Time dependent effects of double cuing in directed forgetting

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Previous research in directed forgetting in pigeons has focused on the effect of single forget cues (F-cues) interpolated within the retention interval in delayed matching-to-sample (DMTS). The present series of experiments focuses on the ability of a remember cue (R-cue) to cancel the effects of a previously presented forget cue both when the forget cue occurs within the retention interval and when the forget cue precedes sample presentation. In the first experiment, an R-cue decreased the effect of an F-cue within the same retention interval in successive DMTS if the R-cue immediately followed the F-cue, but not if the second cue was delayed until the end of the retention interval. In Experiment 2, the double-cue effect was extended to choice DMTS. In addition, when a novel stimulus replaced the R-cue in the double-cue probe trials, matching performance was not restored, indicating that through its conditioning history the R-cue had gained control over memory processes in a direction opposite to that of the F-cue. Experiment 3 presents evidence that presample R- and F-cues can also effectively gain control over matching performance. Matching to R-cued samples was superior to matching to F-cued samples. When F-cued samples were followed immediately by R-cues, matching performance was not restored to R-cue levels, suggesting differential encoding of the R-cued and F-cued samples.

Recently, several investigators have studied processes in animal short-term memory, using techniques analogous to the directed forgetting procedure common in human information processing research (Grant, 1981; Kendrick, Rilling, & Stonebraker, 1981; Maki & Hegvik, 1980; Maki, Olson, & Rego, 1981). These studies typically utilize delayed matching-to-sample procedures with instructional stimuli interpolated in the retention interval between sample and test or comparison stimuli. A common finding is that when given instructional stimuli predicting the occurrence (remember cue, or R-cue) or non-occurrence (forget cue, or F-cue) of future comparison stimuli, performance on trials in which comparison stimuli are presented following the presentation of F-cues is greatly reduced relative to performance on R-cued trials. Explanations for the ability of F-cues to gain stimulus control over forgetting have centered around the question of whether the cues interfere with rehearsal or retrieval. Maki and Hegvik (1980), Maki et al. (1981), and Stonebraker and Rilling (1981) argued for the termination of an ongoing rehearsal process during the retention interval by the F-cues. Rilling et al. (in press) and Kendrick et al. (1981), however, favor an interpretation based on the F-cue controlling pro-

cesses that maintain a retrieval facilitating context at the end of the retention interval.

While previous investigators have concentrated on examining the function of F-cues in the directed forgetting paradigm, less attention has been paid to the function of the R-cues. In most of the work performed to date, it has been unclear whether or not R-cues gain any stimulus control whatsoever. Grant (1981) and Maki et al. (1981) reported manipulations in which there was little or no difference between overall matching performance on R-cued trials and on trials in which no cues were presented. Performance on both of these conditions, however, was superior to performance following an F-cue, when that cue normally predicted the cancellation of the comparison stimulus.

Grant (1981) provided the first evidence that R-cues actually do gain stimulus control. In order to determine whether or not the R-cue might, to some extent, mitigate the effectiveness of a previously presented F-cue, Grant utilized a double cuing strategy in which the presentation of an F-cue was followed by the presentation of an R-cue on infrequent "probe" trials. According to Grant, if an R-cue can partially cancel the effectiveness of an F-cue, accuracy should be better on forget-remember (F-R) probe trials than on probe trials in which F-cues alone were presented. Using F-cues that were presented immediately after sample termination and R-cues that were presented immediately after F-cue termination, Grant found that the F-cue was nearly

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totally effective in eliminating the effect of an initial F-cue. Grant gave two possible accounts for these results. One possibility was that when an F-cue is presented it takes some period of time for the level of processing to decrease. If this is the case, an R-cue after an F-cue may have halted the decrease in the level of processing. A second possibility presented by Grant was that the level of processing was reduced by the F-cue and then restored to precue levels by the subsequent presentation of the R-cue.

Regardless of which of the two above accounts is correct, Grant assumed that the F-cue served to terminate or reduce an active process within the retention interval, a position similar to that of Maki and Hegvik (1980) and Stonebraker and Rilling (1981). If this account is correct, then the temporal relationship between the F- and R-cues is a crucial variable. Although Grant has demonstrated that an R-cue that immediately follows an F-cue can eliminate the effect of the F-cue, an R-cue that is delayed after the termination of the F-cue should be less effective in doing so. If an F-cue terminates a rehearsal process, forgetting should begin to occur following an F-cue. The longer the delay is until the subsequent R-cue, the higher the probability that the sample has been forgotten, eliminating the chance for a restoration of sample rehearsal. In other words, at some point in time an R-cue should no longer be able to mitigate the effectiveness of a previously presented F-cue, and matching performance on F-R probe trials should be similar to performance on F-cued trials rather than R-cued trials.

