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By

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ABSTRACT

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by

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Current views of delayed matching-to-sample (DMTS) performance in pigeons postulate the active maintainence (rehearsal) of a representation of the sample stimulus during the delay interval. Honig and Wasserman (1981) have termed this type of processing retrospective. In an alternative account, prospective processing, a representation of an upcoming comparison (test) stimulus is maintained during the delay interval, rather than a representation of the sample. The present series of experiments attempt to determine whether processing is retrospective or prospective in DMTS, as well as in delayed simple discrimination (a related procedure). In the first experiment, White Carneaux pigeons were simultaneously trained on two tasks: identity and symbolic matching. Only one set of sample stimuli was used, and was followed by one of two comparison sets. Instructional stimuli superimposed on the sample, and continuing throughout the delay, predicted the upcoming comparison set (identity or symbolic matching on that trial). On probe trials comparison sets were incorrectly cued. The decrement in performance on those trials revealed that the instructional cues had gained control over some aspect of processing, suggesting the use of prospective, rather than retrospective, processing. In a second, similar experiment, instructional cues were superimposed on a single sample set and predicted a delayed matching task or a delayed simple discrimination. Once again, results on probe trials suggested prospective processing. A final experiment modified the procedure of the first experiment by presenting cues that were uncorrelated with the upcoming matching task. The results of the experiment indicated that pigeons are capable of retrospective processing. However, prospective processing appears to be the process typically used, when there are no constraints which would hinder or prevent its use. This finding is contrary to the usual assumption of retrospective processing.

To my wife, Regina, in
appreciation for her patience
and love throughout my
graduate endeavors.

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INTRODUCTION

Short-term or active memory in laboratory animals has been a topic of increasing interest in recent years. Most research in animal memory has used a small number of experimental paradigms, the most common being delayed matching-to-sample (DMTS). In DMTS, accurate performance requires discriminative control of behavior by one or more external stimuli that are no longer present. Following the presentation of a sample stimulus and a retention interval, during which the sample is absent, animals are typically reinforced for responding to matching comparison stimuli and are not reinforced for responding to nonmatching comparison stimuli.

Two variations of delayed matching-to-sample have dominated the research in the area. The first variation is the two choice delayed matching-to-sample. In two choice DMTS with pigeons a trial typically begins with the presentation of a sample stimulus on the center key of a three-key array. Completion of a response requirement on the sample stimulus terminates the sample and initiates a retention interval. Following the retention interval side keys are transilluminated: one with the matching stimulus and the other with a nonmatching stimulus. The dependent variable of interest is the percentage of correct choices made.

The second variation is the successive DMTS, originally described by Konorski (1959) and later developed by Wasserman

(1976). In this procedure a single key is used rather than a three-key array. Following the a sample presentation and retention interval a single comparison stimulus is presented on the same key as the sample. If the comparison stimulus matches the sample stimulus responding is reinforced, whereas responding is not reinforced if a nonmatching comparison stimulus is presented. The dependent variable of interest in this procedure is the rate of responding during the comparison stimulus, usually presented as the percentage of comparison stimulus responses made to matching comparisons.

In both the two-choice and the successive procedures matching can be defined in a variety of ways. The most common are identity matching, oddity matching, and symbolic matching. In identity matching the sample and matching comparison are physically identical (e.g., red is a matching comparison following a red sample). In oddity matching comparison stimuli are presented that are either identical to or dissimilar to sample stimuli, as in identity matching, but the definition of a matching stimulus is the opposite of that for identity matching. For example, following a red sample stimulus a green comparison would be a matching stimulus and a red comparison would be a nonmatching stimulus. In symbolic matching comparison stimuli bear no intrinsic relationship to sample stimuli and the definition of matching and nonmatching comparisons is purely arbitrary. For example, red and green might be given as sample stimuli, while vertical and horizontal lines are given as comparison stimuli.

The experimenter might arbitrarily determine that red-vertical and green-horizontal are matching combinations, and red-horizontal and green-vertical are nonmatching combinations.

Across the many variations of DMTS one fact stands out: since the sample stimulus is not present when comparison stimuli are presented, accurate matching performance, despite retention intervals ranging up to several seconds, implies that the subject has access to the information contained in the absent sample. Much of the recent research with DMTS has favored the interpretation of an active process (rehearsal) to bridge the delay between sample and comparison stimuli (Grant, 1981; Maki, in press; Maki & Hegvik, 1980; Maki, Olson & Rego, in press; Roitblat, 1980; Stonebraker & Rilling, in press; Wagner, 1976). In addition, previous investigators have assumed that sample stimuli were transformed into codes that allow animals to bridge the gap between samples and comparisons. It is often assumed that the code refers to visual attributes of the sample stimulus (Maki, Riley, & Leith, 1976; Roberts, 1972; Roberts & Grant, 1976; Ruggerio & Flagg, 1976) or some other mnemonic copy of the sample. Taken together, the rehearsal and sample coding positions would seem to favor the interpretation that animals perform DMTS by actively rehearsing the sample (maintaining some visual attribute of the sample stimulus) throughout the retention interval.

While the conventional interpretation has been that animals actively process the sample during the retention interval, it is equally possible that animals actively process the upcoming comparison stimulus in order to perform accurately in DMTS. As Tulving and Bower (1974) point out in their discussion of human memory, correct performance on a retention test is not sufficient to determine what the properties of the memory trace are. Riley, Cook and Lamb (in press) add that the fact that an animal can match-to-sample after a delay interval shows that the animal is capable of bridging the gap between the initial event and the choice situation, nothing more. Accurate matching gives no indication of what process is being used to span the retention interval.

