Retrospective and prospective short-term memory in delayed response tasks in rats

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Separate groups of rats were trained and tested on asymmetrically and symmetrically reinforced successive delayed matching-to-sample (DMTS) or delayed discrimination (DD) tasks in Experiment 1. Each rat received training and testing on symmetrically reinforced DMTS and DD tasks in Experiment 2. The only difference between each task was that the rats had to respond correctly to a light or tone test stimulus, S_2 , if it matched a light or tone sample stimulus, S_1 , in DMTS, but could respond to either S_2 if S_1 had been a particular stimulus in DD. Only correct leverpresses were reinforced in the asymmetrically reinforced version of each task. Both correct presses and correct omissions were reinforced in the symmetrically reinforced version of each task. Response biases to leverpress during tests for delayed responding to S_1 were reduced in both symmetrically reinforced tasks, but only in the DD task did such contingencies produce consistently poorer performance in responding to either S_1 in Experiment 1. Declines in accuracy of performance that occurred in both experiments were greater to the visual than to the auditory S_1 only in the DMTS tasks with increased intervals between S_1 and S_2 . A third experiment, in which rats had to respond to S_2 if it matched S_1 (DMTS) or if S_2 mismatched S_1 (DMmTS), was carried out. Modality of S_1 similarly affected accuracy of delayed responding in each task, as in the first two experiments. Methodological and theoretical implications of these results are discussed in terms of Honig and Thompson's (1982) dual-process theory of working memory.

Honig and Thompson (1982) distinguish between retrospection, memory of a previous stimulus, and prospection, retention of an instruction for future responding to the previous stimulus, in short-term memory of non-human animals. The form of a delayed response task may promote one type of processing over the other. In delayed conditional discrimination (DCD), in which responding to a stimulus from a set of stimuli (Blough, 1959) or to a singly presented stimulus (Konorski, 1959) is based on actual or symbolic matching to a prior sample stimulus, retrospection may be necessary. Prospection may occur when either the initial stimulus provides all the information for responding, as in delayed simple discrimination (DD), or after the organism has determined if the test stimulus matches the sample in DCD. Furthermore, retrospection may be more difficult than prospection if the latter requires less information to be retained. Increasing retention intervals between sample and test stimuli does reduce performance more drastically in delayed con-

ditional than in delayed simple discrimination, in pigeons (Honig & Wasserman, 1981; Smith, 1967). Increasing retention intervals after the sample stimuli also disrupts matching more than does increasing them after the conditional stimulus, in pigeons (Honig & Dodd, 1983; Weisman & DiFranco, 1981).

Differences in general performance between DCD and DD or conditional delayed discriminations may provide only weak evidence for the dual-process theory, however. Delayed matching is not always as easily disrupted by increased retention intervals as was the case in the studies already cited. Well-trained pigeons (Grant, 1976) or those presented with sample stimuli of longer durations (16 sec) (Shimp & Moffitt, 1977, Experiment 1) maintain highly accurate matching. Furthermore, prospection could conceivably produce as poor, or worse, retention than retrospection, if the instructions to be rehearsed are as, or more, complex than the stimuli to be remembered. Consequently, the effects of the physical characteristics of the sample stimulus and the nature of the response rules in DCD and DD tasks may better differentiate one process from the other. If retrospection predominantly occurs in DCD, the nature of the sample stimulus, rather than the response rules signaled by it, should affect delayed performance. If prospection occurs mainly in DD tasks, however, the nature of the response rules, rather than the characteristics of the sample stimulus, should affect delayed performance.

In this study, we used the fact that rats match better to a tone than to a light sample stimulus in delayed matching-to-sample (DMTS) tasks (Cohen, Escott, & Ric-

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ciardi, 1984; Wallace, Steinert, Scobie, & Spear, 1980), to test the above hypothesis. In those previous studies, rats had to respond to a second light or tone test stimulus, S_2 , for reinforcement if it matched a first light or tone sample stimulus, S_1 . Accuracy for delayed matching to S_1 was determined by increasing the retention interval (RI) between S_1 and S_2 . In the present study, we presented the same sequential pairs of light and tone stimuli but varied the contingencies for reinforcement so that, in DMTS, responding on S_2 was reinforced if it matched S_1 , but in DD, responding on S_2 was reinforced only if it followed a specific S_1 . We predicted that modality of S_1 would affect performance only in DMTS. In the first experiment, we also varied the complexity of the response rule for reinforcement. The simpler, and presumably easier to prospect, rule merely required the animal to leverpress on S_2 after an appropriate S_1 . Since responding on only half the stimulus pairs would be reinforced, this rule was for asymmetrical reinforcement. The more complex rule allowed animals to obtain reinforcement for both correctly responding to S_2 and correctly omitting a response to S_2 . Since animals could obtain reinforcement on each stimulus pair, this rule was for symmetrical reinforcement. We expected that increased complexity of the latter instructional code would inversely affect delayed performance more in DD than in DMTS. Cohen et al. (1984) found that symmetrical reinforcement reduced a bias to leverpress with increased RIs in DMTS, which enhanced already better delayed matching to the tone S_1 .

The experiments in the present study were also designed to permit analysis of performance by measures of signal sensitivity derived from the theory of signal detection (TSD). Although detailed accounts of TSD exist (e.g., McNicol, 1972), we present a brief description of and rationale for this mode.

TSD was originally developed to assess human capacity for signal detection independent of response bias (Swets, Tanner, & Birdsall, 1961; Tanner & Swets, 1954). Unlike methods from classical psychophysics, which attempt to eliminate response bias, TSD procedures encourage the subject to adopt a wide range of biases or criteria. Manipulation of the payoff structure for making correct and incorrect responses and varying the probability of a signal occurring on a trial are two common methods used to promote changes in criteria. Criteria range from the more conservative, where subjects try to reduce incorrect positive responses (false alarms) at the expense of obtaining correct positive responses (hits), to the more lax, where subjects try to obtain hits, even though false alarms will increase. Proportions of hits and false alarms at each criterion level are measured to form a curvilinear function, the receiver operating curve (ROC), from these data points. ROC defines a unitary signal-sensitivity measure as the area underlying this curve. The proportion of the area, $P(A)$, beneath ROC ranges from .50, no signal detection, to 1.00, perfect signal detection. $P(A)$ rather than d' , the standard score form, is preferred when assumptions of normality and

homogeneity of variance of sensory events of signal and noise in the subject are in doubt (McNicol, 1972).