The context-dependent retrieval position espoused by Kendrick et al. and Rilling et al. would make predictions contrary to the predictions made by a rehearsal termination position. According to the retrieval position, what is important is not so much what goes on during the retention interval as what is going on at the end of the interval when the comparison stimulus is presented. As long as the proper context is maintained, retrieval of the sample stimulus memory will occur. This position would make a prediction about Grant's procedure consistent with his results; that is, following an initial F-cue immediately with an R-cue should result in remembering due to the reestablishment of the proper retrieval facilitating context. However, this position would also predict remembering when the F- and R-cues are separated in time, as long as the R-cue can reestablish the appropriate context. The retention interval behavior during the middle portion of the retention interval is irrelevant. These alternative accounts were evaluated in Experiment 1; conditions in which F-R probes were presented with delays between the cues were compared with conditions in which no delays occurred between the cues. Experiment 2 extended the double-cue procedure from successive to choice delayed matching-to-sample and

also controlled for the possibility that the effects of an R-cue on a previously presented F-cue are due to something other than the conditioning history of the R-cue.

To date, all of the directed forgetting work in pigeons has utilized post-sample R- and F-cues interpolated within the delay interval. These cues may control matching accuracy by influencing processes that occur during the retention interval or during the comparison stimulus, but they cannot influence processes during sample presentation due to their postsample occurrence. During a sample, a bird has no indication of whether an F-cue or an R-cue will be presented and, subsequently, whether or not comparison stimuli will be presented. Many investigators (e.g., Farthing, Wagner, Gilmour, & Waxman, 1977; Rilling et al., in press; Roberts & Grant, 1978) have defined the processing that occurs during the sample as encoding, while the processing during the retention interval and comparison stimuli have been termed storage (rehearsal) and retrieval, respectively.

An additional question of interest is whether or not presample R- and F-cues function similarly to postsample cues. If presample cues can gain control over matching accuracy, it will be important to determine how this control is achieved. It is possible that presample cues would control rehearsal or retrieval, as is the case in postsample cuing. On the other hand, it may be possible that an organism encodes R-cued and F-cued sample stimuli differentially when it is informed prior to or during the sample presentation that memory for the sample will not be required (F-cued trials). Maki (1979) and Maki, Gillund, Hauge, and Siders (1977) reported conditions in which either the sample itself or the presample events signaled how the trial would end (in the presence or absence of comparison stimuli). The common result in these studies was decreased matching accuracy on those trials in which comparison omission was signaled. However, given their procedure, it is impossible to determine whether these results are due to variations in encoding, variations in rehearsal, or both (it was precisely this concern which led to the development of postsample cuing). Unlike postsample cuing, variations in encoding are possible with presample cuing. It may not be economical to actively process a stimulus when the memory for that stimulus will not be required, and the degree of processing of the sample stimulus may then depend on the type of presample cue. Experiment 3 examined the effects of presample R- and F-cues and the susceptibility of the effects of presample F-cues to cancellation by postsample R-cues.

EXPERIMENT 1

This experiment examined matching performance when an F-cue and an R-cue were presented within

the same retention interval. Three conditions were used during infrequent probe trials. In one instance (Condition A), F-cues presented at the beginning of the retention interval were followed by R-cues with no delay between the cues. This procedure is similar to one used by Grant (1981). In a second condition (B), the F-cue was presented at the very beginning of the retention interval and an R-cue was presented at the very end, with a 3.0-sec delay separating the cues. F-cues alone were also given (the standard directed forgetting procedure used in past experiments; e.g., Maki & Hegvik, 1980; Stonebraker & Rilling, 1981).

Method

Subjects. Three adult White Carneaux pigeons were used. Two birds (P1025 and P2378) were experimentally naive at the beginning of the experiment, while the third bird (P924) had had previous training on the procedure described below. The birds were maintained at $80\% \pm 15$ g of their free-feeding weights. The birds were individually housed 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. The interior dimensions were $35 \times 35 \times 30$ cm. Only the center 2.5-cm circular response key, which required a force of .15 N for activation, was used. The response key could be transilluminated with red (606 nm) or green (555 nm), or could display a vertical or horizontal $.3 \times 2.5$ cm white line on a black ground. The stimuli were produced by an Industrial Electronics Engineers projector (Model 10-3723-757-L). The key was located above the 5×6 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 photoelectric relay initiated the reinforcement timer. An exhaust fan, located on the wall opposite to the response panel, partially masked extraneous noises. Experimental events were controlled by standard electromechanical programming equipment located in an adjacent room, with a paper-tape reader controlling the sequence of events.