If processing during the retention interval is of the sample the following events would take place on a single DMTS trial: following sample termination some representation of the sample is maintained throughout the retention interval. When comparison stimuli are presented a decision rule is retrieved from long-term memory as the comparison(s) is(are) compared to the representation of the sample stimulus currently in memory. The decision rule indicates which stimulus is correctly paired with the sample (i.e., which stimulus is a match). However, if animals process the correct comparison stimulus during the retention interval the sequence of events would be somewhat different. According to this account, a sample stimulus would retrieve a representation of the matching comparison stimulus while the sample stimulus was still present. The organism would then code an instruction to respond to a specific comparison stimulus and a representation of that stimulus would be maintained throughout the retention interval in an anticipatory fashion. Upon presentation of comparison stimuli the organism would perform accurately by responding to the comparison that was in some way isomorphic to the representation currently being maintained in active memory. Delayed matching-to-sample performance is equally possible with either of the above strategies. The question of interest in this series of experiments is whether pigeons process the sample or the comparison during the retention interval in DMTS.

Honig and Wasserman (1981) distinguish between retrospective and prospective accounts of short-term memory. Retrospective accounts view the animal as looking back upon its recent past for clues to guide its choice among currently available response alternatives. Prospective accounts view the animal as preparing for upcoming response decisions by narrowing its range of behavioral options. In terms of DMTS, retrospective processing translates into maintaining a representation of the sample during the retention interval and prospective processing translates into maintaining a representation of a comparison stimulus during the retention interval (possibly, but not necessarily, the matching comparison on that trial).

Other researchers have also questioned the assumption that the pigeon's representation of the information contained in the sample is in the form of a copy of the sample. Both Honig (1978) and Maki, Moe, and Bierley (1977) proposed that the sample stimulus itself may not be remembered during a delayed matching trial, but rather that the sample stimulus may be tranformed into an "instruction". What this means is that the subject remembers "what to do" at the end of the retention interval rather than which stimulus began the trial (Maki, in press). Roitblat (1980) proposed that in order to determine the correct choice on a single DMTS trial there must be some translation process by which the sample is transformed to the correct test (comparison) stimulus. He points out that this translation may occur at any point between the onset of the sample stimulus and the time a choice is made. He presents two possibilities along the same lines as the retrospective-prospective distinction made by Honig and Wasserman (1981). One possibility is that the bird could remember a more or less direct copy of the sample stimulus during the delay and apply the translation rule to the representation only when comparison stimuli are presented. During the retention interval the memory is coded as a "copy" of the sample stimulus, as in the simple "copy" hypothesis proposed by Roberts (1972). A second alternative given by Roitblat is that:

> "...the bird could immediately translate the sample stimulus into a form isomorphic with the correct test stimulus and maintain that representation in memory during the delay. Therefore, the information present in the sample is maintained for most of the delay interval in a form similar to the upcoming correct comparison stimulus." (p. 347)

Roitblat presents an experiment designed to discriminate among alternative memory codes (retrospective vs prospective processing). His experiment analyzed confusion errors and was based on an experiment by Conrad (1964) using human subjects. Conrad asked subjects to remember visually-presented consonants. When errors were produced in that experiment, they tended to be acoustically similar to the correct item, but not visually similar. This suggested to Conrad that the subjects stored the representations of the visually presented items in an acoustic code. Roitblat used a symbolic DMTS in which color sample stimuli were followed by line orientation comparison stimuli, and line orientation sample stimuli (for a different bird) were followed by color test stimuli. Three colors (blue, orange, and red) and three different line orientations (0, 12, and 90 degrees from vertical) were used. For both colors and lines, two of the stimuli were more similar to each other than they were to the third. Dissimilar colors were associated with (matched) similar line orientations and similar colors were associated with dissimilar line angles. If the animal encoded the sample stimulus and maintained that code across the delay (retrospective processing) confusion errors should have been between similar samples rather than between dissimilar samples. This would have been revealed by errors between dissimilar comparison stimuli. If, on the other hand, pigeons processed prospectively and the code during the retention interval referred to comparison attributes, confusion errors should have been between similar comparison stimuli even though the samples in those cases were disimilar. Roitblat found that confusion errors were between similar comparison rather than between similar sample stimuli, suggesting that some attribute of the comparison stimulus was coded in memory (prospective processing) rather than some attribute of the sample.

Riley, Cook and Lamb (in press) examined the nature of the code used by animals to bridge the retention interval in DMTS by reviewing several recent studies. They presented what they felt was evidence for three separate types of codes. Two of the codes were consistent with Honig and Wasserman's retrospective-prospective processing distinction and involve maintenance of information about attributes of either the sample stimulus or the comparison (test) stimulus.

The evidence that Riley, Cook and Lamb present to demonstrate the existence of prospective processing, or test codes, is the work by Roitblat (1980) described above. They agree with Roitblat that his birds in his experimental situation used prospective processing, but they maintain that in other situations retrospective processing (sample coding) is used. The evidence they present as support for the assertion that sample attributes can be part of coded information comes from studies involving transfer of conditional discrimination performance to novel stimuli.

Riley, et al. cite several studies which demonstrated transfer of matching-to-sample to novel stimuli. They proposed that this tranfer has three implications. First, it indicates that pigeons have generalized a performance rule. An example of such a rule would be peck the test stimulus which matches the code. Second, it implies, to them, that the existence of a code for the new stimulus did not depend on prior training in the experimental stituation. The third implication for them was that positive transfer requires that the mediating code refer to sample attributes. They maintained that test coding requires experience with the test (comparison) in order to associate attributes of the test with the sample. A demonstration of positive transfer to novel stimuli seemed, to Riley et al., to demand that performance in the task be based on a code referring to sample attributes.

Despite Riley, et al.'s enthusiasm, the latter two implications are equivocal for a number of reasons. They admit to two considerations which are cause for doubt. First, the data in the studies they present are aggregated across trials, thus hidden learning effects may be present. Second, many of the studies they presented as evidence for sample codes used simultaneous discrimination tasks in which the sample was still present on one key while a single comparison was presented on another key. Because the sample and test stimuli overlap in time, the birds may have responded to a stimulus configuration (Carter, 1977). Responding under these circumstances does not require short-term retention, as the animal would not be treating the problem as a conditional discrimination.

