternative models of the cuing effect and its apparent dependence on end-of-trial reward are outlined.

It is a well-documented fact that human memory processes can be brought under stimulus control. In studies of "directed forgetting" (Bjork, 1972), one stimulus functions as a cue to forget (F cue) and another stimulus functions as a cue to remember (R cue). In one kind of study (e.g., Woodward, Bjork, & Jongeward, 1973), each verbal item is followed by one of the cues, and recallability of the R-cued items is occasionally tested. Recall of *all* items is ultimately tested, with the result that recall of F-cued items is low. The notion of directed forgetting and related concepts such as "termination" and "resetting" of memory processes have begun to appear as explanatory constructs in the animal memory literature (Honig, 1978; Maki, 1979; Olton, 1978), but, until very recently, directly relevant empirical work was lacking.

Maki and Hegvik (1980) modified a technique used with humans called "intraserial cuing" (Bjork, 1972) for use with pigeons. In their study, the basic task was a version of delayed matching-to-sample (DMTS), which is often used to assess animal short-term memory (STM). In DMTS, one of two conditional stimuli (samples) is presented at the beginning of a trial. After a delay, two other stimuli (comparisons) are presented. Choice of one of the comparisons is reinforced contingently on the identity of the preceding sample. There were two important features of Maki and Hegvik's procedure. First, each sample was followed by the presence or absence of a brief

stimulus (postsample cuing). Second, stimuli designated as R cues were always followed by the usual comparison stimuli, but the comparisons were omitted during the trials containing F cues (comparison omission). The comparison-omission treatment reduced accuracy of choices following F cues (as determined by infrequent probe trials). Moreover, the cuing effect was time-dependent, with the loss of matching accuracy (forgetting) directly related to the length of delay between cues and comparisons.

Maki and Hegvik noted that the detrimental effects of F cues could have been obtained for any one of three reasons. The cues might well have functioned as "instructions" about when to remember and when to forget. But, F cues were also associated with the lack of an opportunity to choose between comparison stimuli and with the lack of an opportunity for reinforcement. To control for the latter two potential causes of the cuing effect, Maki and Hegvik devised a "comparison-substitution" procedure in which a different set of discriminative stimuli replaced the usual comparisons following F cues; a response to one of the substituted stimuli was always reinforced independently of the identity of the preceding sample. In that procedure, choice responses and reinforcement were guaranteed to end the majority of trials, but there was no need for the pigeon to remember samples following F cues because degree of retention of the sample was irrelevant to successful performance of the substituted discrimination. It was found, however, that both the cuing effect and its time-dependence were largely eliminated after experience with the substitution training.

Maki and Hegvik's results thus present an inter-

This research was supported by National Institute of Mental Health Grant R01 MH31432-02. Requests for reprints should be sent to W. S. Maki, Department of Psychology, North Dakota State University, Fargo, North Dakota 58105.

esting problem. It appears as though considerable forgetting occurs after an F cue but not when the trial ends in a set of substituted discriminanda, choice responding, and reinforcement. At this point, it is not clear which aspect of the substitution procedure (discriminated responding or reinforcement) is most responsible for reduced F-cue effects. Moreover, it is not yet known if the F cue (following comparison-omission training) simply acts proactively, disrupting performance of the conditional discrimination at the time of choice between comparisons.

EXPERIMENT 1

The present experiment was designed to address some of the concerns mentioned above in the following ways. First, the comparison-substitution procedure was modified so as to diminish the possibility that choice between comparison stimuli would be responsible for the attenuated cuing effects during comparison-substitution. In this experiment, comparison stimuli were replaced by a single stimulus to which a single response was inevitably reinforced. It was predicted that if reinforcement-omission was singularly critical in producing F cues, then this kind of comparison-substitution procedure should abolish the cuing effect, even though choices between comparison stimuli did not occur. Second, latencies to choose between comparisons were monitored. It was reasoned that if F cues interfere just with choices among comparison stimuli (and not necessarily with memory-related processes), then such interference should be revealed by longer choice latencies as well as by lesser choice accuracy. Third, Maki and Hegvik used presence and absence of a brief houselight as cues; the present experiment employed differently colored lights in an attempt to generalize the cuing effects to other sets of stimuli.

