STIMULUS CONTROL OF DELAYED MATCHING IN PIGEONS: DIRECTED FORGETTING

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Pigeons were trained in delayed matching-to-sample with two postsample stimuli. A postsample R-cue signaled that a matching choice phase would follow. A postsample F-cue signaled that a matching choice phase would not follow. Previous research found reduced matching accuracy on F-cued probe trials when comparison stimuli were presented in the choice phase. The present four experiments systematically varied the events following an F-cue to determine the conditions under which the F-cue reduces delayed-matching accuracy. When F-cues and R-cues controlled different behavior, matching on probe trials was poor. When both cues controlled the same behavior, matching on probe trials was good. This result is best explained by the theory that comparison stimuli retrieve the sample representation, but only in the behavioral context established by the R-cue. The present research supports the view that response-produced stimuli serve a contextual role in animal short-term memory.

Key words: delayed matching-to-sample, short-term memory, directed forgetting, context, retrieval, key peck, pigeon

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Delayed matching-to-sample (DMTS) has been employed to investigate short-term memory in animals (D'Amato, 1973; Grant & Roberts, 1976; Kendrick, Tranberg, & Rilling, in press; Maki, 1979; Medin, Reynolds, & Parkinson, 1980; Roberts & Grant, 1978; Shimp & Moffitt, 1974; Tranberg & Rilling, 1980; Zentall, Hogan, Howard, & Moore, 1978). In the typical DMTS procedure, a sample stimulus is presented for a limited duration and, after a brief delay without the sample, the choice phase of the trial begins, in which the comparison stimuli are presented. A response to the comparison stimulus that matches the previous sample is reinforced, whereas a response to the nonmatching comparison stimulus terminates the trial without reinforcement.

A phenomenon known as "directed forgetting" (Bjork, 1972; Bjork & Geiselman, 1978)

is studied in humans by instructing the subjects either to remember an item or to forget it. The instruction to remember is an R-cue, and the instruction to forget is an F-cue. To test the efficacy of the cues, subjects are occasionally asked to remember F-cued items. Directed forgetting is seen when retention of F-cued items is inferior to retention of R-cued items.

To study directed forgetting in animals, Maki and Hegvik (1980) altered the basic delayed matching-to-sample procedure so that a brief postsample stimulus, an F-cue, signaled cancellation of the choice phase of the trial. On occasional probe trials a choice phase was presented following the F-cue, contrary to training. Matching accuracy on probe trials was 75%, compared with 93% on baseline trials. Maki and Hegvik (1980) interpreted this directed forgetting in pigeons by assuming that the pigeons rehearsed the sample stimulus during the delay on conventional trials but the F-cue terminated rehearsal.

Stonebraker and Rilling (in press) supported this rehearsal interpretation by demonstrating that the effect of the F-cue was time-dependent. They positioned remember cues (R-cues), signaling the choice phase of a trial, and forget cues (F-cues), signaling cancellation of the choice phase, at three times within the delay: immediately after the sample, in the

middle of the delay, and at the end of the delay. Their rationale was that reduced matching on F-cued probe trials may be due to the novelty of the comparison stimuli after an F-cue, rather than to termination of rehearsal. In that case all cue positions should equally reduce matching. The rehearsal position assumes that reduced matching accuracy on probe trials depends on the point of interpolation because the later the cue, the more time to rehearse and the less time to forget. In the experiment, the later the F-cue, the better was probe matching. This result was interpreted as support for rehearsal.

Previous research has not determined the conditions under which the F-cue reduces delayed matching. The present experiments, therefore, analyze control of delayed matching by an F-cue. In previous studies, the F-cue always signaled abortion of the trial, whereas conventional trials ended with a choice phase. Experiments 1 and 2 assessed the role of the R- and F-cues in providing an opportunity for reinforced choice responses. In Experiment 1, the F-cue signaled a sample-independent discrimination instead of presentation of comparison stimuli relevant to the sample, and an R-cue signaled a conventional DMTS choice phase. Thus, choice phases occurred on both types of trials. Experiment 2 assessed the role of choice responses by presenting food independently of a choice phase following F-cued delays, thereby eliminating the opportunity for choice responding; a conventional DMTS choice phase occurred after R-cued delays. Experiments 3 and 4 assessed the role of stimulus control of behavior by the R- and F-cues. The purpose of Experiment 3 was to determine if probe matching is worse when R- and F-cues control different delay behavior rather than the same behavior. To assess separately the roles of behavior during and at the end of delays, Experiment 4 varied the behavior controlled by R- and F-cues *during* the delays but held constant the behavior required at the *end* of all delays.