Riley, et al. overlook what seems to be the most damaging fault in using the transfer studies they present as support for retrospective processing. In all of the studies comparison stimuli were presented that were isomorphic with sample stimuli (identity and oddity matching, but no symbolic matching). If, for example, the sample was red and the comparison was red, demonstrating that birds processed "red" during the retention interval is no more evidence for sample codes than it is for test codes. In all of the studies Riley, et al. present animals have all of the information they need for either retrospective or prospective processing, once the appropriate rule is learned. If given a red sample, birds could prospectively process a red comparison to aproach it (identity matching) or avoid it (oddity matching). Transfer of matching would indicate that birds have learned the general rule to process a comparison stimulus isomorphic with the current sample. This would be in line with Riley, et al.'s first stated impliction, but their second and third stated implications seem weak. Based on the transfer studies they present as evidence for sample codes, codes could refer to either sample or comparison attributes.

In order to determine the meaning of the code to the animal, as far as whether it refers to the sample or the comparison stimulus, the experimental situation must be arranged so that the different possible types of codes refer to discriminably different properties. Roitblat (1980) accomplished this by using symbolic matching-to-sample with colors as samples and lines as comparisons or vice versa. The transfer studies cited by Riley, et al. failed to accomplish this by using isomorphic samples and comparisons. The following experiments are designed to examine whether retention interval processing is prospective or retrospective in DMTS. In Experiments 1 and 2 this is done by insuring that the possible codes for the sample and comparison stimuli have discriminably different properties. Also, the training situation is arranged such that the tasks may be performed either retrospectivly or prospectivly. Given that these experiments suggest prospective processing, the design of Experiment 3 favors the use of retrospective processing in an attempt to (1) establish that retrospective processing is possible, and (2) compare performance using retrospective vs. prospective processing.

EXPERIMENT 1

In this first experiment birds were simultaneously trained on two matching-to-sample tasks: identity matching and symbolic matching. This was accomplished using one set of sample stimuli (red or green) and two sets of comparison stimuli (red vs green and vertical vs horizontal). Instructional stimuli were superimposed on the sample stimuli and continued into the retention interval. These cues predicted whether colors (identity matching) or lines (symbolic matching) would be presented on that trial.

A retrospective account of active processing during the retention interval in DMTS maintains that what is being processed during the retention interval is some code of the sample (e.g., a visual image of the sample; a sample-specific mediating response; etc.). If that is the case, the cues associated with various comparison sets should not change the processing during the retention interval. There is only one sample set, and one or the other member of that set would be processed on each trial regardless of the cue on that particular trial.

A prospective account maintains that what is being processed during the retention interval is a test code or some attribute of a comparison stimulus rather than a sample code. If this is the case, very different behaviors should occur during the identity and matching tasks. Birds would need to utilize the information given by the cues predicting the upcoming comparison set, and processing during the retention interval would then be appropriate to the expected set.

During each DMTS trial, birds must at some point in time, retrieve the decision rule regarding which comparison stimulus is correct (i.e. whether the "match" is an identical stimulus, as in identity matching, the non-identical counterpart, as in oddity matching, or some arbitrarily paired stimulus, as in symbolic matching). This process is what Roitblat referred to as a "translation process" by which the sample is transformed to the correct test (comparison) stimulus. If retrospective processing occurs, this rule retrieval would exist at the time of the comparison presentation. Therefore, it should not matter which set of comparison stimuli are presented and birds should perform equally well whether the instructional stimuli correctly or incorrectly predict the comparison sets. If prospective processing occurs, the rule retrieval would exist sometime during the sample stimulus or at the beginning of the retention interval. The instructional stimuli during the sample and retention interval are therefore vitally important, informing the organism which comparison stimulus (e.g. a color or a line) to rehearse or anticipate. Unlike the retrospective account, incorrectly cueing the comparison sets for a bird using prospective processing should cause a decrement in performance, since the stimulus being processed is not presented and the stimuli being presented are not currently being processed.

This experiment attempts to determine whether processing during DMTS is prospective or retrospective in nature by training birds with cues that perfectly predict comparison sets and occasionally testing birds with incorrectly cued comparison sets. Attempts were made to design the experiment in such a way as not to bias the birds towards one process or the other.

METHOD

SUBJECTS. Eight experimentally naive adult White Carneaux pigeons were used. Birds were maintained at 80% +/- 15g of their free-feeding weights. 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. Interior dimensions were 35 x 35 30 cm. The 2.5 cm keys required a force of 0.15 N for activation. The response key could be transilluminated with red (606 nm), green (555nm), a 1.0 cm diameter circle, a 1.0 cm equilateral triangle, or a vertical or horizontal 0.3 x 2.5 cm white line on a black background. The stimuli were produced by an Industrial Electronics projector (Model # 10-3723-757-L). The keys were located 23 cm from the floor and side keys were located 8 cm from the front and back walls. The center key was midway between the two side keys, 9 cm above the 5 x 6 cm magazine opening. Located 4.5 cm above the center key was a 28 V houselight (cm 1820). Also located on the intelligence panel was a circular speaker grill. During reinforcement a 28 V light (Sylvania 28

PBS) within the magazine enclosure was illuminated. Activation of a Lehigh Valley Electronics photoelectronic relay initiated the reinforcement timer. An exhaust fan, located on the wall opposite 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. All birds were magazine trained and autoshaped according to the procedure described by Stonebraker and Rilling (in press). Following autoshaping, birds were trained on a two choice delayed matching-to-sample task. During DMTS training a sample stimulus was presented (either red or green) and was terminated with the first keypeck after 12 seconds had elapsed. Red and green samples were pseudorandomly presented such that the same color did not appear more than three times in succession and each occurred equally often per session. Superimposed on the sample stimulus was either a circle or triangle which continued on the key throughout the retention interval, which followed the sample. Triangles predicted the occurrence of line orientation comparison stimuli (symbolic matching) and circles predicted the occurrence of wavelength comparison stimuli (identity matching). The two comparison stimuli, either vertical and horizontal lines or red and green, were presented simultaneously on side keys. Comparison stimuli were counterbalanced such that each color and line occurred an equal number of times on each side key. A single keypeck to the comparison stimulus that matched the sample terminated both comparison stimuli and resulted in reinforcement. A peck to the nonmatching comparison terminated both stimuli and initiated a new trial. The intertrial interval was 30 seconds.