Method

Subjects. Twelve adult pigeons (1 White Carneaux and 11 White Kings) were maintained at at least 80% of their free-feeding weights. The birds were housed individually and were provided free access to grit and water. A daily ration of mixed grain was provided during experimental sessions and during supplemental postsession feeding when necessary.

Apparatus. Two identical conditioning chambers were placed in lightproof, ventilated outer shells. The front wall of each chamber contained three transparent pecking keys backed by in-line projectors. Each projector could display a white, red, or green disk or a white vertical or horizontal line. A grain feeder was located behind an aperture beneath the center key; when the feeder was activated, the aperture was illuminated. A 7.5 × 7.5 cm square hole was cut in the metal roof of each chamber; the hole was centered midway between the side keys, and its front edge was 5 cm from the front wall. The hole was covered with a milk-white Plexiglas panel above which were two incandescent bulbs, one orange and one green. When none of these stimuli were presented, the chamber was left dark. An Automated Data Systems 1800E/II computer, located in another room, was programmed to schedule stimuli, record choice latencies to the nearest 10 msec,

and report data via an on-line printer. In respects not mentioned here, the apparatus was identical to that described earlier (Maki, 1979).

Procedure. The birds had served in previous studies (e.g., Maki & Hegvik, 1980) and thus had been well overtrained on the basic task. During the first 4-5 days of training, all birds performed the following task at high levels of accuracy (at least 87.5% correct). Each trial commenced with a 20-sec intertrial interval, followed by the appearance of a white disk on the center key. A single peck darkened the key and produced one of two samples. A sample of food consisted of a 2-sec activation of the feeder, and a sample of no food consisted of 2 sec during which no stimuli were presented. The side keys were then illuminated with comparison stimuli (red and green disks). A peck on either side key darkened both keys and resulted in a 2-sec period during which reinforcement (2-sec access to grain) could occur. A peck on the red key following a sample of food was correct (reinforced), as was a peck on the green key following a sample of no food. All four types of trials defined by combinations of sample (food or no food) and position of correct comparison stimulus (right or left side key) occurred equally frequently in a random order during each 64-trial session. During the next 30 days, the delay between sample offset and comparison onset (initially 0 sec) was increased .5 sec/day contingently on criterial (87.5% correct) performance. During the next 10-19 days, delays were adjusted so as to achieve consistent criterial performances. The resulting "long" delays, determined separately for each bird, averaged 9 sec (range: 6-13 sec). Pretraining concluded with 4-11 days in which half of each type of trial during each day contained "short" (2-sec) delays for each bird.

During the next phase of training, the birds were adapted to the overhead colored lights destined to serve as postsample cues. Each of the 64 daily trials contained one of the overhead lights (orange or green) presented .5 sec after sample offset for a 1-sec duration. Each of the 16 trial types (defined by postsample cue, delay, sample, and position of correct choice) occurred equally often. Training continued until each bird had regained criterial performance levels. The adaptation training averaged 25.7 days (range: 20-43 days).

The birds were then assigned to two treatment groups (omission and substitution) of six birds each. Assignments were made so that lengths of long delays were about the same; for the omission group, delays averaged 9.1 sec (range: 6-13 sec) and for the substitution group, delays averaged 8.8 sec (range: 6-12.5 sec). At this point, cue functions were determined. For half the birds in each group, the orange overhead light served as the F cue and the green overhead light served as the R cue; for the other birds, the cue functions were reversed. Also, half the birds from each group worked in one of the two chambers, and the other half worked in the other chamber.