EXPERIMENT 1

In previous research on directed forgetting in pigeons the F-cue signaled the loss of an opportunity for reinforcement, whereas the R-cue signaled an opportunity for reinforced choice responding. Experiment 1 eliminated

this differential opportunity for reinforcement by correlating both R- and F-cues with an opportunity for reinforced choice responding. This was accomplished in an A-B-A design. In Condition A both the R-cue and the F-cue signaled an opportunity for reinforcement. Each trial began with a red or green sample stimulus on the center key for a minimum of 12 sec. A peck after the 12 sec terminated the sample, and an R- or F-cue appeared immediately and lasted 1 sec. In Condition A, the R-cue signaled a conventional delayed matching-to-sample choice phase: red and green stimuli on the side keys. The F-cue signaled a sample-independent choice phase: horizontal line (S−) and vertical line (S+) on the side keys. In Condition B, the R-cue, as before, signaled a DMTS choice phase while the F-cue signaled cancellation of the trial. Thus, in Condition A, the R-cues and F-cues signaled different kinds of choice trials, but similar opportunity for reinforcement of correct choice behavior. In Condition B, on the other hand, the two cues signaled differential opportunity for reinforcement of choice behavior. If abortion of the trial after an F-cue is important to the loss of delayed matching accuracy after an F-cue, presentation of choice stimuli after F-cues may eliminate this effect.

METHOD

Subjects

Four naive adult White Carneaux pigeons were maintained at 80% ±20g of their free-feeding weights and were individually housed in a temperature-controlled, constantly illuminated colony room. Water and grit were always available.

Apparatus

A three-key Lehigh Valley Electronics pigeon chamber was used. The 2.54-cm diameter plastic keys required a force of 15g (.15 N) for activation. The three keys were positioned 5.5 cm apart, 9 cm from the top of the chamber, 8 cm from the sides and 25.5 cm from the floor. The houselight (28V dc, GE757) was above the center key, 2.5 cm from the top of the chamber. The grain magazine was 5 by 5 cm, 11.5 cm from the floor and positioned under the center key. The keys were illuminated by a display projector (IEE Series 10, 28V dc, GE-757). The walls of the chamber were white

matte with an unpainted aluminum stimulus panel. Masking noise was provided by a small ventilation fan. Electromechanical programming equipment controlled by a paper-tape reader was in an adjoining room.

Procedure

In all conditions, reinforcement was 2.5-sec access to mixed grain. The maximum number of reinforcers attainable depended upon the stage of the experiment. After pretraining, the actual number of reinforcers delivered depended upon the birds' performance.

Pretraining. All birds were first magazine trained on a variable-time (VT) 45-sec schedule following Catania and Reynolds' (1968) constant-probability formula. When birds were approaching the magazine and eating reliably, autoshaping trials began. Autoshaping trials were programmed by the same VT 45-sec schedule. Each trial consisted of 6 sec of red or green illumination of the center key. Red and green were presented randomly, except that one color could not appear more than three times successively and each occurred an equal number of times a session. Autoshaping continued in approximately one-hour daily sessions until a minimum of 100 pecks to the center key occurred in a single session. One to three autoshaping sessions were required.

Acquisition of delayed matching-to-sample. The basic procedure was two-choice delayed matching-to-sample with red and green keylights as sample and comparison stimuli. Following a 30-sec intertrial interval (ITI), the red or green sample stimulus transilluminated the center key for a minimum of 12 sec. A key peck after 12 sec terminated the sample stimulus and initiated a 1-sec supraordinate stimulus. A white 5-mm diameter circle on the center response key (R-cue) signaled the red and green comparison stimuli at the end of the delay (a matching trial). A white 3-mm equilateral triangle (F-cue) signaled horizontal (S−) and vertical (S+) line stimuli at the end of the delay (sample-independent discrimination). Following termination of a delay with an R-cue, the side keys were illuminated red and green, and a single peck to the comparison color that matched the sample resulted in reinforcement. A peck to the nonmatching color initiated the ITI. Following termination of an F-cued delay, one side key was illuminated by a white horizontal bar and the other side key by a

white vertical bar, each 2 mm by 2.54 cm on a black surround. A peck to the vertical bar resulted in reinforcement and a peck to the horizontal bar initiated the ITI. The delay was thus 1 sec and wholly filled by an R- or F-cue.

Red and green samples were semirandomly presented such that the same color did not appear more than three times in succession and each occurred equally often per session. R-cues and F-cues were equally likely after red and green samples, did not appear more than three times in succession, and occurred equally often per session. Comparison stimuli and the line stimuli were counterbalanced such that each color and line occurred equally on each side key.

Birds were exposed to the full set of contingencies from the first session of DMTS. There were 36 R-cued and 36 F-cued trials per one-hour session. Delay intervals began at 1 sec, the same duration as the F− and R-cues, but were incremented by 1 sec upon the completion of two sessions with 80% or more correct matching responses. All birds thus advanced to and remained at 4-sec delays.

Baseline and testing. Two conditions were arranged in an A-B-A format. In the A condition, the F-cues signaled presentation of the horizontal and vertical stimuli, as during acquisition. In the B condition, the F-cue signaled ending of that trial without side-key stimuli and without an opportunity for reinforcement of choice responding. The ITI began 3 sec after F-cue offset and was undifferentiated from the 3-sec delay. Probe testing did not begin in a condition until there had been at least 20 training sessions, with the last 5 consecutive sessions at or above 80% correct matches, that is, at least 29 correct matches on the 36 R-cued trials.