Procedure. Birds P1025 and P2378 were magazine trained and autoshaped according to the procedure described in Stonebraker and Rilling (1981). Following autoshaping, the 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) in order to obtain maximum matching performance. During DMTS training, a sample stimulus was presented (either red or green) and was terminated with the first keypeck after 12 sec had elapsed. A retention interval followed the sample. Interpolated within the retention interval was either a vertical or a horizontal line stimulus which predicted the occurrence (R-cue) or nonoccurrence (F-cue) of the upcoming comparison stimulus, respectively. The cue was presented immediately after the termination of the sample stimulus and was of a .5-sec duration. The key remained dark for the remainder of the delay interval. On R-cued trials, the delay interval was followed by the presentation of a comparison stimulus (either red or green). The comparison stimulus on matching trials (red-red and green-green) was presented for a minimum of 5 sec. A single peck after 5 sec terminated the keylight and resulted in reinforcement. Throughout Experiment 1, reinforcement consisted of 2.5-sec access to mixed grain. Reinforced responses to the comparison stimulus were excluded from the data analysis. The comparison stimulus on nonmatching trials (red-green and green-red) terminated automatically after 5 sec, and responses were not reinforced. On F-cued trials, the

comparison stimulus was not presented and the retention interval was immediately followed by the intertrial interval. The intertrial interval (ITI) was 30 sec. A 40-msec 1,000-Hz tone of approximately 80 dB was presented at the onset of each comparison stimulus as an additional cue indicating the presence of that stimulus. The importance of the tone was on F-cued probe trials in which the comparison stimulus was presented following an F-cue. Since birds often turned away from the key after an F-cue, it was necessary to signal the presence of the comparison stimulus on those trials. 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 trial type occur no more than two times 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 all matching comparison stimuli by the total number of responses during all 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 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. The retention interval was increased in 1-sec increments each time the criterion was met until the terminal value of 4 sec was reached. Bird P924 had previously been trained on the above procedure and was performing above 80% at 4-sec retention intervals. It was at this point that P924 was added to the experiment.

When the birds reached the 80% criterion for two consecutive sessions, the procedure was changed such that 50% of the R- and F-cues were delayed within the retention interval, while the remaining 50% were presented immediately after the termination of the sample, as depicted in Figure 1. The order of immediate and delayed R- and F-cues was pseudorandomized such that all occurred an equal number of times, all distributed equally among the four trial types, and no cue occurred more than three trials in succession. Two cue-delay conditions were used: In Condition A, the cue was delayed .5 sec from sample termination; in Condition B, the cue was delayed 3.5 sec from sample termination. The cue-delay conditions were constant within a session, but alternated between sessions. In other words, if, in Session 1, 50% of the cues were immediate and 50% were delayed .5 sec, then in Session 2, 50% of the cues were immediate and 50% were delayed 3.5 sec.

Probe sessions began when a bird performed at or above 80% for five consecutive sessions. Probe sessions were given every third session, or less frequently if needed to maintain baseline (R-cued) matching performance above 80%. Probe sessions alternated between Condition A and Condition B until five of each had been presented. Probe sessions that failed to maintain a 75% discrimination ratio on baseline trials were eliminated from the final analysis, and additional probe sessions were given to replace them.

Probe sessions consisted of 64 standard trials (R- and F-cued, immediate and delayed) and 8 randomly located probe trials, two of each of the four trial types (red-red, red-green, green-red, green-green). In one of each of the trial types, an immediate F-cue (horizontal line) was presented during the retention interval. In other words, F-cues were followed by the presentation of the comparison stimuli, contrary to training, according to the procedure used by Stonebraker and Rilling (1981). On the remaining four probe trials, an immediate F-cue was followed by an R-cue in the same temporal location as delayed R-cues for that session. In Condition A, whenever R-cues were delayed .5 sec after termination of the sample, the R-cue immediately

Figure 1. A schematic representation of trial events during baseline and probe trials for Conditions A and B. Note the temporal position of R- and F-cues within the retention interval and the presentation or omission of comparison stimuli for each trial type.

followed the .5-sec F-cue and was, in turn, followed by the comparison stimulus at the end of the retention interval. In Condition B, when R-cues were delayed 3.5 sec after the termination of the sample, the R-cues on probe trials were presented 3.0 sec after the F-cues. On all probe trials, responses terminating comparison stimuli on matching trials were reinforced, while non-matching comparison stimuli terminated automatically after 5 sec and pecks to these stimuli did not result in reinforcement. This contingency is identical to that of R-cued trials. Baseline and probe conditions are schematically represented in Figure 1.

Results

Discrimination ratios were calculated from the responses to comparison stimuli during probe sessions on F-cued probe trials (FX, forget/no cue), double-cued probe trials (FR, forget/remember), and delayed R-cue standard trials (XR, no cue/remember). These three trial types are depicted under "probes" in Figure 1. The results for each bird are presented in Figure 2 for Conditions A and B. For each condition, data are presented for the three types of trials.