The treatment phase then commenced and lasted 30 days. For the omission group, the comparison stimuli were omitted in each trial that contained an F cue. When comparison stimuli were omitted, 2 sec was added to the delay to compensate for the duration of the reinforcer that otherwise might have occurred. For the substitution group, comparison stimuli were replaced by a white cross (both vertical and horizontal lines displayed simultaneously) presented on one of the side keys; the cross was equally likely to appear on either key, and a single peck on the key containing the cross was always reinforced. For both groups, trials containing R cues terminated normally in comparison stimuli and reinforcement for correct choices. Trial structures for both omission and substitution groups during this phase are diagrammed in Table 1.

The experiment ended with 40 more days of comparison-omission and comparison-substitution treatments. Sessions during this phase differed only in that four additional probe trials occurred in each session. One probe trial occurred in each block of 17 trials. Every block of probes contained 16 trials and spanned 4 days. All probe trials ended in comparison stimuli and rein-

Table 1
Trial Structures During Comparison-Omission and
Comparison-Substitution

Sample	Cue	Comparison	
		Omission	Substitution
Food	R	R+,G- or G-,R+	R+,G- or G-,R+
	F	(omitted)	X+,0 or 0,X+
No Food	R	G+,R- or R-,G+	G+,R- or R-,G+
	F	(omitted)	0,X+ or X+,0

Note—Comparison stimuli were red (R) and green (G) side keys, or a white cross on one key (X) and no stimulus on the other key (0). Stimuli to which responses were reinforced and not reinforced are designated by "+" and "-", respectively.

forcement for a correct choice. Half of the probe trials contained F cues and half contained no light during the delay (N cues). Within each block of 16 probes, each combination of cue (F vs. N) and delay (short vs. long) occurred four times, once with each of the four combinations of sample (food vs. no food) and position of correct comparison (right vs. left). Choice latencies were also recorded on R- and N-cue probe trials.

Results

Probe-trial tests. The effects of postsample cuing conditions on matching accuracy during the 40 sessions containing probe trials are shown in Table 2. Inspection of the group averages suggests that matching accuracy was decreased following an F cue, but that the size of this effect depended on other variables. First, the effects of F cues were much larger in the omission group than in the substitution group. Second, the disruption due to F cues was largest when the to-be-remembered event was a sample of food. Third, given those qualifications, the cuing effect was time-dependent; F cues had the greatest influence on accuracy when cue-comparisons delays were long.

The reliability of that description was statistically verified in the following ways. For each bird, mean percentages of correct responses were based on 20 probe trials (10 blocks by 2 trials) for each combination of sample, delay, and cue (R vs. N) and on 320 R-cue trials (40 days by 8 trials) for each sample at each delay. Because Maki and Hegvik also had noted cuing effects that were different for different

samples, data on matching-to-samples of food and no food were analyzed separately. For each sample, two orthogonal contrasts were examined. First, results from R- and N-cue trials were compared. Second, data from F-cue probes were compared with the combined data from R- and N-cue trials.

Accuracies of matching-to-samples of no food did not depend on whether trials contained R cues or N cues, and there were no significant interactions between that contrast and other variables [largest $F(1,10) = 1.32$]. Matching-to-samples of no food was less accurate following F cues relative to R and N Cues combined [$F(1,10) = 6.25$, $p < .05$], but this contrast did not change reliably over levels of any other variable [largest $F(1,10) = 1.26$].

Accuracies of matching-to-samples of food, on the other hand, were complexly determined by postsample cue, length of delay, and by whether the omission or substitution treatment was used. Table 2 shows that matching was less accurate after N cues than after R cues at long delays in both omission and substitution groups; the R vs. N contrast differed reliably across delays [$F(1,10) = 5.03$, $p < .05$], but no effects involving groups were significant (all $F_s < 1$). Simple main effects analyses showed that the accuracies supported by R and N cues were reliably different at long delays [$F(1,10) = 5.07$, $p < .05$] but not at short delays [largest $F(1,10) = 1.52$].