Five test sessions followed each training condition. A test session contained 4 F-cued probe trials in which the red and green comparison stimuli were presented at the end of the delay instead of horizontal and vertical bars (Condition A) or instead of the ITI (Condition B). The sample stimulus was red on two probe trials and green on the other two. A response to the matching comparison produced reinforcement, and an incorrect response ended the probe trial. Training sessions alternated with test sessions as long as 80% or more correct matches were maintained in training sessions; if not, additional training sessions were

given until the 80% criterion was obtained before another test session was given.

RESULTS

Figure 1 shows the percentage of correct matches in test sessions for each of the four pigeons as a function of Conditions A and B. In the first A condition (left panels) all birds maintained high matching accuracy on both R-cued trials and F-cued probe trials. Mean correct matches across birds and sessions were 87.9% on R-cued trials and 89.0% on F-cued probes. As a result of the opportunity for non-differential reinforcement on choice responding associated with F- and R-cues, the cues did not acquire differential control over matching. The middle panels of Figure 1 show that the B condition effectively reduced matching on F-cued probe trials. Mean accuracy on R-cued trials was 92.4% and the F-cued probe mean was 53.3%, near chance. When F- and R-cues were correlated with differential opportunity for reinforcement of choice responding, they

gained stimulus control over matching. Data for the replicated A condition appear in the right panels of Figure 1. The overall means across birds and sessions were slightly better than the means of the first A condition, 93.7% on R-cued trials and 97.5% on F-cued probes. Nondifferential opportunity for reinforcement of choice responding resulted in loss of stimulus control over matching by the F- and R-cues. In summary, overall mean matching accuracy on probe trials over the A-B-A conditions was 89.0%, 53.3%, and 97.5% respectively.

Figure 2 shows response rates on the center key during delays in each condition. When the F-cue signaled an opportunity for reinforcement for sample-independent choice responding (Condition A), center key rates during the delays were similar on R- and F-cued trials, 54.3 and 48.6 means responses per min, repectively, averaged across birds and test sessions, in the first A condition; and 42.0/min and 59.2/min in the second A condition.
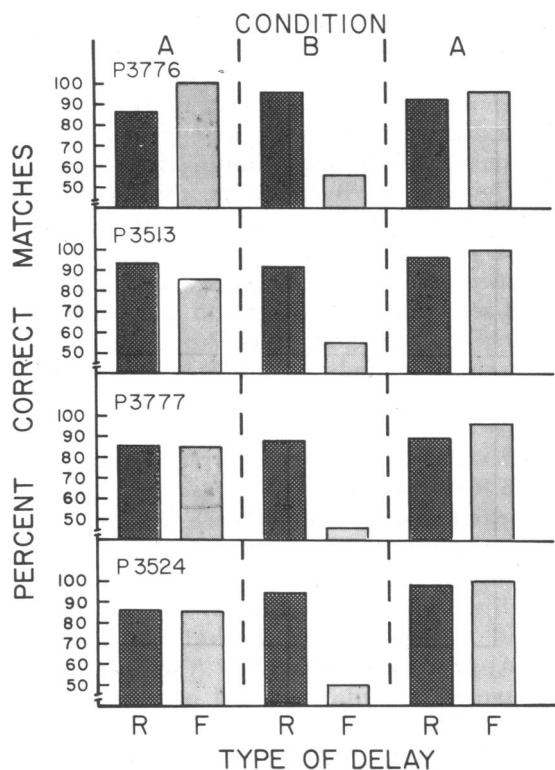

Fig. 1. Percentage of correct choice responses on R-cued (R) trials and F-cued probe trials (F) when the F-cue was followed by sample-independent discriminative stimuli (Condition A) and when the stimuli were omitted (Condition B). (Experiment 1)
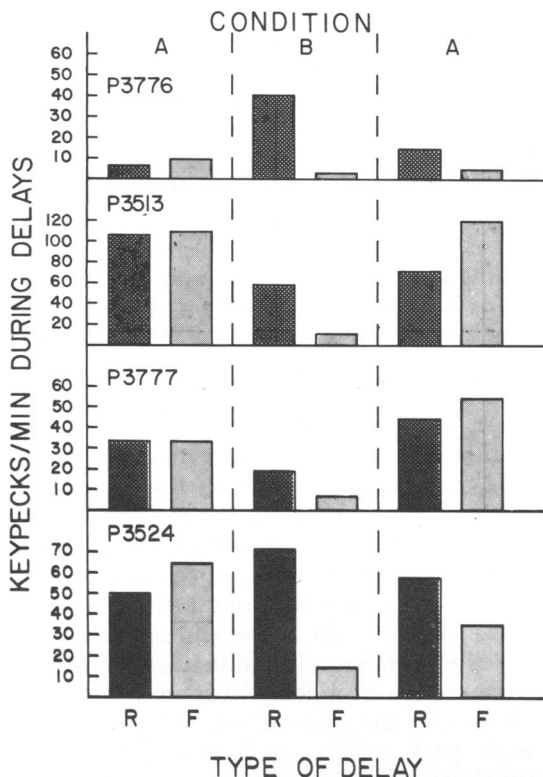
Fig. 2. Responses on the center key during the R-cued delays (R) and the F-cued delays (F) when the F-cue was followed by sample-independent discriminative stimuli (Condition A) and when the stimuli were omitted (Condition B). (Experiment 1)