Matching performance of 100% indicates perfect matching, whereas performance at 50% indicates chance (equal responding to matching and non-matching comparison stimuli). For all birds, performance on R-cued trials (XR) was consistently better than performance on F-cued trials (FX) in both Condition A and Condition B. In Condition A,

when the second cue in the FR trials immediately followed the first, performance was nearly identical to that in the XR trials. In Condition B, when the second cue was delayed until the end of the retention interval, performance was identical or similar to performance on FX trials.

Averaged across birds, the results for Condition A were 91% matching on XR trials (91% of the responses to comparison stimuli on those trials were to matching stimuli), 73% on FX trials, and 92% on FR trials. When the delayed R-cues were placed at the end of the retention interval in Condition B, performance averaged across birds was 90% on XR trials, 70% on FX trials, and 64% on FR trials.

Informal observation of birds during testing revealed that F-cues terminated key-orienting and key-pecking behavior. In the FR trials, R-cues served to maintain key orienting (Condition A) or restore key orienting (Condition B).

Discussion

The matching performance on R-cued trials was

Figure 2. Discrimination ratios (percentage of comparison stimuli responses made on matching trials) for the three probe-trial types for each of the two conditions. In both conditions, the first .5-sec cue began immediately after the termination of the sample. In Condition A, the second cue began .5 sec after sample termination, while in Condition B the second cue began 3.5 sec after sample termination. In trials XR and FX, only one cue was presented within the retention interval, an R-cue in the second cue location and an F-cue in the first cue location (respectively). In the FR trials, both cues were presented within the interval. 100% indicates perfect matching performance and 50% indicates chance performance.

consistently accurate, regardless of the temporal location of those cues, a finding that is consistent with Stonebraker and Rilling (1981). Also consistent with this previous study is the finding that, in all instances with an F-cue at the beginning of the retention interval, matching performance on probe trials was reduced relative to R-cued trials. Maki and Hegvik (1980) and Stonebraker and Rilling (1981) hypothesized that an active rehearsal process was maintained during the retention interval until the presentation of the cues. When an F-cue was presented, rehearsal was terminated, but when an R-cue was presented, rehearsal continued until the presentation of comparison stimuli. Their data provided strong support for the function of the F-cue, but little direct evidence that an R-cue ever gained any control over behavior. The results presented here when the F-cue was immediately followed by an R-cue provide evidence that R-cues do gain control over behavior and subsequent matching accuracy. These results are consistent with those provided by Grant (in press), that is, the R-cue is almost completely effective in eliminating the effect of an initial F-cue. If an F-cue serves to terminate the rehearsal process, the immediate presentation of an R-cue can apparently reinitiate the process, which is maintained until the presentation of the comparison stimulus.

When the F-cue was presented at the beginning of the retention interval and the subsequent R-cue was withheld until the end of that interval (Condition B), the results were quite different from when there was no delay between the cues (Condition A). In Condition B, the R-cue was unable to restore accurate matching performance following an F-cue. The fact that key orientation was restored by the R-cue at the end of the retention interval indicates that the poor matching performance was not simply due to birds not seeing the R-cue (a functional F-cued trial). A rehearsal position would maintain that the poor matching performance in Condition B on double-cued trials was based on the notion that F-cues terminate rehearsal while R-cues maintain or reestablish rehearsal. When an F-cue is immediately followed by an R-cue, rehearsal is restored before any substantial forgetting can occur. When the presentation of an R-cue after an F-cue is delayed, the R-cue is ineffective in reestablishing rehearsal because the item has been forgotten due to the prior termination of rehearsal.

The results of the present study do not seem to be as easily explained by the context-dependent retrieval position, as stated by Rilling et al. (in press), as they are by a rehearsal position. In the context-dependent retrieval position, the events at the end of the retention interval (establishing the appropriate context for retrieval at the time of the comparison) are

more important than what goes on during the retention interval. Informal observation of the birds during the retention interval in the present study indicated that the R-cue at the end of the retention interval was effective in bringing the birds back to the key prior to the onset of the comparison stimulus. If one assumes that key orientation reestablishes the appropriate context for retrieval, then performance should be accurate in this instance, but it is not. It is possible, however, that there is more to the retrieval-facilitating context than bodily orientation. Kendrick et al. (1981) present an experiment in which, like the present experiment, birds left the keys following F-cues and returned to the keys at the end of the retention interval. The results of their study were in the direction opposite to those in the present study (i.e., bird's "remembered" on probe trials). The demonstration of high matching accuracy when R- and F-cues controlled different retention interval behavior (orienting vs. not orienting towards the key) but similar end-of-retention interval behavior (key orienting) was taken by Kendrick et al. as support for the context-dependent retrieval position. One possible procedural difference between the study of Kendrick et al. and the present study that may account for the discrepant results is the fact that the birds in the Kendrick et al. study were trained to return to the key following an F-cue in baseline, whereas the birds in the present study returned to the key only after an F-cue on infrequent probe trials. The procedure used by Kendrick et al. may have developed an expectancy for returning to the key or for response-dependent stimuli following an F-cue. This expectancy may be a crucial part of the context that is developed in baseline trials. According to the context-dependent retrieval position, then, although the R-cue in Condition B does bring the bird back to the key, the entire context necessary for retrieval, including an expectancy for response-dependent stimuli, is not reestablished, and poor matching performance results.