Throughout Experiment 1 reinforcement consisted of 2.0 second access to mixed grain. Seventy-two trials were given each session, 36 identity and 36 symbolic matching. All trial types and combinations of stimuli occurred an equal number of times.

From the responses 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 on both matching tasks 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. Only one bird, P6813, was unable to reach criterion performance at retention intervals greater than 1 sec. This bird was dropped from the experiment at this point.

Probe sessions began when a bird performed at or above 80% on both tasks for four consecutive sessions. Probe sessions were given every other session, or less frequently as was needed to maintain baseline matching performance above 80%. Probe sessions consisted of 64 standard trials and 8 probe trials. On probe trials triangles were incorrectly paired with wavelength comparison stimuli (identity matching) and circles were incorrectly paired with line orientation comparison stimuli (symbolic matching). Comparison stimuli locations were counterbalanced and all trial types were probed during each session. The eight probe trials were therefore red (sample) + circle : vertical (left)/horizontal (right); red + circle : horizontal/ vertical; red + triangle : red/green, red + triangle : green/red; green + circle: vertical/horizontal; and so on. Reinforcement contingencies were identical to those on standard trials. A total of 15 probe sessions were given to each bird.

RESULTS

All eight birds reached the criterion of 80% for both tasks concurrently at 1 sec retention intervals. This took an average of 28.9 sessions, ranging from 17 to 61 sessions. Seven of the birds were able to meet the 80% criterion at increased retention intervals. All seven of these birds achieved 4 sec retention intervals, in an average of 46.3 sessions (range=26 to 72 sessions). All seven of these birds also met the criteria to begin testing, and it took birds an average of 37.4 sessions to complete the 15 session test phase (range= 29 to 60 sessions). Since probe sessions alternated with non-probe sessions, the minimum number of sessions possible to complete the 15 session test phase was 29.

Discrimination ratios were calculated from the choice responses to comparison stimuli, both for standard and for probe trials. The results for the seven birds that were tested are presented in Figure 1. Matching performance of 100% indicates perfect matching, whereas performance at 50% indicates chance (equal responding to matching and nonmatching comparison stimuli). For all birds there was a decrement in matching performance on probe trials in relation to standard (baseline) trials. This decrement existed whether the task was identity or symbolic matching. The average matching percentage was 89.5 on baseline trials and 72.2 on probe trials.

Also recorded were the response latencies to comparison stimuli on baseline and probe trials. These latencies are presented in Table 1. The latencies for baseline trials were obtained from the four sessions immediately preceding the beginning of testing. For identity matching the overall mean latencies were 1.00 sec on baseline trials and 1.07 sec on probe trials (trials that were incorrectly cued). For symbolic matching the overall means were .94 sec on baseline trials and 0.98 sec on probe trials.

FIGURE 1. Matching performance on baseline and probe trials for each task. Baseline trials were trials in which cues correctly predicted the matching task. Probe trials were trials in which the matching task was incorrectly cued. A discrimination ratio of 100% indicates perfect performance, with responding to comparison stimuli occurring exclusively on matching trials. A discrimination ratio of 50% indicates chance performance, with equal response levels to matching and nonmatching comparison stimuli.

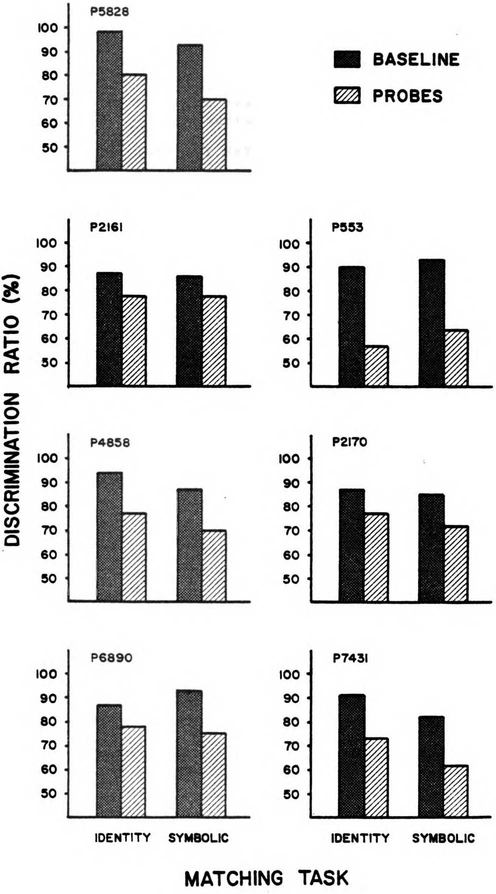

P5828
BASELINE
PROBES
P2161
P553
P4858
P2170
P6890
P7431
100
90
80
70
60
50
DISCRIMINATION RATIO (%)
IDENTITY
SYMBOLIC
IDENTITY
SYMBOLIC
MATCHING TASK

Table 1
Mean response latencies to
comparison stimuli (in sec)

	IDENTITY MATCHING		SYMBOLIC MATCHING	
BIRD	BASELINE	PROBES	BASELINE	PROBES
P5828	0.84	1.35	0.85	0.95
P2161	0.86	0.87	1.00	1.07
P553	1.28	0.95	0.74	0.88
P4858	0.90	1.04	1.00	1.01
P2170	1.00	1.01	1.13	1.26
P6890	1.38	1.10	0.91	0.89
P7431	0.75	1.20	0.92	0.83