When the F-cue signaled cancellation of a trial (Condition B), response rates during delays differed on R- and F-cued trials, 47.1/min and 9.2/min, respectively. Thus, pecking the center key during delays was maintained when the last phase of the trial provided an opportunity for reinforced choice responding, and was extinguished when the opportunity for reinforcement was cancelled. Moreover, when pecking rates during R- and F-cued delays were similar, probe matching was good, and when pecking was dissimilar during R- and F-cued delays, probe matching was poor.

It should also be noted that matching on R-cued trials was disrupted in all birds when they were changed from Condition A to Condition B. The mean accuracy on R-cued trials for the last five training sessions of Condition A was 87% and for the first five training sessions of Condition B, 68%. The later switch from Condition B to the replicated Condition A produced no disruption. Accuracy on R-cued trials for the last five training sessions of Condition B was 91% and for the first five training sessions of the replicated Condition A, 92%.

EXPERIMENT 2

Experiment 1 demonstrated that when the F-cue signals an aborted trial, probe matching is poor; that is, the F-cue controls loss of matching accuracy. When the F-cue signals a sample-independent opportunity for reinforced choice responding, probe matching is good; R- and F-cues do not control differential matching. However, the F-cued trials of Condition A and Condition B differed in two ways. First, Condition A provided an opportunity for a reinforcer following an F-cue, and Condition B did not. Second, Condition A provided stimuli at the end of the F-cued delay that required a response similar to the response required after R-cues, and Condition B did not. Thus, nondifferential R- and F-cued opportunities for reinforcers were confounded with nondifferential R- and F-cued choice responding. (However, R-cued choices were sample-dependent and F-cued choices were sample-independent.)

The purpose of Experiment 2 was to unconfound these variables by separating the opportunity for reinforcers from choice responding. On F-cued trials, food was delivered 3 sec after F-cue offset, independently of behavior and without stimuli for choice responding. Because the birds' delayed matching was highly accurate on R-cued trials, the probability of food delivery was high on both R-cued and F-cued trials. The R- and F-cues, therefore, signaled nondifferential probabilities of food delivery but differential opportunities for choice responding.

METHOD

Subjects

The four White Carneaux pigeons of Experiment 1 served. Two White Carneaux pigeons with previous DMTS training were also added. Acquisition of DMTS, for these two birds, was as described in Experiment 1.

Apparatus

The apparatus of Experiment 1 was used.

Procedure

The basic procedure described in Experiment 1 was employed with the following modifications. F-cued trials did not end with horizontal and vertical choice stimuli and response-dependent reinforcement as in Experiment 1, but now ended without stimuli and with response-independent presentations of mixed grain. The F-cue continued to be the triangle keylight stimulus. Denny's (1967) elicitation theory suggests that under this condition the pigeons may approach the magazine following the F-cue rather than remaining at the response keys, as they typically did in Experiment 1 (Condition A). Magazine approaches might then be adventitiously reinforced and effectively compete with the choice response required on probe trials. Therefore, magazine approach was defined as interruptions of a photobeam within the magazine enclosure and was recorded during R-cued and F-cued delays. Delays continued to be 3 sec from R- and F-cue offset. A minimum of 20 baseline sessions with the last five at or above 80% correct matching were required prior to testing.

RESULTS

Figure 3 shows mean matching accuracies averaged across test sessions for each bird. On R-cued trials and F-cued probe trials, five of the six pigeons matched accurately, with 91.7% mean correct responses, across the five

birds and the five test sessions, on R-cued trials and 94.0% correct on F-cued trials. Bird 3777 exhibited poor matching, 60.0% on F-cued probe trials vs. 86.0% on baseline R-cued trials. Examination of delay behavior indicated that Bird 3777 was the only pigeon to approach and insert its head into the magazine enclosure during F-cued delays. This is labeled (MAG) in Figure 3. Mean magazine approaches over the five test sessions were 13 during F-cued delays vs. zero during R-cued delays. The other birds approached the magazine when the hopper was operated at the end of the delays, but never during delays. Informal observation indicated that these birds remained oriented at the response keys during R- and F-cue delays. This is labeled (KEY) in Figure 3.