A unitary signal-sensitivity measure from a range of criteria avoids overestimation of sensitivity from conservative criteria and underestimation of sensitivity from lax criteria. According to D'Amato (1970), analyzing S_1 retention by TSD methods is a logical application of this theory. Such methods should especially be used in tasks in which response biases may be prevalent. Weiskrantz (1968) suggests that Konorski's variant of DCD is more likely to produce a bias for positive responding than is Blough's procedure, because reinforcement is asymmetrically available in the former. Even when reinforcement is symmetrically available in the Konorski DCD, such biases may be reduced but not eliminated in rats (Cohen et al., 1984). We decided to use Konorski's delayed matching task, despite its inherent characteristic to produce response biases, because rats acquire it more easily than they do Blough's version (Wallace et al., 1980). To control for such biases, we employed a TSD sensitivity measure. Since promoting various criterion levels in rats is, at best, difficult, we used an estimation of $P(A)$, $P(\bar{A})$, from only one set of hits and false alarms at each RI. Calculation of $P(\bar{A})$ is described in the first experiment.

EXPERIMENT 1

Method

Design

Two separate groups of rats received identical pairs of sequential stimuli, but one group acquired a successive delayed matching-to-sample task (DMTS) and the other, a delayed simple discrimination (DD). Each rat acquired both the asymmetrically and symmetrically reinforced form of its particular task. A trial began with either onset of chamber lights or a tone (S_1) followed by a 1-sec interval and then either of the same two stimuli (S_2) accompanied by a retractable lever. Thus, there were four different pairs of stimuli: light-light (L-L), tone-tone (T-T), light-tone (L-T), and tone-light (T-L). For reinforcement, animals in the DMTS task had to press to S_2 when it matched S_1 (L-L, T-T). No reinforcement was available on mismatching pairs (L-T, T-L) in the asymmetrically reinforced version of this task. In the symmetrically reinforced form of DMTS, reinforcement was also available if pressing was omitted to S_2 when it differed from S_1 (L-T, T-L). For reinforcement, animals in the DD group had to press to any S_2 if it followed a particular S_1 . Pressing to S_2 after the other S_1 was not reinforced. In the symmetrically reinforced version, reinforcement was also contingent for not pressing to S_2 after the other S_1 . Half the animals in the DD group first learned, and were tested on, the asymmetrical and symmetrical versions of DD in which pressing to S_2 following a light S_1 was reinforced. For the other DD animals, tone S_1 signaled reinforcement for a leverpress. After learning and being tested on this task, the animals were trained and tested on the two forms of the reversed DD task in which pressing to the other S_1 was reinforced.

A multiple baseline procedure was used during the delay test phase following acquisition of each form of DMTS and DD task. Blocks of test trials, each containing fixed increased RIs of 5, 10, and 20 sec, were separated by reacquisition blocks containing 1-sec RIs. Data from each block of test trials were compared with baseline data from the previous block of reacquisition trials. These procedures were designed to overcome any differences in acquisition be-

tween various forms of the DMTS or DD tasks and to allow us to analyze matching to, or differentiation of S_1 by a signal sensitivity score, $P(\bar{A})$, as described by McNicol (1972). We predicted that increased RIs would reduce $P(\bar{A})$ scores more to light than to tone S_1 only in the DMTS group, but would reduce $P(\bar{A})$ scores more for symmetrical than for asymmetrical reinforcement primarily in the DD task.

Subjects

Twelve male albino (Wistar) rats, approximately 90-150 days old at the start of the experiment, served as subjects. They came from our breeding colony and were individually housed with food continuously available in their home cages. They were maintained on a water-deprivation schedule in which water was available for 15-20 min approximately 30 min after each daily session. Animals were divided into equal DMTS and DD groups. Two DMTS animals failed to acquire the task within 60 sessions and were replaced by two animals that had served as subjects in an operant discrimination task with both stimuli as components of a compound $S+$. These replacement rats were considered acceptable because they had experienced the same prediscrimination procedures to learn to press a retractable lever within 5 sec every 30 sec, but had not received any retention intervals during compound discrimination training.

Apparatus

The apparatus was that described by Cohen et al. (1984). It consisted of four commercially available (BRS/LVE) operant chambers, each containing a retractable lever and a .05-ml water dipper on one of the walls and five lights and a tone generator in the ceiling. Each operant chamber was enclosed in a BRS/LVE sound- and light-attenuating isolation chamber, whose ventilation fan produced constant 55-dB masking noise. An external speaker in the running room emitted 62-dB white noise to further mask sounds from programming equipment in the adjacent room. Two 2.5-sec stimulus events, onset of ceiling lights and a 75-dB 2.8-kHz tone, were used. Operant chambers remained dark during intertrial and retention intervals. Reinforcement was .05 ml of sweetened water (.10% sodium cyclamate, w/v) delivered by the dipper.

Procedure

The animals were randomly divided into two separate task groups of six animals each. Each animal received initial approximation training to press a lever every 30 sec within 5 sec of its presentation in the chamber. This training was followed by 4 weeks of preliminary discrimination training, in which positive and negative stimulus pairs were presented in alternating blocks of 10 or 5 trials per session (100 trials) in either the DMTS or DD task. These procedures were designed specifically to reduce the number of animals that might fail to acquire the task. Since these procedures are described elsewhere (Cohen et al., 1984), the following description concentrates on the final training and testing phases of DMTS and DD.

Discrimination training. Animals in both the DMTS and DD groups received sequential pairs of 2.5-sec light and tone stimuli in four possible orders: L-L, T-T, L-T, and T-L. The two stimuli were separated by a 1-sec retention interval (RI) during training. Onset of S_2 was accompanied by a lever that remained out up to 5 sec. Initiation of each trial occurred with onset of S_1 every 24 sec after termination of S_2 of the preceding trial. Each session contained 100 trials. The four different sequential pairs of stimuli appeared equally in each session in a semirandom order, so that matching or mismatching pairs, or the same S_1 of either kind of pair, did not occur more than three times in a row.