Whether the R-cue restores rehearsal or reestablishes the context necessary for retrieval, it is apparent from the present experiment that the R-cue does gain control of the retention interval behavior in a direction opposite to that of the F-cue. Whether or not it will effectively cancel the effects of a previously presented F-cue appears to be dependent on the temporal relationship between the two cues.

EXPERIMENT 2

The results of Experiment 1 raise two questions. The first stems from the fact that, in both the present study and in the work reported by Grant (1981), the double-cue procedure has been used in the successive delayed matching-to-sample paradigm. Di-

rected forgetting has also been demonstrated in two-choice DMTS (Kendrick et al., 1981; Maki & Hegvik, 1980; see Maki, in press, for review). In two-choice DMTS, matching and nonmatching comparison stimuli are simultaneously presented on the side keys of a three-key array and the dependent variable of interest is percentage of correct choices rather than the rate of response measure used in successive DMTS. The question arises as to whether the mitigating effects of an R-cue following an F-cue equally apply to the choice procedure. The present experiment presented double cues in a choice procedure.

The second question that stems from the results of Experiment 1 is whether the mitigating effects seen when a second cue immediately follows an F-cue are peculiar to R-cues. Grant (1981) has pointed out that the effects of the R-cue in double-cueing experiments may not be the result of its prior conditioning history in which it predicted upcoming comparison stimuli. Any stimulus presented immediately following an F-cue might possibly attenuate the effectiveness of that F-cue. It is possible that the occurrence of any stimulus after an F-cue would signal the upcoming comparison stimuli, since two cues within the same retention interval occurred only in probe trials that always contained comparison stimuli. Thus, the effects in Experiment 1 may not be due to the R-cue per se. This possibility was tested in Experiment 2 by the presentation of a novel stimulus after an F-cue, a control condition suggested by Grant.

Method

Subjects. Two adult White Carneaux pigeons with previous choice DMTS experience and experience with R- and F-cues were used. All other conditions were identical to those in Experiment 1.

Apparatus. The apparatus was identical to that employed in Experiment 1.

Procedure. The basic procedure was two-choice delayed matching-to-sample, with red and green keylights as sample and comparison stimuli. Following a 30-sec ITI, a red or green sample stimulus transilluminated the center key for a minimum of 12 sec. A keypeck then terminated the sample and initiated a 1-sec R-cue or a 1-sec F-cue. A white 5-mm-diam circle on the center response key (R-cue) signaled the comparison stimuli on that trial, while a white 3-mm equilateral triangle (F-cue) signaled that the comparison stimuli were canceled on that trial. Three seconds after the termination of an R-cue, both side keys were transilluminated red and green and a single keypeck to the color that matched the sample resulted in reinforcement. A peck to the nonmatching color initiated the ITI. On F-cued trials, the ITI began 3 sec after F-cue offset, at the end of the 4-sec retention interval.

Red and green sample stimuli were pseudorandomly presented such that the same color did not appear more than three times in succession and each occurred an equal number of times per session. R- and F-cues were equally likely after red and green samples, the same cue did not appear on more than three consecutive trials, and each cue occurred an equal number of times per session. The comparison stimuli were counterbalanced on side keys and the same configuration did not appear more than three times on consecutive trials. There were 36 R-cued trials and 36 F-cued trials per session.

Fifteen training sessions were conducted prior to testing. A test session contained 12 probe trials in which the comparison stimuli were presented 3 sec after an F-cue, or 2 sec after the second cue in the retention interval in double-cued probe trials. As in R-cued trials, a response to the matching comparison produced reinforcement and an incorrect response ended the trial. The five test sessions alternated with training sessions as long as 80% or better correct choice performance was maintained on training sessions. If less than 80% correct choices occurred in a training session, testing was delayed and training continued until the 80% criterion was reached.