Figure 4 shows rates of center key pecking per minute during R- and F-cued delays averaged over the five test sessions. In general, response rates were similar between the two delays. Rates between birds varied considerably, however, from 12.7/min to 68.3/min on F-cued delays and from 14.6/min to 69.6/min on R-cued delays. Bird 3777 responded at similar rates following the R-cues (42.5/min) and the F-cues (39.2/min). Informal observation indicated that Bird 3777 pecked during both R- and F-cues while they were on, and remained

oriented at the response keys with little pecking after R-cue offset, but approached the magazine after F-cue offset. Bird 3777, therefore, exhibited differential delay behavior and matched poorly on probe trials. Bird 5350 exhibited differential delay key pecking after R-cues (17.7/min) and F-cues (49.1/min), but did not approach the magazine during F-cued delays and exhibited good matching on probe trials. This is shown by comparing the upper right panel of Figure 4 to the upper right panel of Figure 3.

EXPERIMENT 3

Experiment 2 demonstrated that when an F-cue is followed by food independently of choice stimuli and responses, probe matching is good; R- and F-cues do not control differential matching. The poor probe matching of Bird 3777 is an exception. In addition to being the only bird exhibiting poor probe matching, Bird 3777 was also the only bird that behaved differently during delays depending upon whether they were R-cued or F-cued. Bird 3777
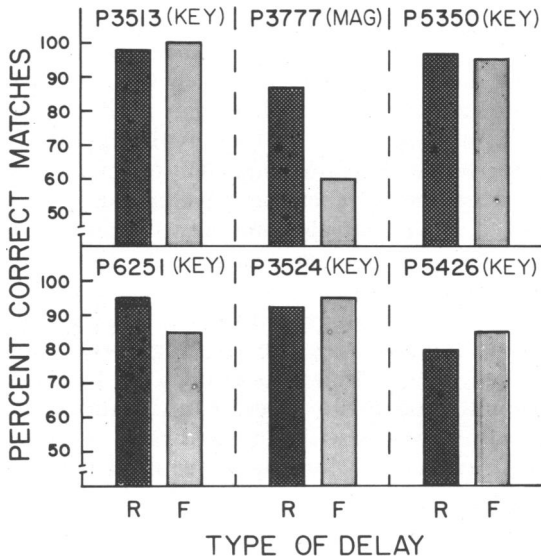

Fig. 3. Percentage of correct choice responses on R-cued trials (R) and F-cued probe trials (F) when the birds oriented to the response keys (KEY) or approached the magazine (MAG) during F-cued delays. The F-cue was followed by response-independent food in baseline. (Experiment 2)
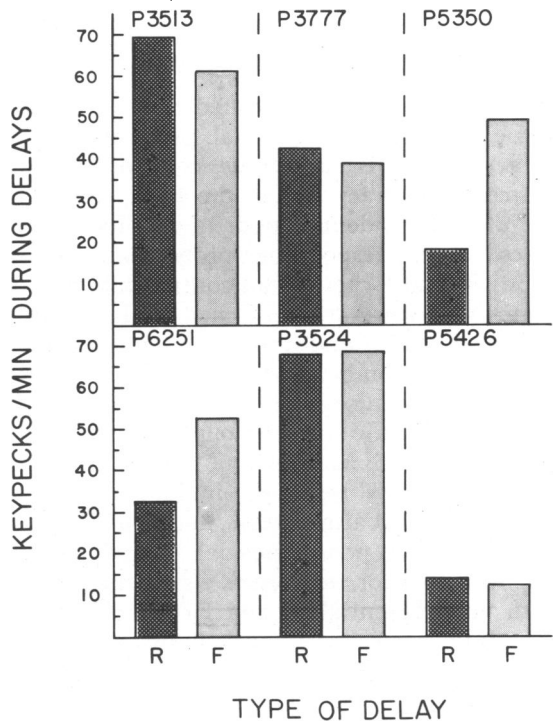

Fig. 4. Responses on the center key during the R-cued delays (R) and the F-cued delays (F) when the F-cue was followed by response-independent food. (Experiment 2)

approached the magazine after F-cues, but not after R-cues. The other birds did not exhibit different R- and F-cue behavior, and probe matching was good. A similar effect was noted in Experiment 1. In Condition B, the rate of pecking the center key was high during R-cued delays and low during F-cued delays and probe matching was poor. In the A conditions of Experiment 1, the rate of pecking the center key was similar after both cues and probe matching was good. Thus, in all conditions where the R- and F-cues generated different delay behavior, matching was poor, and where the cues generated similar behavior, matching was good. These findings suggest that the delay behavior controlled by R- and F-cues may be a critical variable.

The purpose of Experiment 3 was to determine whether differential control of matching by R- and F-cues depends on their control of differential delay behavior. Five pigeons were trained to respond differently following R- and F-cues. These birds remained oriented toward the response keys following R-cues but approached the magazine following F-cues. Since behavior after R- and F-cues differed, poor probe matching was predicted. Bird 3777 was trained to remain oriented toward the response keys following both R- and F-cues. Now that the cues controlled similar behavior on R-cued and F-cued trials for this bird, good probe matching was predicted.