Table 2 also shows that the effects of F cues on matching-to-samples of food were different from those of R and N cues. First, accuracies of matching produced by F cues were reliably less than those produced by R and N cues [$F(1,10) = 39.88$, $p < .001$]. This contrast was largest in the omission group [$F(1,10) = 39.55$, $p < .001$] and at long delays [$F(1,10) = 7.36$, $p < .05$]. Moreover, the contrast was especially large in the omission group at long delays, as indicated by the significant Contrast by Delay by Group interaction [$F(1,10) = 9.81$, $p < .05$]. For the substitution group, neither the overall contrast (F vs. R and N cues combined) nor its interaction with delays was significant (all $F_s < 1$). In the omission group, however, the contrast was significantly larger at long delays [$F(1,10) = 12.98$, $p < .05$], even though the contrast was significant at short [$F(1,10) = 7.60$, $p < .05$] as well as at long delays [$F(1,10) = 87.99$, $p < .001$]. Finally, it should be noted that matching-to-samples of food following F cues was reliably worse than matching following N cues (considered alone) at both short [$F(1,10) = 10.71$, $p < .05$] and long delays [$F(1,10) = 55.58$, $p < .001$].

Choice latencies. Table 3 summarizes choice latencies obtained during F- and N-cue probe trials. Each bird's latencies were averaged for each combination of sample, cue, and delay; latencies were not further conditionalized on correctness of choices because, in some cases, there were no errors. Within-group variability was high, so nonparametric tests (Mann-

Table 2
Mean Percentage Correct Matching in Omission and Substitution
Groups During Probe Tests as a Function of Sample,
Postsample Cue, and Delay

Sample	Cue	Omission		Substitution	
		Short	Long	Short	Long
No Food	R	93.9	91.8	93.4	91.0
	N	92.5	90.8	94.2	93.3
	F	77.5	81.7	80.0	81.7
Food	R	96.0	89.7	96.5	84.8
	N	89.2	72.5	96.7	75.8
	F	76.7	44.2	95.8	81.0

Table 3
Mean Choice Latencies (in Seconds) in Omission and
Substitution Groups as a Function of Sample,
Postsample Cue, and Delay

Sample	Cue	Omission		Substitution	
		Short	Long	Short	Long
No Food	N	1.13	1.24	1.42	1.82
	F	1.42	1.84	1.44	1.53
Food	N	1.17	1.41	1.77	1.71
	F	1.35	2.04	1.71	1.57

Whitney U and Wilcoxon T) were performed; interactions were assessed by analyses of difference scores.

For samples of no food, latencies following F cues were longer than those following N cues, an effect that was most pronounced in the omission group ($U = 2$, $p < .01$); F cues reliably increased latencies in the omission group ($T = 0$, $p < .05$) but not in the substitution group ($T = 6$). This Cuing by Group interaction was similar across delays ($U = 14$), but it can be noted that the interaction was reliable at long delays ($U = 3$, $p < .05$) but not at short delays ($U = 9$).

For samples of food, latencies were influenced interactively by all three factors ($U = 5$, $p < .05$). The Cuing by Groups interaction was reliable at long delays ($U = 4$, $p < .05$) but not at short delays ($U = 10$), a pattern similar to that noted with samples of no food. At long delays, the cuing effect was not reliable for the substitution group ($T = 8$) and, while not significant in the omission group either ($T = 1$), five of six subjects were slower following F cues than following N cues.

Adaptation. It is important to note that the "unconditioned" effects of the stimuli that later became R and F cues were very different from the "conditioned" effects of F cues eventually manifested in probe trials. The initial interference from the post-sample cues was confined to matching-to-samples of no food, but the ultimate effects of F cues (see Table 2) were confined to matching-to-samples of food.

By the end of pretraining prior to initial introduction of the overhead lights, performances were stable and accurate, averaging over 90% correct. During the last 3 days of pretraining, the 12 birds averaged 93.4% and 94.8% correct matching-to-samples of no food for short and long delays, respectively; as assessed by a repeated measures analysis of variance, the difference was not significant ($F < 1$). For matching-to-samples of food, however, the birds averaged 97.6% at short and 90.7% at long delays, and that difference was significant [$F(1,11) = 15.88$, $p < .01$].