Half the animals in each task group were first trained and tested on the asymmetrally reinforced version of their respective task and then trained and tested on the symmetrically reinforced form. The remaining animals were trained and tested first on the symmetrically reinforced and then on the asymmetrally reinforced version of their tasks. DMTS animals received these two stages of training and test-

ing, but DD animals received an extra training and testing phase. In the first phase of training, half the DD animals were trained with the light S_1 as positive for leverpressing and half were trained with tone S_1 as positive. After receiving training and testing under each type of reinforcement symmetry, DD animals were trained and tested on a reversal of their original task. If pressing to S_2 following a light (or tone) S_1 had been reinforced in the first discrimination, now pressing to S_2 following a tone (or light) S_1 was reinforced. Of the three DD rats trained to press after light S_1 , two were first symmetrically reinforced and then asymmetrally reinforced; the third rat had the order reversed. Of the DD rats that first acquired the tone S_1 discrimination, two received asymmetrical and then symmetrical reinforcement. To minimize the disruptive effects of changing from one S_1 discrimination to another in the DD task, we tried to keep the same type of reinforcement contingency in the initial version of the new S_1 discrimination that had existed in the second stage in the first S_1 discrimination. This ABBA sequence for changing reinforcement symmetry was carried out for all rats switched from light S_1 to tone S_1 discrimination. Two rats, initially trained with the tone S_1 discrimination for symmetrical reinforcement on the second stage, however, failed to acquire the reversed light S_1 discrimination for symmetrical reinforcement in the first stage of the second training phase within seven sessions. Therefore, we retrained and tested these animals on the asymmetrally reinforced form of the light S_1 discrimination first.

Every rat in both task groups received a 3-day rest period in its home cage with free access to food and water before each change in training and testing conditions.

In the asymmetrally reinforced form of DMTS, pressing to S_2 produced reinforcement when it matched S_1 (L-L, T-T), but no reinforcement could be obtained when S_2 differed from S_1 (L-T, T-L). In the symmetrically reinforced version of DMTS, not pressing to S_2 when it differed from S_1 (L-T, T-L) would produce reinforcement, as did pressing when S_2 matched S_1 (L-L, T-T). In the asymmetrally reinforced version of the visual S_1 DD, pressing to either S_2 following a light S_1 (L-L, L-T) was reinforced. No reinforcement occurred for pressing on pairs initiated by tone S_1 (T-T, T-L). In the symmetrically reinforced version, omitting a press on pairs initiated by the tone S_1 was also reinforced. In the auditory S_1 DD, pressing to either S_2 following a tone S_1 (T-T, T-L) rather than a light S_1 (L-L, L-T) was reinforced. Omitting a press to either S_2 following light S_1 was also reinforced in the symmetrically reinforced version of this task. In either DMTS or DD tasks, animals could be reinforced only on half the trials in a session for asymmetrical reinforcement but on every trial for symmetrical reinforcement.

An animal was considered to have acquired its specific discrimination task when it pressed correctly on 75% of its total presses in each of two successive sessions. To reach this criterion, the animal had to make at least 30 reinforced and 10 nonreinforced presses per session. This criterion insured that animals did not reach a high proportion of correct presses when they failed to respond correctly for as many or more times.

S_1 delay tests. Delayed responding to S_1 was assessed at RIs of 5, 10, and 20 sec on each task in the following manner. After reaching criterion on a particular version of the discrimination task, each rat received the first block of retention test trials for two sessions (200 trials) with a 5-sec RI in each trial, followed by a series of reacquisition sessions to criterion with 1-sec RIs. A second block of delay test trials for two sessions, with a 10-sec RI in each trial, was presented and followed by a second series of reacquisition sessions to criterion. A final block of delay test trials for two sessions, with a 20-sec RI in each trial, followed the previous reacquisition sessions. If the animal was to be either switched to another form of the same discrimination or, in the case of DD animals, retrained on the reversed discrimination, a final series of reacquisition sessions was run.

Data analysis. Each block of training trials at criterion (200 trials) provided baseline performance for comparison with the following block of 200 delay test trials. Each delay test and baseline block of trials contained 100 matching and 100 nonmatching stimulus

pairs, half of each beginning with the auditory S_1 and half beginning with the visual S_1 . For each DMTS animal, proportions of reinforced and nonreinforced leverpresses on each type of stimulus pair for each S_1 were recorded. In each baseline and test block, DMTS animals could make 50 reinforced presses each to L-L and T-T pairs and 50 nonreinforced presses each to L-T and T-L pairs. For DD animals, number of reinforced and nonreinforced responses was determined by the nature of S_1 . Therefore, proportions of reinforced and nonreinforced presses out of 100 trials to each S_1 were noted. For DD animals trained on the visual S_1 , DD, 100 reinforced presses to stimulus pairs containing a light S_1 (L-L and L-T) and 100 nonreinforced presses to tone S_1 pairs (T-T and T-L) could be made on each block. For DD animals trained on the auditory S_1 , discrimination, 100 reinforced presses to tone S_1 pairs (T-T, T-L) and 100 nonreinforced presses to light S_1 pairs (L-L, L-T) could be made on each block.

Matching to, or differentiation of, S_1 in DMTS or DD, respectively, was determined by an estimate of stimulus sensitivity, $P(\bar{A})$, derived from signal detection theory (McNicol, 1972). $P(\bar{A})$ is an estimate of $P(A)$, the proportion of area lying under a receiver operating curve (ROC) determined by several pairs of proportions of correct or reinforced (hits) and incorrect or nonreinforced (false alarms) presses. Since $P(A)$ makes no assumptions about the distribution of sensory events of signal and noise in the subject, it can be determined graphically. $P(A)$ will range from .50, no differentiation of, or matching to, S_1 , to 1.00, perfect differentiation of, or matching to, S_1 . $P(\bar{A})$ is determined from only one pair of proportions of hits and false alarms. Two possible linear ROC functions may be obtained from a single pair of hit and false-alarm proportions: one through that data point to a common 0 point and the other through it to a common point of unity. $P(\bar{A})$ is the average of the sum of areas lying under both lines which may be calculated algebraically as:

$$P(\bar{A}) = 0.5[(4xy - 3y - y^2 - x^2 + x)/2y(x - 1)],$$

where y = proportion of hits and x = proportion of false alarms.