EXPERIMENT 2

This second experiment also attempts to determine whether the processing utlized by pigeons in short-term memory tasks is prospective or retrospective in nature. In Experiment 1, both matching tasks were conditional, i.e. the correct discriminative response at the end of the trial depended upon both the sample and the comparison stimuli, and changed from one trial to another. Information from the sample and the comparison in conditional discriminations must be processed conjointly for the bird to make a correct decision. Honig and Wasserman (1981) described a delayed simple discrimination in which the sample stimuli signalled different outcome contingencies in the presence of a single test stimulus. Memory on these tasks are typically more robust than during delayed matching trials. In Experiment 1 birds were simultaneously trained on two conditional delayed matching tasks. In the present experiment birds were simultaneously trained on one delayed matching task and one delayed simple discrimination. The same strategy used in Experiment 1 was utilized, in that a single sample set (red and green) was used and superimposed instructional stimuli were paired with the two different test events: red or green for delayed matching and a single white keylight for delayed simple discrimination. Also, in Experiment 1 a choice matching procedure was used, in that both the correct and incorrect comparison stimuli were simultaneously presented on side keys. The present experiment utilized the successive DMTS of Konorski (1959) and Wasserman (1976) instead. In this procedure only one comparsion stimulus is presented on any given trial, and the dependent variable of interest is rate of response to that stimulus, rather than correct or incorrect choice.

The two tasks in this experiment, delayed matching and delayed simple discrimination, thus differ in requirements for processing information. In the delayed simple discrimination the bird has all of the information needed to determine the outcome of a trial at the time of the sample. In the delayed matching task neither the sample nor the comparison contains enough information to determine trial outcome: correct performance depends on the conjoint evaluation of information from the sample and the test stimuli.

As in Experiment 1, the two tasks in Experiment 2 could equally be performed using retrospective or prospective processing. According to the retrospective account some attribute of the sample is maintained throughout the retention interval. At the onset of the comparison stimulus a comparison is made between the sample currently being processed and the present stimulus. If, for example, the sample being processed was red, birds might maintain a representation of red throughout the retention interval, then respond when presented with red (a conditional match) or white (a delayed simple discrimination S+) but not green. If the sample was green, birds might maintain a representation of green throughout the retention interval, then respond when the comparison was green, but not when it was white (a delayed simple discrimination S-) or red. The instructional stimuli should not affect what is being processed during the retention interval. Being essentially irrelevant to the task, those cues should not gain stimulus control if retrospective processing is used.

According to the prospective account, the instructional stimuli once again provide information necessary to perform the matching tasks. When presented with a cue signalling conditional matching birds would need to process a colored comparison during the retention interval. It is possible that birds could process either the comparison isomorphic with the current sample with the general rule to approach, or they could process the opposite stimulus with the general rule to withdraw or inhibit responding when the comparison was presented. The transfer of matching data reviewed by Riley, et al. (in press) and some recent work by Zentall, Edwards, Moore, and Hogan (1981) would seem to suggest the former. Regardless of which colored comparison they processed, it would have to be one color or the other in order to match accurately. When presented with an instructional stimulus signalling a delayed simple discrimination simply processing some attribute of the comparison would not be sufficient, since the comparison on both matching and nonmatching trials was a white keylight. Birds must also (or instead) code some response instruction (i.e. "peck" or "peck white" following red samples and "don't peck" or don't peck white" following green samples).

Whereas in Experiment 1 the prospective account required the processing of one of two distinct stimuli (colors or lines) during the retention interval, birds in Experiment 2 require either the processing of a stimulus (color) or the processing of a response rule (peck or don't peck), depending on the task. On probe trials, in which tasks are incorrectly cued, matching performance should be reduced when instructional stimuli are followed by the inappropriate comparison stimuli. If a bird is processing red or green during the retention interval in anticipation of a red or green comparison stimulus it should perform poorly when presented with white. Likewise, when processing "peck" or "don't peck" and is presented with a conditional discrimination (colors) performance should be reduced from baseline levels.

METHOD

SUBJECTS. Eleven experimentally naive adult White Carneaux pigeons were used. Birds were maintained as in Experiment 1.

APPARATUS. The apparatus was similar to that employed in Experiment 1.

PROCEDURE. All birds were magazine trained and autoshaped according to the procedure described in Stonebraker and Rilling (in press). Following autoshaping birds were simultaneously trained on a successive DMTS and a delayed simple discrimination. For both tasks a sample stimulus was presented (either red or green) and was terminated with the first keypeck after 12 sec had elapsed. If no keypeck was emitted during the 30 sec period following the end of the 12 sec interval, sample stimuli automatically terminated. Superimposed on the sample stimulus was either a vertical or horizontal line, which continued on the key throughout the retention interval (which followed the sample). Vertical lines predicted the occurrence of wavelength comparison stimuli (delayed matching task) and horizontal lines predicted a white comparison stimulus (delayed simple discrimination). Comparison stimuli were presented for a minimum of 5 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. In the delayed matching task comparison stimuli terminated automatically after 5 sec on nonmatching trials (red-green and green-red) and were terminated with a single keypeck after 5 sec on matching trials (red-red and greengreen). This keypeck also resulted in reinforcement. In the delayed simple discrimination the white comparison terminated automatically after 5 sec following green sample stimuli (S-) and were terminated with a single keypeck after 5 sec following red sample stimuli (S+), and this keypeck resulted in reinforcement. The intertrial interval was 30 sec.

Throughout Experiment 2 reinforcement consisted of 2.5 sec access to mixed grain. All trial types occurred equally often and were pseudorandomly presented, as in Experiment 1. Since there were four trial types in the DMTS task (red-red, red-green, green-red, and green-green) and only two in the delayed simple discrimination (red-white and green-white) 48 of the 72 trials per session were DMTS and the remaining 24 were delayed simple discrimination.