When the overhead lights were introduced during adaptation, matching accuracy was decreased. Matching-to-samples of no food during the first 3 days

of adaptation averaged 58.9% and 81.3% correct for short and long delays, respectively, while matching-to-samples of food averaged 93.8% and 83.5% correct. The increase in accuracy of matching-to-samples of no food as a function of delay length was reliable [$F(1,11) = 17.30$, $p < .01$], as was the decrease in matching-to-samples of food [$F(1,11) = 15.62$, $p < .01$]. The loss in accuracy of matching-to-samples of food over delays, however, was not significantly different from that noted during the final pretraining days [$F(1,11) = 1.48$]. Thus, the primary effect of the overhead lights was to initially reduce accuracy of matching-to-samples of no food, especially at short delays. As a consequence of the extended adaptation to the lights, however, these effects disappeared such that, during the last 3 adaptation days, performances were indistinguishable from terminal pretraining performances.

Treatment phase. After adaptation was completed and postsample cues and end-of-trial events were first correlated, another effect was noted—matching accuracy following R cues was reduced. The effects were very specific, being confined to matching-to-samples of food following long delays and being exhibited only by the omission group—and then only during the first few days of the treatment phase. During the first 3 days, the omission group averaged 59.7% correct matching-to-samples of food after long delays, while the substitution group averaged 85.4% [$F(1,10) = 8.47$, $p < .05$]. Performances in the other conditions all exceeded 87.5% for both groups [largest $F(1,10) = 1.30$]. The birds in the omission group recovered from the initial loss in accuracy rather quickly, averaging 78% correct during the second 3 days and consistently over 80% thereafter (for matching-to-samples of food after long delays); other than during the first block of 3 days, no other between-groups comparisons for this measure were significant [largest $F(1,10) = 3.92$].¹

Discussion

One of the main aims of the present experiment was to determine whether presence vs. absence of discriminated responding was an important determinant of the variations in effectiveness of F cues reported by Maki and Hegvik (1980). In the original comparison-substitution procedure, comparison stimuli (colors) were replaced by a set of discriminanda (lines) after F cues, and a response to one of the lines was reinforced independently of the identity of the preceding sample. In the present version, a single stimulus was substituted to which a single response was always reinforced. This modification eliminated the necessity of discriminating and choosing between the two stimuli while still guaranteeing that the majority of the F-cue trials in the comparison-substitution procedure would end in reinforcement. That this version

of the substitution procedure still attenuated the cuing effect suggests that reinforcement-omission, rather than prevention of choices, is the feature of the comparison-omission procedure that is responsible for producing effective F cues.

In this study, time-dependent effects of F cues produced by the omission procedure were confined to samples of food. Maki and Hegvik observed the same kind of asymmetry. One possible explanation is that matching-to-samples of food and no food involve a presence (food) vs. absence (no food) discrimination. If a sample of food were forgotten, the birds might be biased to respond as if the sample were absent. If, however, a sample of no food were forgotten, then the birds might still exhibit the bias (to respond to absence of food) and show good performance. Thus, clear evidence of the time-dependent cuing effects could be discovered only with samples of food, because the same effects on matching-to-samples of no food would be obscured by the response bias.

Even though the asymmetry in the accuracy data does not pose an insoluble problem for a memory-related account of cuing effects, the latency data are more threatening. The fact that postsample cues had differential effects on latencies to choose between comparison stimuli suggests an alternative explanation that emphasizes performance processes at the time of choice instead of retention processes during the delay. An F cue might cause a lapse of attention to the demands of the matching task. This lapse could be manifested in two ways. First, the supposed inattention could result in longer choice latencies. Second, the behavior when the comparisons were finally perceived might not be as well controlled by the comparison stimuli, resulting in an increased error rate.