Previous studies in DCD either were not appropriately designed to generate reliable proportions of hits or false alarms or, if so, used proportion of correct responses [$P(c)$] or discrimination ratios (DR) of number of false alarms to number of hits instead of $P(\bar{A})$. By using blocks of 200 baseline and delay test trials, however, we could generate adequate proportions of hits and false alarms for calculating $P(\bar{A})$ s. $P(\bar{A})$ is superior to $P(c)$ or DR as an index of delayed S_1 differentiation (DD) or matching (DMTS) because it takes into account both declines in hits as well as increases in false alarms. $P(c)$ and DR take into account only number of nonreinforced presses or false alarms. $P(c)$ or DR may be acceptable if the only source of change in stimulus differentiation or matching is due to changes in false alarms, as in two-alternative forced choice tasks (McNicol, 1972), such as simultaneous DMTS. To illustrate this point, consider a rat, trained in the successive DMTS, which adopts a strict criterion by obtaining only 40% hits and no false alarms. Both $P(c)$ and DR overestimate its performance with perfect scores of 1.00 and 0, respectively, but $P(\bar{A})$ shows a slightly poorer performance of .84. Now, if the rat uses a lax criterion by obtaining 99% hits and 60% false alarms, $P(\bar{A})$ is still .84 but $P(c)$ and DR underestimate performance with scores of .62 and .61, respectively. By using a combined proportion of correct responses and omissions, $P(C)$, we will not obtain as great variations with changes in criteria, but, in our example, $P(C)$ yields lower scores of .70 and .74 than does $P(\bar{A})$. Statistical comparisons among these measures (Cohen & Fuerst, 1985) for data from Cohen et al. (1984) support these differences.

Results

Proportion of reinforced (hits) and nonreinforced (false alarms) presses, from which $P(\bar{A})$ scores were derived, was calculated for each animal at each baseline and test

block. These three proportion measures were further changed into arcsin transformations to normalize the data and reduce its heterogeneity of variance for parametric statistical analysis, as suggested by Winer (1971). The data were graphed in raw score form, however, for ease of explanation. A five-way ANOVA [task (DMTS, DD) $\times$ reinforcement symmetry (asymmetrical, symmetrical) $\times$ S_1 modality (light, tone) $\times$ blocks (baseline, test) $\times$ RI (5, 10, 20 sec)] with repeated measures on the last four factors was run on each transformed dependent variable. We followed Ferguson's (1981) suggestion of using Newman-Keuls tests rather than more powerful orthogonal comparisons for individual comparisons.

Proportion of Hits (Reinforced Leverpresses)

Figure 1 shows the proportion of hits and false alarms (nonreinforced presses) at each baseline (1-sec RI) and test block (5-, 10-, 20-sec RI). As seen in Figure 1, reinforced responses to the light S_1 in the DMTS task (on L-L pairs) and DD task (both L-L and L-T pairs) declined on test blocks from baseline levels only for symmetrical reinforcement. No other consistent changes in hits to either the light S_1 in asymmetrical reinforced tasks or the tone S_1 in either form of each task were observed. A significant interaction of S_1 modality $\times$ reinforcement symmetry $\times$ blocks [$F(1,10) = 6.74, p < .05$] and appropriate individual comparisons ($p < .05$) supported these observations. A significant interaction of task $\times$ reinforcement symmetry $\times$ retention interval [$F(2,20) = 5.50, p < .05$] was also found; this was caused by the fact that a significantly ($p < .05$) higher hit rate occurred in DMTS than in DD tasks for symmetrical reinforcement at the 5-sec RI (pooled over baseline and test blocks).

Proportion of False Alarms (Nonreinforced Leverpresses)

False alarms in DMTS animals were nonreinforced responses to L-T and T-L pairs for matching to light S_1 and tone S_1 , respectively. False alarms in DD animals were nonreinforced responses to T-T and T-L pairs combined for differentiation of light S_1 and nonreinforced responses to L-L, L-T pairs combined for differentiation of tone S_1 . Changes in false alarms were clearly more consistent than changes in hits with increased RIs. Under all conditions, false alarms increased with increased RIs. Indeed, these increases were generally greater at 10- and 20-sec RIs than at 5-sec RIs. A significant block $\times$ RI interaction [$F(2,20) = 11.54, p < .01$] and individual comparisons ($p < .01$) confirmed these observations. Greater increases in false alarms to the visual than to the auditory S_1 occurred only for the DMTS group. A task $\times$ S_1 modality $\times$ blocks interaction [$F(1,10) = 7.77, p < .05$] and individual comparisons ($p < .05$) supported this observation. Furthermore, greater increases in false alarms were found in DMTS than in DD tasks only for matching to or differentiation of the visual S_1 (false alarms on T-T and T-L pairs in the DD animals). Reinforcement symmetry affected increases in false alarms to the auditory S_1 primarily in the DMTS tasks.

Figure 1. Mean proportions of hits or reinforced (RP) and false alarms or nonreinforced (NP) presses for matching to each sample stimulus (S_1) in DMTS tasks or for differentiating each sample stimulus (S_1) from the other in DD tasks during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 1. ASYM = asymmetrically reinforced, and SYM = symmetrically reinforced form of each task.

As is evident in Figure 1 and from an interaction of task $\times S_1$ modality $\times$ reinforcement symmetry $\times$ blocks [$F(2,20) = 4.94, p < .05$], greater increases in false alarms to the tone S_1 occurred in the asymmetrically than in the symmetrically reinforced DMTS.

S_1 Matching or Differentiation Scores, $P(\bar{A})$

Figure 2 shows $P(\bar{A})$ scores for baseline (1-sec RI) and delay test blocks (5-, 10-, and 20-sec RIs). $P(\bar{A})$ scores

in DMTS indicate the ability of animals to successfully match S_2 to S_1 over various RIs. $P(\bar{A})$ scores in DD indicate the ability of animals to differentiate a light from tone S_1 when pressing to the light S_1 produced reinforcement (visual S_1 problem) or to differentiate a tone from light S_1 when pressing to the tone S_1 was reinforced (auditory S_1 problem). $P(\bar{A})$ s in the DMTS task for the visual S_1 were derived from proportions of hits to L-L and false alarms to L-T pairs; $P(\bar{A})$ s for the auditory S_1 were derived from proportions of hits to T-T and false alarms to T-L pairs. $P(\bar{A})$ s in the DD task for the visual S_1 were derived from proportions of hits to L-L and L-T pairs combined and false alarms to T-T and T-L pairs combined; $P(\bar{A})$ s for the auditory S_1 were derived from proportions of hits to T-T and T-L pairs combined and false alarms to L-L and L-T pairs combined.