METHOD

Subjects

The six White Carneaux pigeons from the previous experiment served.

Apparatus

The apparatus of Experiment 1 was used.

Procedure

The basic design of Experiment 2 was used. Bird 3777 was handshaped to peck the dark center key during and after F-cues, rather than approaching the magazine enclosure. Delay and stimulus parameters were as in Experiment 2, but advancement to food delivery after an F-cued delay was now controlled by the experimenters, who required successive approximations to a center key peck. The key peck was well-established by the end of the first session, at which time a single peck on the dark center key after the delay ended pro-

duced reinforcement automatically. Birds 3513, 5426, 5350, 6251, and 3524 were shaped to approach the magazine opening following F-cues. Again advancement to food delivery after an F-cue was experimenter-controlled, and magazine approach was handshaped following F-cues. Magazine approach was well-established in the first session; thereafter the birds were required to break the photobeam within the magazine enclosure after the delay had ended to produce reinforcement automatically. R-cued trials were as in previous experiments. Sessions had 72 trials and all parameters were as described in Experiment 2. Following a minimum of 20 training sessions, with the last five at or better than 80% correct matches, testing began. The test procedure was as described in Experiment 2; comparison stimuli were presented 3 sec after F-cue offset on 4 of the F-cued trials (probe trials). Five such test sessions were conducted on days alternating with baseline sessions.

RESULTS

Figure 5 shows the matching accuracies of each pigeon following R-cued baseline trials and F-cued probe trials. Bird 3524 failed to maintain criterion baseline prior to testing and was discarded. In the MAG condition matching was near chance for three of the four pigeons (see Figure 5) and was reduced, relative to R-cued trials, for the fourth pigeon (5350). Mean number of magazine approaches per session over the five test sessions was: Bird 3513, R-cued = 1, F-cued = 24; Bird 5350, R-cued = 0, F-cued = 28; Bird 5426, R-cued = 2, F-cued = 95; Bird 6251, R-cued = 0, F-cued = 75. Bird 3777 remained oriented toward the response keys (magazine approaches on R- and F-cued trials = 0), and probe matching was accurate relative to Bird 3777's performance in Experiment 2 and to baseline trials. However, Bird 5350 and Bird 3777 performed similarly on F-cued probe trials, 75% and 80%, respectively.

Evidence that delay behavior is a critical variable in differential control of delayed matching by R- and F-cues can readily be seen by comparing the results of this experiment with those of Experiment 2. In the KEY condition the mean F-cued probe matching across birds was 90% vs. 55% in the MAG condition. When birds approached the magazine during F-cued delays but not R-cued delays, probe
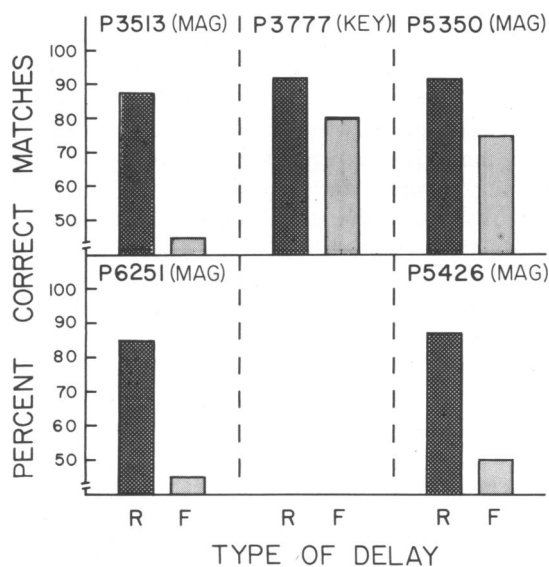
Fig. 5. Percentage of correct choice responses on R-cued trials (R) and F-cued probe trials (F) when the birds were required to remain oriented toward the response keys during both types of delay (KEY) or to approach the magazine opening during F-cued delays but not R-cued delays (MAG). (Experiment 3)

matching was poor; when the birds remained oriented toward the response keys during both R- and F-cued delays, probe matching was good. This implicates differential R- and F-cued delay behavior as a critical variable responsible for differential cue control of delayed matching.

EXPERIMENT 4

The results of Experiments 1, 2, and 3 demonstrate that when R- and F-cues control different delay behavior, probe matching is poor; and when the cues control similar delay behavior, probe matching is good. Zentall et al. (1978) have suggested that sample-specific mediating behavior (Blough, 1959; Carter & Werner, 1978; Cumming & Berryman, 1965) may serve to bridge the delay between the sample stimulus and the comparison stimuli just as rehearsal in humans bridges the retention interval. This account explains the data of Experiments 1, 2, and 3 by assuming that the R-cue controls sample-specific mediating behavior and the F-cue prevents it, or terminates it in some conditions, as evidenced by different R- and F-cue delay behavior. In other conditions the F-cue does not prevent mediating be-

havior and this may be evidenced by similar R- and F-cue delay behavior.