Three types of probe trials were used. Each type occurred four times per session, once for each sample-comparison combination. The first type was the F-cue alone (FX). Comparison stimuli were presented 3 sec after the offset of the F-cue. The second type was the F-cue followed by the R-cue (FR). The 1-sec R-cue was presented immediately after offset of the F-cue and ended 2 sec before the comparison stimuli. The third type was the F-cue followed by a novel stimulus (FN). Immediately after offset of the F-cue, the center response key was transilluminated with white light for 1 sec; the comparison stimuli followed 2 sec later. The experiment ended after the fifth test session.

Results

Average matching performances for each bird are presented in Figure 3. Both birds performed at 95% on R-cued baseline trials within probe sessions (RX). There was a decrement in matching performance on F-cued trials relative to the R-cued baseline performance for both birds. When F-cues that immediately followed sample termination were in turn followed by R-cues (FR), matching performance was restored to baseline levels, an average of 97.5%. Such was not the case when the second cue was a novel stimulus (FN). In this instance, performance averaged 77.5%, above the 67.5% on F-cued trials but well below the 95% average on R-cued trials.

Figure 3. Discrimination ratios for each of the four trial types. In RX and FX trials, R- and F-cues immediately followed the termination of the sample while no cue was presented in the second cue location. In FR and FN trials, an R-cue and a novel stimulus (respectively) immediately followed the termination of the initial F-cue.

Discussion

As has been demonstrated repeatedly (Maki, in press; Rilling et al., in press), matching accuracy was greatly reduced on F-cued trials relative to R-cued trials. This has been demonstrated in successive matching-to-sample, as in Experiment 1, as well as in the two-choice procedure presented here. The finding that an R-cue can cancel the effects of a previously presented F-cue in the choice procedure indicates that the effects found in the successive procedure of Experiment 1 are generalizable across tasks. The double-cue effect is thus not limited to the successive procedure.

Whenever a second cue is presented within a retention interval, comparison stimuli invariably follow. The effects of a second stimulus in canceling the F-cue could be the result of the birds' learning this contingency, rather than being a specific function of the R-cue (Grant, 1981). If this is the case, a novel stimulus should restore matching performance as completely as an R-cue. Such a hypothesis is not supported by the results of the present experiment. In the double-cue conditions, performance was much higher when the F-cue was followed by an R-cue than when it was followed by a novel stimulus. This result would seem to suggest that in standard, single-cued directed forgetting in pigeons, the R-cue gains control over memory processes by predicting upcoming comparison stimuli. This control is in a direction opposite to that of the F-cue.

Although novel stimuli were not as effective in canceling F-cues as R-cues were, performance on forget-novel trials was superior to that on single F-cued trials. One possible explanation is that some learning was taking place on those probe trials. This learning is plausible, since the white keylights were entirely novel stimuli. Although the novel stimuli occurred infrequently, they were distinct from the other cues and were always followed by comparison stimuli. In essence, it is possible that these novel stimuli rapidly became functional remember cues. A second possibility is that it takes a certain amount of time for F-cues to terminate rehearsal, and the novel stimuli could have retroactively interfered with the processing of the F-cue before rehearsal termination was complete.

EXPERIMENT 3

Experiment 3 was an attempt to determine whether or not presample R- and F-cues can gain control over matching accuracy, as has been demonstrated with cues interpolated within the retention interval. Presenting the cues before sample presentations creates unique methodological problems. Previous research (Stonebraker & Rilling, 1981, and Experiment 1 of this paper) has demonstrated that one function of an F-cue signaling comparison cancella-

tion is to terminate orientation towards the response key. If sample stimuli are keylights presented on the response key, effective exposure duration to samples following an F-cue will probably be less than effective exposure duration to samples following an R-cue. Nelson and Wasserman (1978), Roberts (1972), and Roberts and Grant (1974) have clearly demonstrated that retention is an increasing function of exposure to the sample. Therefore, the tendency to turn away from the key following an F-cue would trivialize any difference in matching performance on R- and F-cued trials. A possible solution to this problem is to utilize a procedure similar to that used by Maki and Hegvik (1980). These investigators successfully used samples of food and no food symbolically paired with comparison stimuli of red and green keylights. If a sample consists of the presentation of food, birds are expected to eat, whether that food presentation occurs following an R- or an F-cue. If the other sample is a blackout period during which the houselight is turned off, response key orientation should not be necessary to equate sample exposure following each of the cues.

While sample exposure following each of the cues is held constant in the above procedure, processing that occurs during samples (encoding) may differ after each of the cues. The control of retention gained by postsample cues must be over postsample processes. Presample cues, however, could possibly influence the degree of encoding of a sample. Given that presample cues can gain control over matching accuracy, a further question of interest is whether that control is exerted over encoding or only over postsample processes. In Experiments 1 and 2, it was demonstrated that the presentation of an R-cue can eliminate the effect of a previously presented F-cue, as long as the second cue occurs before substantial forgetting has occurred. In the present experiment, following an F-cued sample with the immediate presentation of an R-cue should shed light on whether the F-cue is diminishing processing during the sample or merely influencing processing after sample termination. If samples following R- and F-cues are differentially encoded, the postsample R-cue should not be able to completely restore the memory of the sample. If, on the other hand, encoding is equal following R- and F-cues and the only difference is in postsample processing, an R-cue presented immediately after the sample should completely eliminate the influence of the prior F-cue, as in Experiments 1 and 2. According to this view, the R-cue would precede any reduction in processing and should therefore reduce F-cue effectiveness.