As shown in Figure 2, $P(\bar{A})$ scores generally declined on test blocks from baseline levels. $P(\bar{A})$ s declined more to the visual than to the auditory S_1 only in DMTS, however. Reinforcement symmetry influenced $P(\bar{A})$ scores most consistently in the DD group, where $P(\bar{A})$ s declined with increased RIs more in the symmetrically than in the asymmetrically reinforced problem. A similar effect was observed for the visual S_1 in DMTS at 5- and 20-sec RIs. Comparisons between DMTS and DD tasks also revealed that declines in $P(\bar{A})$ were greater in the former than in the latter only for the visual S_1 . A significant five-factor interaction [$F(2,20) = 4.22, p < .05$] was obtained. Individual comparisons generally supported our observations. Only observed declines in $P(\bar{A})$ at 5-sec RI to the auditory S_1 in the asymmetrically reinforced DD failed to reach significance. In the DMTS task, $P(\bar{A})$ s declined significantly more to the visual than to the auditory S_1 ($p < .05$) except at the 5-sec RI in the asymmetrically reinforced version. No significant differences between visual and auditory S_1 differentiation were found in the DD tasks. Individual comparisons for the effects of reinforcement symmetry revealed that, in the DD task, $P(\bar{A})$ s declined to significantly lower levels ($p < .05$) for symmetrically than for asymmetrically reinforced versions to either S_1 , except in the case of the tone S_1 at the 20-sec RI. Greater declines in $P(\bar{A})$ to symmetrically than to asymmetrically reinforced DMTS also occurred at the 5- and 20-sec RIs for visual S_1 ($p < .05$). Individual comparisons between tasks also revealed that $P(\bar{A})$ s declined to significantly lower levels in the DMTS than in the DD task for the visual S_1 at each RI under either condition for reinforcement, but only for the auditory S_1 at the 5-sec RI for symmetrical reinforcement and at the 20-sec RI for asymmetrical reinforcement ($p < .05$).

Discussion

Results from Experiment 1 generally confirmed predictions based on a retrospective/prospective account of working memory. Poorer delayed matching to visual than to auditory S_1 replicated previous findings (Cohen et al., 1984; Wallace et al., 1980) and suggest that rats cannot retrospect a visual S_1 as well as they can an auditory S_1 .

Figure 2. Mean signal sensitivity scores [$P(\bar{A})$] for delayed matching to each sample stimulus in asymmetrically (ASYM) and symmetrically (SYM) reinforced DMTS, and for delayed differentiation of each sample stimulus in asymmetrically and symmetrically reinforced DD tasks during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 1. VS_1 = visual sample stimulus, AS_1 = auditory sample stimulus.

Complexity of the response rule affected performance more consistently in the DD task, as expected. Here, $P(\bar{A})$ s declined from baseline levels more for symmetrical than for asymmetrical reinforcement. These findings suggest that animals found prospection of the more complex symmetrical reinforcement rule more difficult over longer RIs. Differences in delayed responding between variants of DD may not be due to differences in the amount of information provided by each S_1 , but rather may be due to the contrast of such information. In the asymmetrically reinforced version, S_1 determines if reinforcement is possible, but in the symmetrically reinforced version, S_1 indicates only what type of response will be necessary for reinforcement. Introducing additional reinforcement expectancies of higher contrast for sample stimuli in the form of differential probabilities, amount, or kinds of rewards similarly improves actual or symbolic delayed matching performance in pigeons (Brodigan & Peterson, 1976; DeLong & Wasserman, 1981; Edwards, Jagielo, Zentall, & Hogan, 1982; Honig, Matheson, & Dodd, 1984).

Effects of reinforcement symmetry partially replicated those reported by Cohen et al. (1984). Although biases to leverpress with increased RIs were lower for symmetrical than for asymmetrical reinforcement in DMTS, such reductions were insufficient to attenuate declines in $P(\bar{A})$ to the tone S_1 . Reinforcement symmetry did affect changes in $P(\bar{A})$ to the light S_1 . Even though biases to respond to light S_1 were lower for symmetrical reinforcement, $P(\bar{A})$ s declined more for symmetrical than for asymmetrical reinforcement. Since neither S_1 provided different expectancies for the possibility of reinforcement in DMTS, such

effects of reinforcement symmetry on $P(\bar{A})$ scores to light S_1 cannot be explained by the same processes in DD. Since $P(\bar{A})$ levels for either condition of reinforcement were not significantly higher than .50, no retention, at 20-sec RIs, these differences were more an artifact of reduction in hits (reinforced presses) without any compensatory attenuation in increases of false alarms (nonreinforced presses) for symmetrical reinforcement.

Although both groups received the same pairs of stimuli, they did not receive comparable training and testing procedures. DMTS animals received only one form of their task, whereas DD animals experienced a reversal of their initially acquired and tested discrimination. Delayed responding to each S_1 occurred within the same sessions for DMTS, but across sessions in DD. Proportions of hits and false alarms were also based on twice as many test trials within the same block of trials in the DD as in the DMTS task. These procedural differences may have contributed to differences in performance between these tasks. Associated with these problems was the fact that $P(\bar{A})$ scores were calculated from different stimulus pairs between each task. These possibly confounding factors prompted us to carry out the second experiment in which procedures between tasks were more comparable.

EXPERIMENT 2

Method

Design and Rationale

Experiment 2 was a systematic replication of the first experiment. In this experiment we wanted to determine if the type of task would

alter the S_1 modality effect for the same subject trained and tested under more comparable conditions. All rats were trained and tested in symmetrically reinforced DMTS and DD tasks. Order of presentation of tasks was counterbalanced so that half the rats received training and testing first on DMTS then on DD, and half first on DD then on DMTS. When acquiring the DD task, half the rats were reinforced both for pressing to either S_2 following a light S_1 and for not pressing to either S_2 following a tone S_1 ; the other half were reinforced for pressing to either S_2 following a tone S_1 and for not pressing to either S_2 following a light S_1 .