During training, the retention interval was initially set at 1 sec. This interval was maintained until a bird performed at above an 80% ratio on both tasks, using the formula presented in Experiment 1. The retention interval was increased in 1 sec increments each time the criterion was met. The original intent was to train birds to a terminal value of 4 sec, as in Experiment 1. Due to the general inability of birds to maintain accurate performance at increased delay intervals the terminal value was reduced to 3 sec. Birds that were unable to reach criterion performance, and were dropped from the experiment.

Probe sessions began when a bird performed at or above 80% on both tasks for 4 consecutive sessions, and were given every other session or less frequently, as in Experiment 1. Probe sessions consisted of 66 standard and 6 probe trials, one of each trial type. On probe trials vertical line cues were incorrectly followed by a white comparison and horizontal line cues were incorrectly followed by either a red or green comparison stimulus. Reinforcement contingencies on probe trials were identical to those on standard trials. A total of 5 probe sessions were given to each bird.

RESULTS

Only eight out of eleven birds reached the criterion of 80% for both tasks concurrently at 1 sec retention intervals. This took an average of 43.6 sessions, ranging from 23 to 73 sessions.

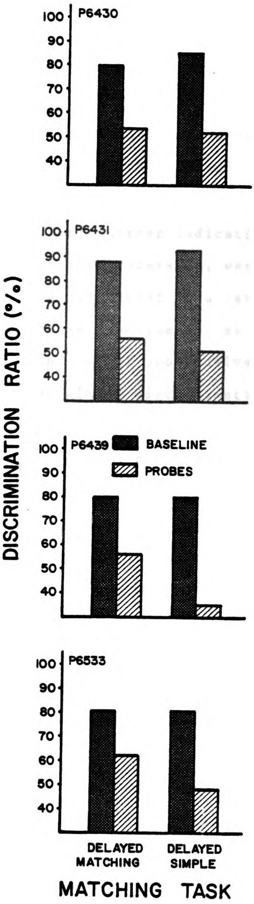
Five of the eleven were able to achieve 3 sec retention intervals, in an average of 54 sessions (range = 25 to 81 sessions). Only four of the eleven were able to meet the criterion to begin testing, and it took birds an average of 30.5 sessions to complete the 5 session test phase (range = 18 to 47). Since probe sessions alternated with non-probe sessions the minimum number of sessions possible to complete the 5 session test phase was 9.

Table 2 presents the response rates during samples, retention intervals, and comparison stimuli (both baseline and probe trials, from probe sessions) for the four birds that completed the experiment. The most notable difference during the samples and retention intervals is the low response rates on green + horizontal trials (the S- trials for the delayed simple discrimination). The overall response rate on those trials was 6.5 responses per minute, as compared to 272.8 on red + horizontal, 191.9 on green + vertical, and 183.0 on red + vertical trials. Discrimination ratios were calculated from the response rates to comparsion stimuli, both for baseline and for probe trials. These ratios are presented in Figure 2. For all birds there was a decrement in matching performance on probe trials in relation to standard (baseline) trials. This decrement existed whether the task was DMTS or delayed simple discrimination. The average matching percentage was 83.5 on baseline trials and 51.8 on probe trials.

Table 2
Responses per minute during samples, retention intervals, and comparison stimuli (both on probe and baseline trials). R=red, G=green, V=vertical, H=horizontal, W=white, and parentheses indicate a sample that is no longer present.

Bird	SAMPLE				RETENTION INTERVAL				COMPARISON STIMULI					
	R+V	R+H	G+V	G+H	(R)V	(R)H	(G)V	(G)H	(R)R	(R)G	(G)R	(G)G	(R)W	(G)W
P6430														
baseline	195.7	244.7	202.0	7.7	170.2	257.7	155.5	71.7	261.2	48.2	79.8	262.6	277.2	50.0
probe									292.8	300.0	160.8	244.8	264.0	240.0
P6431														
baseline	236.4	266.6	254.3	2.5	329.0	193.0	316.7	55.0	237.2	44.8	18.8	235.0	192.8	14.0
probe									240.0	189.6	177.6	235.2	232.8	225.6
P6533														
baseline	226.6	361.1	210.4	9.6	191.9	112.0	196.5	60.7	285.0	47.6	76.0	271.4	275.2	65.4
probe									276.0	7.2	302.4	232.8	309.6	331.2
P6439														
baseline	73.4	218.8	101.1	6.2	252.0	247.3	179.7	59.7	133.6	31.6	35.2	134.0	132.4	33.8
probe									165.6	115.2	182.4	208.8	88.8	163.2

FIGURE 2. Matching performance on baseline and probe trials for each task. Baseline trials were trials in which cues correctly predicted the matching task. Probe trials were trials in which the matching task was incorrectly cued. A discrimination ratio of 100% indicates perfect performance, with responding to comparison stimuli occurring exclusively on matching trials. A discrimination ratio of 50% indicates chance performance, with equal response levels to matching and nonmatching comparison stimuli.


P6430
P6431
P6439
P6533
BASELINE
PROBES
100
90
80
70
60
50
40
DISCRIMINATION RATIO (%)
DELAYED MATCHING
DELAYED SIMPLE
MATCHING TASK

EXPERIMENT 3

Experiments 1 and 2 both demonstrated a decrement in performance on probe trials in relation to standard, baseline trials. This decrement suggests that the instructional cues did gain control over the birds' behavior, further indicating that prospective, rather than retrospective processing, was used (since the instructional cues would be irrelevant in a retrospective process). Although both of these experiments, as well as that of Roitblat (1980), suggest the use of prospective processing by pigeons in DMTS and delayed simple discrimination, Riley, Cook, and Lamb (in press) argue that birds can also process retrospectively. While it may be true that birds can use retrospective processing, the evidence Riley, et al. present seems equivocal for a number of reasons, as previously stated. The present experiment attempts to determine whether or not birds can perform DMTS utilizing a retrospective process. Unlike the previous two experiments, which were designed in an attempt not to bias the bird towards one process or another, the present experiment was designed to favor retrospective processing.