EXPERIMENT 2

The second experiment was conducted to determine whether the "forgetting" observed subsequent to an F cue resulted from a general performance deficit. It was reasoned that if F cues cause a transient loss of stimulus control by subsequently presented discriminative stimuli, then the general disruptive effects of F cues should be obtained regardless of the relevance of those stimuli to the DMTS task. For example, this kind of a general disruption could arise from the identity of the F cue as an S- (a signal for nonreinforcement). In the omission procedure, the F cue is correlated with nonreinforcement, and signals for nonreinforcement seem to have emotional consequences (e.g., turning away from the stimulus source; Terrace, 1972). If the emotional "upset" persisted after the F cue until the time of choice, then it could disrupt performance, even

though the sample memory might remain intact. There is nothing in such an account, however, that would logically specify comparison stimuli per se as necessary to the demonstration of that disruption. If a bird's choice behavior following an F cue was disrupted because that behavior was not fully under discriminative control, then choices between *any* pair of simultaneously presented stimuli should be reduced in accuracy. Thus, the prediction tested in this experiment was that performance of a discrimination quite unrelated to the matching task should be impaired subsequent to an F cue to the extent that the F cue proactively affects performance.

Method

The entire omission group (six birds) from Experiment 1 was used. Two birds began work in this experiment immediately after Experiment 1, and the other four birds began after having first served in another experiment.² The apparatus was the same as in Experiment 1.

All birds were first trained to perform a discrimination between simultaneously presented vertical and horizontal lines. During this training, half of each day's 64 trials consisted of DMTS trials containing R cues and short or long delays. In the remaining 32 trials, line-discrimination trials occurred. After the usual inter-trial interval, these line trials commenced with the presentation of the two lines, vertical on one side key and horizontal on the other. A peck on either side key darkened both keys and began a 2-sec period during which reinforcement occurred if the key containing the vertical line had been pecked. In these line-discrimination trials, vertical was equally likely to be presented on the left and right side keys. Training continued until each bird had averaged at least 87.5% correct during 3 consecutive days; training was concluded after an average of 12.3 days (range: 11-17 days).

Then followed 16 days of probe-trial testing done in the context of comparison-omission. DMTS trials containing F cues with comparisons omitted were reinstated in place of line-discrimination trials. Thus, the standard comparison-omission procedure described in Experiment 1 once again prevailed during 64 trials of the 68 trials presented each day. The other four trials were probes. Two of the probes were line-discrimination trials conducted as described above, each occurring in a randomly selected position of trial positions 1-17 and 35-51. These probes provided a check for retention of the line discrimination. One of the other two probes occurred in one of trial positions 18-34, and the other probe occurred in one of positions 52-68. All of these probes began as DMTS trials, contained F cues, and terminated after a long delay in one of two sets of stimuli. Half the trials ended with the usual comparison stimuli (red and green side keys) and reinforcement delivered contingently on a correct choice (red given a sample of food and green given a sample of no food). The other half of the probes ended with the presentation of the two lines; a peck at the vertical line was reinforced regardless of identity of the preceding sample. Data were thus available from 32 short- and 32 long-delay trials containing R cues, 32 line-discrimination trials, 16 DMTS trials containing F cues and colored comparisons, and 16 DMTS trials containing F cues but ending with the line discrimination. Choice latencies were also recorded in all probe trials.

Results and Discussion

Mean percentage of correct responding during probe-trial testing are presented in Table 4. In most kinds of trials, performances were extremely accurate, averaging in excess of 90% correct. As could be

Table 4
Delayed Matching (DMTS) and Line Discrimination
Performances (Mean Percentages Correct) as a
Function of Preceding Cue

Trial	Cue	Stimuli	
		Lines	Colors
Discrimination		94.2	
DMTS	R		91.6
	F	86.5	66.7

expected, that description applies to DMTS trials containing R cues (at both short and long delays). That it also applies to line-discrimination probes suggests that discontinuation of the bulk of the line-discrimination trials did not result in a retention loss. Most importantly, the line discriminations following F cues were just as well performed. Only sample-dependent choices between colors following F cues were inaccurate. Planned comparisons confirmed the reliability of these observations. Choices of colored comparisons following F cues were less accurate than in any of the other three kinds of trials [$F(1,5) = 89.61$, $p < .001$, which did not differ among themselves ($F < 1$). Also, the effect of F cues on accuracy of choices between colored comparisons paralleled the effect noted in Experiment 1; matching-to-samples of food were less accurate (47.9%) than matching-to-samples of no food (85.4%) [$F(1,5) = 9.00$, $p < .05$].