Testing for S_1 differentiation in DD was more comparable to testing for S_1 matching in DMTS in this experiment. Symmetrical reinforcement in which different responses to each S_1 were reinforced made it possible to compare differentiation between light and tone S_1 within the same block of sessions. To carry out such within-block comparisons, we had to include both omissions and presses in definitions of hits and false alarms in the DD task. The outcome of presses was sufficient to determine hit and false-alarm rates in DMTS, however, due to the nature of that task. Light S_1 differentiation was determined from signal sensitivity $P(\bar{A})$ s derived from proportions of hits to L-L and false alarms to T-L. Tone S_1 differentiation was indicated by $P(\bar{A})$ s based on proportions of hits to T-T and false alarms to L-T. If pressing to light S_1 and not pressing to tone S_1 were reinforced, then hits were reinforced presses to L-L and reinforced omissions to T-T; false alarms were nonreinforced presses to T-L and nonreinforced omissions to L-T. If pressing to tone S_1 and not pressing to light S_1 were reinforced, hits were reinforced presses to T-T and reinforced omissions to L-L; false alarms were nonreinforced presses to L-T and nonreinforced omissions to T-L. $P(\bar{A})$ s for S_1 differentiation measured the subject's capacity to differentiate between sample stimuli for each type of response.

It should be noted that $P(\bar{A})$ for light S_1 differentiation based on hits to all pairs with light S_1 (L-L, L-T) and false alarms to all pairs with tone S_1 (T-T, T-L) would be arithmetically identical to $P(\bar{A})$ for tone S_1 based on the same combination of hits and false alarms. By using $P(\bar{A})$ for light S_1 based on proportions of L-L hits and T-L false alarms, and $P(\bar{A})$ for tone S_1 based on proportions of T-T hits and L-T false alarms, we insured that each measure could vary independently. Other combinations of hits and false alarms could have been used to derive independent measures of $P(\bar{A})$ for each S_1 , but we chose these combinations because (1), they allowed for a comparison between S_1 with S_2 held constant, and (2), they were most similar to combinations used to determine light and tone S_1 matching in DMTS.

By using the same stimulus pairs to obtain hit and false-alarm data in each task, we were also able to determine if the S_1 modality effect in DMTS was merely due to an artifact of calculating $P(\bar{A})$. The design of the first experiment did not permit such an investigation. In this experiment, however, we also recalculated $P(\bar{A})$ from DMTS based on hits from L-L and false alarms from T-L, as in the DD task for light S_1 differentiation. Such $P(\bar{A})$ s were labeled light S_1 pseudodifferentiation in DMTS because the subject was not actually required to respond differently based on modality of S_1 . $P(\bar{A})$ s from DMTS based on hits to T-T and false alarms to L-T were calculated to obtain tone S_1 pseudodifferentiation. If the S_1 modality effect in DMTS is merely a calculation artifact, then no difference between S_1 differentiation or pseudodifferentiation based on S_1 modality should be observed. In other words, animals should be able to detect L-L from T-L pairs as easily as T-T from L-T pairs in either task. If rats retain a light S_1 less well than a tone S_1 , however, a stimulus modality effect will still be evident more in the DMTS than in the DD task. Better S_1 pseudodifferentiation for the light than for the tone S_1 should occur with increased RIs because of fewer false alarms to T-L than to L-T pairs.

By the same logic, we should also calculate pseudomatching $P(\bar{A})$ s for each S_1 in the DD task and compare them to actual matching $P(\bar{A})$ s in DMTS. Such reconstituted $P(\bar{A})$ s may not be able to be used, however, because hits and false alarms would be from different response modes in the DD task. If hits are from reinforced presses

(omissions), then false alarms will be from nonreinforced omissions (presses) in each pseudomatching $P(\bar{A})$. Any bias to press would create better $P(\bar{A})$ scores when presses constituted hits rather than false alarms. Such effects would produce more variable and widely divergent pseudomatching $P(\bar{A})$ scores for DD than would matching $P(\bar{A})$ scores for DMTS.

Subjects

Eight male albino (Wistar) rats, approximately 150 days old at the start of this experiment, were used as subjects. These rats had acquired a compound light + tone successive discrimination in another experiment. That task was similar to the present discriminations, in that the animals were presented with a lever at fixed intervals to which they had to respond if it had been preceded by the compound stimulus. Because no retention intervals occurred between those stimulus-lever presentations, and because the rats responded similarly to each component of the compound in probe tests, we decided to use them in this experiment.

Procedures

The only difference between the present and the first experiment was that, in this experiment, all animals were trained and tested on symmetrically reinforced DMTS and DD tasks. Order of presentation of the tasks was counterbalanced so that half the rats received DMTS then DD and the other half had the order reversed. Half the animals acquired the symmetrically reinforced DD in which reinforcement was contingent upon leverpressing on S_2 following the light S_1 and not pressing on S_2 following the tone S_1 . For the remaining animals, pressing to tone S_1 and omitting presses to light S_1 were reinforced. Otherwise, the training and testing procedures were the same as those described for Experiment 1.

Data Analysis

As in Experiment 1, proportions of hits and false alarms to specific pairs of stimuli were calculated for each block of baseline and retention test sessions. In the DMTS task, reinforced presses to L-L and T-T were identified as hits; false alarms were nonreinforced presses to L-T and T-L pairs. In the DD task, hits were reinforced presses to L-L and reinforced omissions to T-T; false alarms were nonreinforced presses to T-L and nonreinforced omissions to L-T for animals trained to press to light S_1 and withhold pressing to tone S_1 . For animals trained with the opposite rule, hits were reinforced presses to T-T and reinforced omissions to L-L; false alarms were nonreinforced presses to L-T and nonreinforced omissions to T-L.

$P(\bar{A})$ scores for matching to the light S_1 in DMTS were based on proportions of hits and false alarms to L-L and L-T, respectively. $P(\bar{A})$ s for matching to tone S_1 in DMTS were derived from proportions of hits and false alarms to T-T and T-L, respectively. In the DD task, $P(\bar{A})$ s for light S_1 differentiation were calculated from proportions of hits and false alarms to L-L and T-L, respectively; $P(\bar{A})$ s for tone S_1 differentiation came from proportions of hits and false alarms to T-T and L-T pairs, respectively. A set of supplementary $P(\bar{A})$ s from DMTS data was calculated with the same combination of hits and false alarms as in DD. Light S_1 pseudodifferentiation in DMTS was determined from $P(\bar{A})$ s based on proportions of hits and false alarms to L-L and T-L pairs, respectively; $P(\bar{A})$ s for tone S_1 pseudodifferentiation were based on proportions of hits and false alarms to T-T and L-T pairs, respectively.