In Experiment 3 the procedure of Experiment 1 was replicated with one modification. Instead of circles and triangles predicting which task (identity or symbolic matching) was given on a particular trial, cues were uncorrelated with comparison events. In order to perform this task, birds must now either prospectively process both correct (matching) comparison stimuli or else retrospectively process the sample. It is assumed that prospectively processing two stimuli simultaneously is a far more complex task than prospectively processing one stimulus, as in Experiment 1. Acquisition of DMTS with 1 second retention intervals were compared between Experiments 1 and 3. If acquisition is similar it can be assumed that birds can process retrospectively as easily as prospectively. If acquisition is retarded, the study suggests that either retrospective processing is possible, but more difficult than prospective processing, or birds are incapable of retrospective processing and are instead prospectively processing both correct comparisons simultaneously.

In addition to acquisition, latency to respond to comparison stimuli were compared between Experiments 1 and 3. If birds use prospective processing, then retrieval of the decision rule regarding which comparison stimulus is correct would occur at some point during the sample or at the beginning of the retention interval. If birds use retrospective processing this rule retrieval would occur after the onset of the comparison stimuli and the choice response latency should be longer. Therefore, one would predict that if birds can learn DMTS in Experiment 3 using uncorrelated cues, the response latencies to comparison stimuli would be longer than those in Experiment 1, even if acquisition rates do not differ.

METHOD

SUBJECTS. Seven experimentally naive White Carneaux pigeons were used, as in Experiment 1.

APPARATUS. The apparatus used in Experiment 1 was used.

PROCEDURE. The procedure was identical to the initial procedure of Experiment 1, with the single exception that the instructional cues were not correlated with the matching tasks. Birds were trained using 1 sec retention intervals until they performed at 80% on both matching tasks for two consecutive sessions. In Experiment 1 this was the point at which the duration of the retention interval was increased to 2 sec. In this experiment meeting the two session, 80% criterion meant completion of the experiment.

RESULTS

All seven birds reached the criterion of 80% for both tasks concurrently at 1 sec retention intervals. This took an average of 41.4 sessions, which is greater than the average 28.9 sessions needed for birds with correlated cues (Experiment 1), although these differences were not statistically significant at the 0.05 level. The range of trials necessary for birds with uncorrelated cues was 17 to 64 sessions.

Response latencies were recorded for the two sessions of criterion performance at 1 sec retention intervals for both correlated and uncorrelated cue conditions. Birds that were presented with cues that predicted the upcoming matching task responded to the choice comparison stimuli with a mean latency of 1.18 sec. Birds that were presented with cues that did not predict the upcoming comparison matching task responded to the choice comparison stimuli with a mean latency of 1.22 sec. Matching accuracy during those sessions for each condition were 89.1% and 88.6% for correlated and uncorrelated cues, respectively.

DISCUSSION

Roitblat (1981) presented data which he believed suggested that pigeon DMTS performance utilizes the processing of a representation isomorphic with the test (comparison) stimulus - prospective processing. Experiments 1 and 2 in the present study support the conclusions drawn by Roitblat. These findings are contrary to the common assumption that processing involves a representation isomorphic with the sample stimulus (retrospective processing).

In retrospective processing birds would process a representation of the sample stimulus on a particular trial. This process would be independent of the upcoming comparison stimuli, making the superimposed cues in the present studies irrelevant. Changing the meaning of the cues on probe trials should not influence matching performance if retrospective processing is used. However, the results of Experiments 1 and 2 indicate that the instructional cues do gain control over processing. Incorrectly cueing the type of matching task consistently resulted in a decrement in matching performance, when compared to correctly cued trials. While these results are inconsistent with a retrospective process position, they are precisely as would be predicted with a prospective process position. In prospective prosessing birds would process a representation of one of the comparison stimuli on a particular trial, either the correct comparison (to approach) or the incorrect comparison (to withdraw).

The bird would need the information contained in both the sample and the instructional cue in order to maintain accurate matching performance. The cue would tell the bird which task was eminent (identity vs symbolic in Experiment 1; identity vs delayed simple discrimination in Experiment 2). The sample stimulus would tell the bird which of the two comparison stimuli to process for that task (or whether or not to respond in the delayed simple discrimination). By incorrectly cueing on probe trials the birds would process a stimulus that was correctly paired with the sample, but would be the wrong task for that trial. Since the comparison stimuli on probe trials would therefore not match the stimulus being processed, birds would not have the information necessary for accurate matching. The results obtained in Experiments 1 and 2 are consistent with this prospective account of processing in pigeon DMTS. Prospective processing seemed to be utilized whether the matching task was a simultaneous choice task (Experiment 1) or a successive task (Experiment 2).

In Experiment 1, although there was a decrement in performance on probe trials, performance was not reduced to chance levels. If birds were rehearsing an inappropriate comparison stimulus the question arises as to how birds were able to perform on those probe trials. Recent work by Kendrick, Rilling, and Stonebraker (in press) and by Grant (1980) has suggested that in some circumstances when rehearsal processes fail, a retrieval process can take over, given the proper stimulus context. This retrieval would allow for the above chance performance on those probe trials.

A second question develops when one compares the decrement on probe trials in Experiments 1 and 2. Unlike Experiment 1, performance on probe trials in Experiment 2 was generally reduced to chance levels. This discrepency is consistant with the results of other manipulation that produce performance decrements in DMTS, in that the decrement seen using the successive procedure is usually greater than the decrement seen using a choice DMTS (e.g. compare Maki & Hegvik, 1980, with Stonebraker & Rilling, in press). This is probably due to the influence of a bias to respond in the go/no go successive procedure.