Method

Subjects. Six adult, experimentally naive White Carneaux pigeons were used and were maintained as in Experiment 1.

Apparatus. The apparatus was identical to that employed in Experiment 1.

Procedure. All birds were magazine trained and autoshaped

as in Experiment 1. Following autoshaping, the birds were trained on forget and remember cued delayed matching-to-sample. Each of the 88 trials per session began with the presentation of a vertical (R-cue) or horizontal (F-cue) line on the response key. The cue was presented for a minimum of 1 sec and terminated with the first keypeck after the 1-sec interval. R- and F-cues were equally presented and pseudorandomized such that no cue was presented more than two times in succession. Following R- and F-cues, a sample of either food (1.5-sec access to mixed grain) or no food (2.0-sec blackout produced by turning off the houselight) was presented. The sample was followed by a retention interval that was initially 1 sec in duration and gradually increased to the terminal value of 5 sec, according to the criteria set in Experiment 1. On F-cued trials, the retention interval was followed by the 30-sec ITI. On R-cued trials, the retention interval was followed by the presentation of a comparison stimulus, either red or green. Food-red and no-food/green trials were arbitrarily designated as matching trials, while no food-red and food-green were nonmatching trials. A comparison stimulus on matching trials was presented for a minimum of 5 sec. A single peck after 5 sec terminated the keylight and resulted in reinforcement, 1.5 sec access to mixed grain. Reinforced responses to the comparison stimulus were excluded from the data analysis. A comparison stimulus on nonmatching trials terminated automatically after 5 sec, and responses to this stimulus were not reinforced. All comparison stimuli were accompanied by a 1,000-Hz tone, as in Experiment 1. On R-cued trials, the four trial types (food-red, food-green, no-food/red, no-food/green) were pseudorandomized such that all occurred an equal number of times and none occurred more than two times in succession.

Probe sessions began when a bird performed at or above 80% for all five consecutive sessions, using the discrimination ratio described in Experiment 1. Probe sessions were given every other session, or less frequently as needed to maintain baseline (R-cued) matching performance above 80%. Three types of probe sessions were given. In each instance, 4 of the 88 trials in a probe session were probe trials (one of each of the 4 trial types). In the first probe condition (Pre F), an F-cue was given, a sample was presented, and a comparison stimulus was presented after the retention interval. In the second probe condition (Pre F/Post R), an F-cue was given and a sample was presented and immediately followed by an R-cue during the first 1 sec of the retention interval, which was followed by a comparison stimulus. The third probe condition (Pre R/Post R) was identical to the second, with the exception that the initial cue was an R-cue rather than an F-cue. On all probe trials, responses terminating matching comparison stimuli were reinforced, while nonmatching comparison stimuli terminated automatically, as in Experiment 1. The type of probe session given was pseudorandomized such that no particular type was given more than two times in succession and all were given five times. Probe sessions that failed to maintain a 75% discrimination ratio on baseline trials were eliminated from the final analysis, and additional probe sessions were given to replace them. Birds that failed to demonstrate any control by R- and F-cues in the first probe condition, as demonstrated by accurate (above 70%) matching performance on F-cued trials, were not tested on the remaining two probe conditions.

Results

Discrimination ratios were calculated from response rates to matching and nonmatching comparison stimuli, and these ratios are presented in Figure 4 for each bird. In the Pre F probe condition, performance on probe trials was sharply reduced relative to performance on R-cued baseline trials within the same session. Overall matching performance was 87% on baseline trials and 61% on probe trials in this condition.

Figure 4. Discrimination ratios for baseline and probe trials. All baseline data are from R-cued trials within the related probe sessions. In each probe condition, cues denoted as PRE were presented before the sample and cues denoted as POST were presented for 1 sec within the retention interval, immediately after sample termination. Birds P1377 and P1129 demonstrated a lack of control by R- and F-cues and were therefore not exposed to the two double-cued test conditions.

In a second probe condition, Pre F/Post R, matching performance on probe trials was similar to matching performance on F-cue alone (Pre F) probe trials for all birds with the possible exception of P428. Even P428, however, showed a decrement relative to R-cued baseline trials. Overall matching performance across birds was 87% on baseline trials and 71% on probe trials in this condition.