Arcsin transformations of proportions of hits and false alarms and of $P(\bar{A})$ s were analyzed by appropriate ANOVAs and Newman-Keuls tests for individual comparisons.

Results

Proportion of Hits and False Alarms

Figure 3 shows proportions of hits and false alarms at each baseline (1-sec RI) and test block (5-, 10-, and 20-sec RI) in each task. Although false alarms appeared to

Figure 3. Mean proportion of hits to light-light (L-L) and tone-tone (T-T) pairs; mean proportion of false alarms to light-tone (L-T) and tone-light (T-L) pairs in DMTS and DD tasks during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 2.

increase more from baseline at each test RI and hits declined less in DMTS than in DD, these differences are a measurement artifact. In DMTS, hits and false alarms were defined exclusively in terms of leverpress outcomes, but in DD they were defined in terms of both omissions and press outcomes. Since a strong bias to press still persisted in symmetrically reinforced discrimination, as shown in Experiment 1 and by Cohen et al. (1984), omissions could have enhanced declines in hits and attenuated increases in false alarms to produce the observed group averages in the DD task. To test this possibility, a preliminary comparison between changes in presses and omissions for hits and false alarms in the DD task was carried out by separate ANOVAs of response mode $\times$ blocks $\times$ RI for hits and false alarms. As expected, response mode $\times$ blocks interactions were found for hits [$F(1,14) = 43.07, p < .01$] and false alarms [$F(1,14) = 28.80, p < .01$], which were attributed solely to decreases in reinforced omissions and increases in nonreinforced presses from baseline to test levels. In view of these effects, we carried out separate S_1 modality $\times$ blocks $\times$ RI ANOVAs for hits and false alarms for each task and compared only differences in the patterns of change between tasks as a function of S_1 modality.

Proportion of hits. As shown in Figure 3, S_1 modality affected declines in hits from baseline levels only in the DMTS task. Here, hits declined slightly, but reliably, more to light than to tone S_1 . A significant S_1 modality $\times$ blocks [$F(1,7) = 6.17, p < .05$] interaction occurred. Individual comparisons indicated that only hits to light S_1 significantly declined from baseline levels ($p < .01$) and to levels significantly lower than those for tone S_1 at test blocks ($p < .05$). In the DD task, a main effect for blocks [$F(1,7) = 153.30, p < .001$] and individual

comparisons confirmed that hits to either S_1 declined significantly on test blocks ($p < .01$) to equivalent levels.

Proportion of false alarms. Figure 3 shows that false alarms increased more to the light S_1 (L-T pairs) than to tone S_1 (T-L pairs) in either task. An interaction for S_1 modality $\times$ blocks $\times$ RI was found in DMTS [$F(2,14) = 5.20, p < .05$] and DD [$F(2,14) = 4.25, p < .05$]. Although false alarms increased significantly to each S_1 in the DMTS task, they rose significantly more to the light S_1 than to the tone S_1 at each RI ($p < .05$). False alarms also increased more at the 20- than at either the 10- or 5-sec RI for light S_1 and more at the 10- than at the 5-sec RI for tone S_1 . In the DD task, false alarms increased significantly only to the light S_1 at the 10- and 20-sec RIs ($p < .01$) and to levels significantly above those to the tone S_1 ($p < .05$).

S_1 matching or differentiation scores, $P(\bar{A})$. Figures 4 and 5 show $P(\bar{A})$ scores for each baseline (1-sec RI) and delay test block (5-, 10-, and 20-sec RI) for each task. In Figure 4, $P(\bar{A})$ s for DMTS determine matching to each S_1 ; $P(\bar{A})$ s for DD determine differentiation of each S_1 . In Figure 5, $P(\bar{A})$ s for DMTS were based on recalculations of the same combinations of hit and false-alarm proportions as were those for DD. These $P(\bar{A})$ s, in Figure 5, for DMTS are termed S_1 pseudodifferentiation $P(\bar{A})$ s.

Prior to carrying out ANOVAs for direct comparisons between tasks, we had to determine if using different response measures to generate $P(\bar{A})$ s in DD affected this

Figure 4. Mean signal sensitivity scores [$P(\bar{A})$] for delayed matching (match) to visual (VS₁) and auditory (AS₁) sample stimuli in DMTS and for delayed differentiation (diff) to each S_1 in DD during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 2.

Figure 5. Mean signal sensitivity scores [$P(\bar{A})$] for delayed pseudo-differentiation (p-diff) in DMTS and delayed differentiation (diff) in DD to visual (VS₁) and auditory (AS₁) sample stimuli during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 2.

measure. It will be recalled that if an animal had $P(\bar{A})$ s generated from presses for one S_1 , its $P(\bar{A})$ s for the other S_1 were based on omissions. Preliminary Mann-Whitney U comparisons between $P(\bar{A})$ s generated from presses and those based on omissions failed to reveal any significant differences at each block of sessions. Pseudomatching to sample $P(\bar{A})$ s in DD could not be used, however, because different combinations of presses and omissions would have had to be used in calculating $P(\bar{A})$ s. $P(\bar{A})$ s would have had to be based on proportions of reinforced presses and nonreinforced omissions or on proportions of reinforced omissions and nonreinforced presses. The former combination would be expected to produce greater $P(\bar{A})$ s, especially during delay test blocks due to a bias to lever-press. Preliminary comparisons between both types of $P(\bar{A})$ s at each block (Mann-Whitney U tests) revealed that $P(\bar{A})$ s based on proportions of reinforced presses and nonreinforced omissions were significantly higher than $P(\bar{A})$ s from proportions of reinforced omissions and nonreinforced presses at each test block ($U \geq 9$, $p \leq .01$). $P(\bar{A})$ transformed data were analyzed by four-way ANOVAs (task $\times$ S_1 modality $\times$ blocks $\times$ RI), with all factors repeated and Newman-Keuls tests for individual comparisons.