Mean choice latencies recorded during probe trials are summarized in Table 5. Two analyses were performed. The first compared latencies following F cues as a function of type of comparison (lines vs. colors) and sample (food vs. no food); there were no significant effects (all F s < 1). The second analysis compared the average latency during discrimination trial probes (1.43 sec) with that during all F-cue trials combined (1.76 sec); the increase was significant [$F(1,5) = 7.08$, $p < .05$].

This experiment was motivated by the concern that an F cue might disrupt performance only at the end of a delay and thus result in pecking not controlled by the comparison stimuli. If it were the case that F cues acted just proactively on performance, then performance of any discrimination following an F cue should be impaired. The prediction was partly confirmed; latencies to choose between simultaneously

Table 5
Mean Choice Latencies (in Seconds) in Probe Trials as a
Function of Sample and Type of Comparison

Compari- son	Discrimina- tion	DMTS	
		No Food	Food
Lines	1.43	1.76	1.75
Colors		1.71	1.81

presented stimuli were lengthened by a preceding F cue, both when those stimuli were true comparisons (Experiment 1) and when they were simple discriminative stimuli (the lines in this experiment). F cues, as a consequence of omission training, thus did act to diminish the *speed* of performance. However, the F cues only reduced the *accuracy* of performance when the discrimination was conditional upon a preceding sample stimulus. This finding implicates some delay-interval process involved in STM for sample stimuli as the basis for the detrimental effect of F cues on matching accuracy. Apparently, the F cue does not simply result in uncontrolled responding at the time of a retention test.

GENERAL DISCUSSION

The basic finding of interest is that a postsample stimulus (F cue) associated with comparison-omission reduces accuracy of DMTS performance. The present research, together with that reported by Maki and Hegvik (1980), allows rejection of some possible causes of the cuing effect:

(1) Most obviously, the cuing effect is not due to variations in attention to sample stimuli (as might have been the case in some earlier work; e.g., Maki, 1979). The fact that R and F cues occurred *after* samples insured equal attention to all samples.

(2) The cuing effect does not result from forgetting of "what to do" following F cues. First of all, if that were true, equal losses in matching accuracy should have been obtained following both short and long delays; instead, the magnitude of the accuracy loss depended on the length of the delay, implying loss of STM for sample stimuli and not loss of long-term memory for the DMTS "rules." Second, both comparison-omission and comparison-substitution groups spent the same amount of time, without practice, at matching following F cues; yet, only the omission group showed the cuing effect.

(3) The F cue does not act proactively on accuracy of performance at the time of choice between comparison stimuli. Probing with a different (unconditional) discrimination revealed no deficits, suggesting that the F cue has an effect on processes active during the delay (retention) over and above whatever effect it might have on processes active at the end of the delay (performance).

(4) The fact that the comparison-omission procedure does result in the prevention of choices now appears not to be critical to the production of F cues. Eliminating choices but guaranteeing end-of-trial reinforcement during comparison-substitution still reduced the cuing effect.

(5) The effects of F cues on matching accuracy during comparison-omission cannot be totally attributed to the recovery of the a priori interfering prop-

erties of the stimuli used as cues. The interference was confined to samples of no food early in adaptation, and the interference was most pronounced at short delays. In contrast, comparison-omission training produced F cues that had their greatest effects on samples of food at long delays.