This mediating-behavior position may be examined by separating the control of behavior by R- and F-cues *during* the delays from their control of behavior at the *end* of the delays. If the R- and F-cues control different delay behavior but similar end-of-delay behavior, the mediating-behavior position predicts poor probe matching because the F-cue prevents or terminates delay behavior similar to that after R-cues, which is assumed to be sample-specific. Experiments 1 to 3 did not differentiate between R- and F-cue control of behavior during delays from control of behavior at the end of the delays.

Experiment 4 separated R- and F-cue control of delay behavior from control of end-of-delay behavior. The R-cue controlled one kind of behavior during the delay and the F-cue another. Both cues controlled similar end-of-delay behavior. Specifically, the contingencies required that, on F-cued trials, birds interrupt the photobeam inside the magazine enclosure to produce sample-independent choice stimuli at the end of the delay. Magazine approach was not required during R-cued delays; the comparison stimuli were presented on the side keys automatically at the end of R-cued delays. Thus, the contingencies generated different behavior during the delays (orientation towards the keys on R-cued trials and magazine approach on F-cued trials), but similar behavior (choice behavior) at the end of all delays. Poor probe matching would implicate behavior during delays as the critical variable in differential control of delayed matching by R- and F-cues, whereas good probe matching would implicate the behavior at the end of the delays.

METHOD

Subjects

The five White Carneaux pigeons of Experiment 3, Birds 3777, 3513, 6251, 5426, and 5350, served.

Apparatus

The apparatus of Experiment 1 was used.

Procedure

The basic procedure of the previous experiments was used. Bird 3777 was hand-shaped to approach the magazine opening following F-

cues. The other birds were approaching the magazine following the F-cues as a result of the contingencies of Experiment 3 and were so continued. After a minimum of 3 sec from off-set of the F-cue, the first beam break (magazine approach) produced the sample-independent side-key stimuli (S+: horizontal line; S−: vertical line) for a choice response. R-cued trials were as in previous experiments. Sessions had 72 trials and all other parameters were as in previous experiments. Testing began after a minimum of 20 training sessions with the last five at or better than 80% correct matches. The test procedure was as described in Experiment 1; comparison stimuli were presented 3 sec after F-cue offset on four of the F-cued trials (probe trials) in place of the sample-independent discriminative stimuli. Five such test sessions were conducted on days alternating with baseline sessions. Choice responses and beam breaks were recorded.

RESULTS

Figure 6 shows the matching accuracies of each pigeon following R-cued baseline trials and F-cued probe trials. One bird, 5426, failed to maintain 80% or better correct matches during training and was eliminated. Birds 3777 and 3513 had better than 85% correct
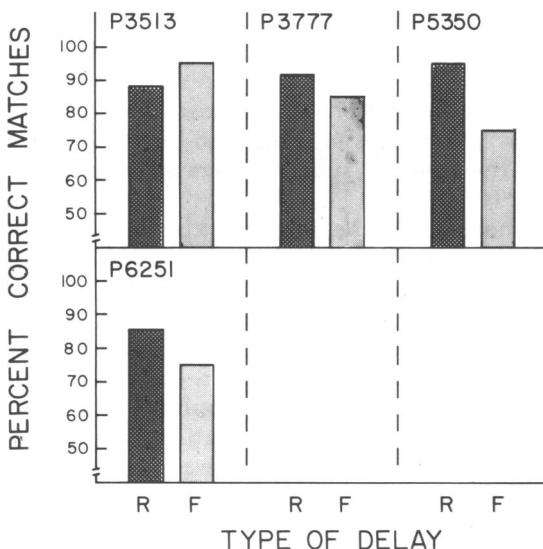

Fig. 6. Percentage of correct choice responses on R-cued trials (R) and F-cued probe trials (F) when the birds returned to the response keys for a sample-independent choice response after approaching the magazine following an F-cued delay. (Experiment 4)

matches. Two birds, 5350 and 6251, had 75% correct matches. These values are means based on all 5 test sessions including the 20 probe trials. The mean number of delay-interval magazine approaches per session over the five test sessions, were: Bird 3777, R-cued = 0, F-cued = 20; Bird 3513, R-cued = 0, F-cued = 43; Bird 5350, R-cued = 0, F-cued = 16; Bird 6251, R-cued = 0, F-cued = 25. Thus, all birds approached the magazine after F-cues but not after R-cues. The importance of end-of-delay behavior relative to behavior during the delay can best be seen by comparing these results with those of the MAG condition of Experiments 2 and 3. When birds approached the magazine opening during and at the end of the F-cued delays, mean matching across birds was poor, 55%. When the birds approached the magazine opening during F-cued delays but the response keys at the end of the delays, mean probe matching across birds was good, 83%. In summary, these data show relatively high matching accuracies when R- and F-cues controlled different delay behavior but similar end-of-delay behavior. This indicates that behavior at the end of the delay is the primary variable responsible for differential control of delayed matching by R- and F-cues.