Honig and Wasserman (1981) suggested that birds might use prospective processing in delayed simple discriminatons as well as DMTS. This notion is supported by the results of Experiment 2. Incorrect cueing of a delayed simple discrimination produced a performance decrement similar to that in DMTS. This decrement again suggests that whatever the bird was processing on a given probe trial was inadequete to support matching performance. According to a retrospective account, the same sample should be processed regardless of the task, and the information necessary for matching should be just as available on incorrectly cued trials as on correctly cued trials. According to a prospective account an incorrect cue would lead to the processing of a stimulus member of the wrong task, and would result in a subsequent performance decrement, as was demonstrated.

In addition to the performance decrements seen during probe comparison stimuli, the response rates during samples and retention intervals also suggest prospective processing, at least for the delayed simple discrimination. If birds processed a representation of the sample during the retention interval one would expect similar response rates during and following all red or all green trials, regardless of the upcoming task. The results of Experiment 2 clearly show a response difference between green trials with a superimposed vertical line and green trials with a superimposed horizontal line. When vertical lines predicted DMTS, response rates were high (similar to red + vertical trials). When horizontal lines predicted an S- trial on delayed simple discrimination, response rates were very low, suggesting that the controlling variable was the upcoming task, rather than the sample stimulus.

Accurate DMTS, in the successive procedure, is typified by high response rates on matching trials (e.g., red-red and green-green) and low response rates on nonmatching trials (e.g., green-red and red-green). Manipulations that disrupt performance typically produce this result by raising response rates on nonmatching trials, rather than lowering response rates on matching trials (e.g., Stonebraker & Rilling, in press; Stonebraker, Rilling, & Kendrick, in press). The low response rates, or apparent "don't peck" rule on green + horizontal trials raises the possibility, however, that in Experiment 2 the poor probe matching performance is simply governed by this differential responding (e.g., high rates on red + horizontal-red and red +

horizontal-green trials and low rates on green + horizontal-green and green + horizontal-red trials). While these results would still indicate control by the cues, and therefore suggest prospective processing, it is desirable to determine whether the poor DMTS performance in Experiment 2 is a result of this carry over of a "peck/don't peck" rule, or if the decrement conforms to the more typical decrements seen when the memory process in DMTS is interfered with. The response rates during probe comparison stimuli (Table 2) clearly suggest the latter. High response rates to probe comparison stimuli following green + horizontal suggests that the poor matching performance was due to some memory failure that resulted from the lack of appropriate rehearsal, rather than simply due to the blind adherance to a "don't peck" rule.

In comparing Experiments 1 and 2 it quite evident that there were differences in the degree of difficulty in training. Counterintuitively, Experiment 2 seemed to be much more difficult for birds to learn and maintain, despite the fact that one of the tasks was delayed simple discrimination (Honig and Wasserman, 1981, reported that delayed simple discrimination was acquired more quickly and performed better with a memory requirement than DMTS when tasks were presented independently). Probe sessions were extremely disrupting to subsequent sessions in Experiment 2, which had one DMTS task and one delayed simple discrimination task, but little disruption was evident in Experiment 1, which had two DMTS tasks. This can be seen by comparing the mean number of sessions required to complete testing to the minimum number of sessions required for testing for each experiment. Also, 7 out of 8 birds were able to match accurately at 4 sec retention intervals in Experiment 1 (acquisition averaged 46.3 sessions), while only 5 out of 11 even reached 3 sec retention intervals in Experiment 2 (acquisition averaged 54 sessions), and only 4 of those birds were able to reach criterion levels necessary to begin testing.

One possibility for these inequities is that successive DMTS (Experiment 2) is more difficult than choice DMTS (Experiment 1). These differences have not been reported in the past despite extensive analysis of the two tasks. A second possibility is that the relative ease of the delayed simple discrimination in some way interfered with the acquisition and maintenance of DMTS when the two were trained simultaneously, as in Experiment 2. Honig and Dodd (Note 1) are currently examining the concurrent processing of these two tasks in order to determine how the two "interact".

Riley, Cook and Lamb (in press) have argued that both prospective and retrospective processes are used by pigeons in DMTS. The results of Experiment 3 support the argument that pigeons can use retrospective processing when necessary, although prospective processing appears to remain the process of preference. Experiment 3 replicated Experiment 1 with the single modification that cues were not correlated with the matching task. Birds were able to learn DMTS with these uncorrelated cues, suggesting retrospective processing (although the possibility that birds prospectively processed two comparison stimuli, both correct or both incorrect comparisons, cannot be ruled out). The fact that birds took fewer trials to learn DMTS with correlated cues might indicate that the process normally used is prospective if the experimental situation does not favor one process over the other. Also, it still remains to be demonstrated that birds can use retrospective processing at delay intervals greater than 1 sec.

One result that does not fit the hypothesis that birds used prospective processing in Experiment 1 and retrospective processing in Experiment 2 is the lack of any differences in the latency to respond to test stimuli between these experiments. With prospective processing the retrieval of a matching rule from inactive memory (the "translation process" described by Roitblat, 1980) occurs during the sample, whereas in retrospective processing it occurs after the onset of the test stimuli. It would therefore be predicted that response latencies would be longer following retrospective processing. One possible explanation for the inability to detect response latency differences is that only mean response latencies were available in the present series of experiments. Therefore, no examinaton of correlation between response latency and matching accuracy was possible. It is possible that birds responded at very short latencies on some trials, perhaps performing at chance levels on those trials, while the response latencies on the other, more accurate, trials were actually longer than those in Experiment 1. The other possibility is that no real differences existed, in which case the model presented here of the retrieval of response rules at different points in time for prospective and retrospective processing would have to be modified.

In summary, the above series of experiments demonstrate prospective processing in both choice and successive DMTS, as well as in delayed simple discrimination. This finding is contrary to the usual assumption of retrospective processing. Retrospective processing is also demonstrated, but only in a condition which favors its use.

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