(6) The asymmetrical effects of F cues on matching-to-samples of food and no food are probably not directly relevant to the central issue of stimulus control of memory processing. The birds appear to learn this problem as a discrimination between presence and absence of a conditional stimulus (food). Given that time-dependent cuing effects were confined to samples of food (presence), it appears that the birds may have reacted to forgetting the absence of food in the same way as they reacted to remembering the absence of food. Note, however, that the asymmetry should not be construed to be a general characteristic of cuing effects, because it is probably unique to our procedures; Stonebraker (Note 1) reported symmetrical cuing effects using visual samples.

Although it is becoming clear how the cuing effect is *not* to be explained, it is less clear how the effect *is* to be explained. A possible course of theoretical action is suggested by the observation that omission of end-of-trial reward seems to be the critical feature of the comparison-omission procedure. Rehearsal of sample memories could be treated as an instrumental response that is weakened by nonreward (Maki & Hegvik, 1980). A post-sample stimulus that signals reinforcement-omission (an F cue) might then be viewed as controlling a "low rate of responding" (i.e., little rehearsal). Emphasis on the rehearsal-reinforcer relationship leads to an intriguing view of the effects of the comparison-substitution treatment. In spite of the fact that occurrence of reinforcement after an F cue at the end of a substitution trial was independent of the identity of the preceding sample and the level of its retention, that sample was shown to nevertheless control choice behavior in probe trials. It could then be argued that rehearsal was "superstitiously" maintained in the comparison-substitution group. It is not clear that this is the best (or even the only) possible interpretation of the cuing effects reported here. As Maki and Hegvik noted, the same kind of hypothesizing could be recast in terms of peripheral mediating behaviors instead of in terms of rehearsal. It is also possible that the Pavlovian

pairings of R cues and reinforcement and of F cues and nonreinforcement that are implicit in the omission procedure could endow those cues with motivational properties. Narrowing of the theoretical field must await further research, the outcome of which should provide a richer understanding of animal memory processes and the mechanisms responsible for our apparent ability to bring them under stimulus control.

REFERENCE NOTE

1. Stonebraker, T. B. *Stimulus control of active rehearsal processes in the pigeon using directed forgetting techniques*. Paper presented at the meeting of the Association for Behavior Analysis, Dearborn, Michigan, May 1980.

REFERENCES

- BJORK, R. A. Theoretical implications of directed forgetting. In A. W. Melton & E. Martin (Eds.), *Coding processes in human memory*. Washington, D.C: Winston, 1972.
- HONIG, W. K. Studies of working memory in the pigeon. In S. H. Hulse, H. Fowler, & W. K. Honig (Eds.), *Cognitive processes in animal behavior*. Hillsdale, N.J: Erlbaum, 1978.
- MAKI, W. S. Pigeons' short-term memories for surprising vs. expected reinforcement and nonreinforcement. *Animal Learning & Behavior*, 1979, 7, 31-37.
- MAKI, W. S., & HEGVIK, D. Directed forgetting in pigeons. *Animal Learning & Behavior*, 1980, 8, 567-574.
- OLTON, D. S. Characteristics of spatial memory. In S. H. Hulse, H. Fowler, & W. K. Honig (Eds.), *Cognitive processes in animal behavior*. Hillsdale, N.J: Erlbaum, 1978.
- TERRACE, H. S. By-products of discrimination learning. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 5). New York: Academic Press, 1972.
- WOODWARD, A. E., BJORK, R. A., & JONGEWARD, R. H. Recall and recognition as a function of primary rehearsal. *Journal of Verbal Learning and Verbal Behavior*, 1973, 12, 608-617.

NOTES

1. The finding that matching following R cues was disrupted upon introduction of the omission procedure is interesting but difficult to evaluate. The same kind of effect was not noted in Maki and Hegvik's (1980) data.
2. The intervening experiment addressed a related question: whether the extra time added to delays by the increased latencies caused extra forgetting. Probe trials contained R cues and long delays incremented by 1.5 sec (over twice the size of the latency effect in Experiment 1). There was no effect of that manipulation on accuracy of matching.

(Received for publication July 2, 1980;
revision accepted September 10, 1980.)