In the third probe condition, Pre R/Post R, there was no overall decrement in matching performance relative to baseline. Baseline matching was at 90%, while probe-trial matching was at 91%.

Discussion

The results of Experiment 3 clearly demonstrate that R- and F-cues presented before the presentation of sample stimuli can control matching performance in a fashion that parallels the results obtained with postsample cues. The decrement in matching on F-cued probe trials is primarily the result of increased responding to nonmatching comparison stimuli rather than decreased responding to matching comparison stimuli. These results closely correspond to those presented by Stonebraker and Rilling (1981), who used postsample cues. Control by the presample R- and F-cues is not established as reliably as it is by postsample cues (two of six birds showed little or no control by the cues). Maki et al. (1977) found

a similar degree of intersubject variability in that, when samples of food predicted omission of comparison stimuli, two birds showed no loss (mean = 100%) and two birds did show a loss (mean = 70%) in matching performance. However, in the present experiment, when control is achieved by R- and F-cues, matching performance on R-cued trials is superior to matching performance on F-cued trials. These differences cannot be attributed to differences in sample exposure due to the use of food and blackout as sample stimuli.

GENERAL DISCUSSION

The demonstration of control by presample instructional stimuli raises the question of what behavior is actually being controlled by the cues. Post-sample cues can only influence postsample processing such as rehearsal or retrieval, but presample cues could possibly influence processing during the sample (encoding), as well. It is possible that there is less encoding of a sample stimulus that was preceded by an F-cue than there is of a sample that was preceded by an R-cue. An alternative possibility is that presample R- and F-cues merely control the same postsample processes as do postsample R- and F-cues.

One present result that may help distinguish between the two above interpretations is the inability of an R-cue presented immediately after an F-cued sample to eliminate the effects of that F-cue. Experiments 1 and 2 demonstrated that as long as an R-cue occurs before an event is forgotten, the R-cue can cancel the previous instruction. Several possible explanations as to why that was not the case in the third experiment need to be explored.

One possible argument that can be raised is that the sample duration that separated the F- and R-cues prevented the R-cue from canceling the F-cue instruction. (When the sample was the response-independent/no-food sample, this termination of the initial cue and the onset of the second cue were always separated by 2.0 sec; the 1.5-sec food presentation did not start timing until the photocell beam was broken, indicating that if birds did not immediately approach the raised hopper the interval between the two cues would increase.) In Experiment 1, when the R-cue was separated in time from the F-cue it was unable to cancel the effects of that F-cue. However, if the F-cue does not control encoding, but merely controls postsample processing, the important interval should be between the to-be-remembered event (the sample) and the R-cue, not between the F-cue and the R-cue. Since the R-cue immediately follows the sample, it should prevent any diminished postsample processing. Such a cue would have been presented before any forgetting could take place, and therefore matching accuracy should have been high, but it was not.

A second possibility is that the R-cue during the retention interval failed to cancel the presample F-cue because the postsample cue was not seen. This possibility was rendered unlikely by observation of retention-interval behavior. While birds usually left the key following F-cued samples, the birds remained oriented towards the key on F-R probe trials. Some birds that never pecked the darkened response key during the retention interval did peck the key when an R-cue was presented during the interval, indicating that at least the R-cue was seen.

The fact that some birds pecked the vertical line during the retention interval, contrary to normal behavior, raises a third possibility as to why matching performance was poor on F-R probe trials. All trials normally started with a response-dependent R- or F-cue. It is possible that these birds reacted to the R-cue within the retention interval as they would to the start of a new trial, which resulted in poor matching performance when comparison stimuli were presented. This possibility was controlled for in the R-R probe trials, in which an R-cue sample stimulus was followed immediately by a second R-cue. If an R-cue during the retention interval indicated a new trial, performance on these trials should have been just as poor as it was on F-R probe trials. This was not the case—performance on R-R probe trials was highly accurate. An argument similar to the third, that the presentation of any stimulus within the retention interval was novel and therefore disrupting, is also controlled for by the R-R probe trials.

The most plausible reason for the inability of a postsample R-cue to completely cancel the effects of a presample F-cue (as was demonstrated in Experiment 1) is differences in processing before the presentation of the R-cue, during the sample. If retention requires processing during the sample, it would be most economical to encode only samples that were to be followed by comparison stimuli, R-cued samples. The finding that a postsample R-cue can render the presample F-cue less effective (at least in three of four birds) seems to indicate that some processing of the memory of the sample can occur during the retention interval after the postsample R-cue despite differential encoding during the sample. Whether this is the result of retrieval of the memory of the sample or the result of rehearsal of the remaining memory trace at the time of the cue, the results suggest that presample F-cues reduce matching accuracy by influencing processes occurring *both* during sample presentation (encoding) and during the retention interval (rehearsal).

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