DISCUSSION

The present experiments demonstrate that R- and F-cues control differential delayed matching when they control differential behavior at the end of the delay. In Condition A of Experiment 1, where R- and F-cues controlled similar end-of-delay behavior, probe matching was good. In Condition B, where the cues controlled different behavior, probe matching was poor. In Experiment 2 food delivery was automatic after F-cues, and those birds that behaved similarly after R- and F-cues matched accurately on probe trials. The one bird that behaved differently after the cues matched poorly. Experiments 3 and 4 confirmed that when R- and F-cues control different end-of-delay behavior probe matching is poor. The results from all four experiments and the results of previous researchers (e.g., Maki & Hegvik, 1980) are consistent with the conclusion that the F-cue reduces accuracy of delayed matching when it gains control of end-of-delay behavior that differs from the end-of-delay behavior controlled by the R-cue.

The data on memory in animals have been given two different theoretical interpretations: rehearsal and retrieval. The rehearsal interpretation of directed forgetting in pigeons is that the F-cue terminates rehearsal of a sample representation in short-term memory, as suggested by Maki and Hegvik (1980), or that it terminates sample-specific mediating behavior (cf. Zentall et al., 1978). As we use it, rehearsal refers to either of these possibilities. The rehearsal view assumes that birds learn to rehearse following an R-cue, and not to rehearse following an F-cue (at least in most conditions). It is further assumed that when matching is good on probe trials the mediating behavior, or rehearsal, controlled by the R-cue is also occurring following an F-cue.

In Condition A of Experiment 1, good probe matching resulted when the F-cue signaled sample-independent choice stimuli. Both the R- and F-cues were correlated with similar probabilities of reinforcement, which may have served to adventitiously reinforce rehearsal after F-cues. In Condition B no reinforcement was available following the F-cue and rehearsal may have been extinguished. In Experiments 2 and 3, probe matching was good when the behavior after the F-cues was similar in the behavior after R-cues. If the R-cue maintains rehearsal, then similar behavior after F-cues suggests maintained rehearsal also. When F-cue behavior differs from R-cue behavior, it is likely that the F-cue prevented or terminated rehearsal. Thus, rehearsal may account for the results of Experiments 1, 2, and 3. However, Experiment 4 found good probe matching when behavior during R- and F-cued delays differed. Therefore, the rehearsal interpretation fails to account for the data of Experiment 4.

The second theoretical interpretation is retrieval. D'Amato and Worsham (1974) studied delayed matching in monkeys and suggested that the comparison stimuli might retrieve a representation of the sample stimulus. Other researchers have found that context is an important variable affecting retrieval, or reactivation, of memories in animals (e.g., Gordon, in press; Feldman & Gordon, 1979; Spear, 1978; Tomie, Murphy, Fath, & Jackson, 1980). Context is defined as all stimuli to which the animal attends, except for the discriminative stimuli. In a review of animal memory, Spear

(1981, p. 13) summarizes the context-retrieval view:

"My view is that there are at least two sources of decrement in responding when contextual stimuli are changed between training and testing but perception of the CS or S^D is held constant. (1) Due to the absence of certain stimuli or because of the equivalent of generalization decrement for the contextual stimuli themselves, there is inadequate contextual support for retrieval of the memory that represents the training episode; and (2) Regardless of the support for retrieval of the target memory, the new stimuli introduced upon a change in context may serve to elicit competing memories that interfere with retention of the target."

The context in the present experiments may have been response-produced stimuli from the end-of-delay behavior controlled by the R-cue. Rilling (1967) demonstrated that pigeons discriminate their own behavior. Moreover, Shimp (1976) has shown that pigeons can remember a sequence of three responses and that the memory of their behavior fades beyond three. Grayson and Wasserman (1979) demonstrated that pigeons can discriminate among two-response sequences and suggest that the correct sequence is in short-term memory just before and during reinforcement, thus supporting an association between correct sequences and reinforcement. They conclude by stating that although ". . . research in the area of short-term memory has historically stressed the retention of externally-presented stimuli, there is no reason to suppose that similar memory processes may not also be involved in the retention of subject-generated responses" (p. 29).

The data of the present experiments may also best be explained in terms of short-term memory of behavior just prior to reinforcement (end-of-delay behavior). However, in our account the response-produced stimuli serve a contextual role, rather than a discriminative role. That is, comparison stimuli may have retrieved the sample representation only when they were presented in the presence of the behavior controlled by the R-cue. When the end-of-delay behavior controlled by the F-cue was similar to the end-of-delay behavior controlled by the R-cue, the "behavioral context" was appropriate to support retrieval and probe matching was good. Likewise, whenever the

end-of-delay behavior controlled by the F-cue differed from the behavior controlled by the R-cue, the "behavioral context" was inappropriate, the comparison stimuli failed to effect retrieval, and probe matching was poor. The findings of the present experiments, as well as previous directed-forgetting studies, thus support a view of animal short-term memory based on context-dependent retrieval in which behavior-produced stimuli serve a contextual role.

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