Inspection of Figure 4 shows that although $P(\bar{A})$ s declined from baseline levels at delay test blocks in each

task, such declines were greater to the visual than to the auditory S_1 only in DMTS for matching-to-sample performance. Delayed discriminative responding was not uniformly better than delayed matching performance. $P(\bar{A})$ s for matching declined more in DMTS to visual S_1 but less to the auditory S_1 than did $P(\bar{A})$ s to either S_1 in DD. A significant interaction of task $\times$ S_1 modality $\times$ blocks [$F(1,7) = 72.01$, $p < .01$] and individual comparisons ($p < .01$) confirmed these observations.

When $P(\bar{A})$ s for S_1 pseudodifferentiation in DMTS were compared to $P(\bar{A})$ s for actual S_1 differentiation in Figure 5, S_1 modality effects were again more prevalent in DMTS than DD. $P(\bar{A})$ s declined more for tone than for light S_1 pseudodifferentiation at 5- and 20-sec RIs. A similar difference at 10-sec RI was seen in the DD task. Although a four-factor interaction barely missed significance [$F(2,14) = 3.15$, $p = .074$], we ran individual comparisons anyway to confirm our observations ($p < .05$).

Discussion

Results in the second experiment, with more comparable testing procedures between tasks, replicated the findings from the first experiment. Modality of S_1 affected delayed responding primarily in DMTS rather than in DD for the same rat. Delayed matching declined more to a visual S_1 than to an auditory S_1 , a finding similar to that reported in earlier research (Cohen et al., 1984; Wallace et al., 1980). That such an effect was largely absent in DD cannot be attributed to differences in calculating $P(\bar{A})$. When $P(\bar{A})$ s in DMTS were recalculated as in DD, S_1 modality was still more influential in affecting declines in these scores in the DMTS than in the DD task. Here S_1 pseudodifferentiation was poorer to tone than to light S_1 because more false alarms occurred to L-T than to T-L pairs. Poorer retention of the light S_1 in DMTS accounts for these differences in S_1 pseudodifferentiation in DMTS.

Although retention of response rules varying in complexity were not compared in this experiment, our findings also indicate that performance in DD may not always be superior to that in DMTS. Under a relatively complex response rule for symmetrical reinforcement, DD performance declined more for tone S_1 but less for light S_1 than did DMTS performance. These findings are contrary to earlier reports of better DD than DMTS performance at increased delays (Honig & Dodd, 1983; Honig & Wasserman, 1981; Smith, 1967) but are not inconsistent with the dual-process theory (Honig & Thompson, 1982).

Although our findings point to a predominant retrospective process in DMTS and a prospective one in DD, neither may be exclusively promoted by each task. Experiment 2 allowed for a more refined analysis of S_1 modality effects in DD through measures of responding to each stimulus pair. S_1 modality affected changes in both hits and false alarms in DMTS, as expected, but S_1 modality also influenced changes in false alarms in the DD task. False alarms increased more to L-T than to T-L pairs

in DD. Such differences were not large enough to affect $P(\bar{A})$ s, but they do raise the possibility that some degree of retrospection of S_1 also occurred in the DD task.

EXPERIMENT 3

The fact that the S_1 modality effect was found only in DMTS in the first two experiments was considered as evidence for retrospective memory in DMTS and prospective memory in DD. One might argue, however, that prospection could also account for the modality effect in DMTS, if rats are less able to maintain an instruction from a sample stimulus to respond to a visual than they are to an auditory test stimulus. Consequently, the modality of the appropriate S_2 for which a response will provide reinforcement, rather than the modality of the initial sample stimulus, should affect actual or symbolic matching. If a tone S_1 indicates that reinforcement is contingent upon responding when S_2 is a light rather than a tone, and light S_1 indicates the opposite contingency, then according to this prospective account, accuracy of delayed responding should be poorer following the tone than following the light S_1 . According to the retrospective account, accuracy of delayed responding to S_2 should still be poorer after the light than after the tone S_1 . We tested these alternative accounts in the third experiment by comparing the performance of rats trained and tested on asymmetrically reinforced DMTS with that of rats trained and tested on an asymmetrically reinforced delayed mismatching-to-sample (DMmTS) discrimination. In the latter task, reinforcement was contingent upon responding to S_2 when its modality differed from S_1 (L-T, T-L pairs).

Method

Subjects

The subjects were 14 male albino rats that were veterans of the same compound discrimination task as those in the first two experiments. The animals were randomly and equally divided into the DMTS and DMmTS groups.

Procedure

The basic procedures for training and testing were the same as those described for the initial experiments. All animals were trained and tested on the asymmetrically reinforced versions of their assigned task. Reinforcement was contingent for pressing on S_2 only when it matched S_1 (L-L, T-T) in DMTS and only when it differed from S_1 (L-T, T-L) in DMmTS. Correct omissions were not reinforced in either task. Three-way ANOVAs [task (DMTS vs. DMmTS) $\times$ blocks (baseline vs. delay tests) $\times$ RI (5, 10, 20 sec)], with repeated measures on the last two factors and Newman-Keuls tests for individual comparisons, were carried out on arcsin transformations of proportions of hits (reinforced presses), proportions of false alarms (nonreinforced presses), and $P(\bar{A})$ retention scores.

Results

Proportions of Hits and False Alarms

Figure 6 shows proportions of hits and false alarms at each baseline (1-sec RI) and test block (5-, 10-, and 20-sec RIs) in each task. Hits declined slightly more to the light than to the tone S_1 in each task, as shown in Figure 6 and found by a significant S_1 modality $\times$ blocks interac-

Figure 6. Mean proportion of hits and false alarms for delayed matching (DMTS group) or mismatching (DMmTS group) to the visual (VS_1) and auditory (AS_1) sample stimuli during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 3.

tion [$F(1,12) = 17.27, p < .01$]. A significant triple interaction of these two factors with task was also uncovered [$F(1,12) = 7.05, p < .05$], but this was only due to significantly more hits made to light than to tone S_1 at baseline in DMTS ($p < .05$).

False alarms increased substantially from baseline at each delay, but did so more to the light than to the tone S_1 in each task. A significant interaction between S_1 modality and blocks [$F(1,12) = 11.56, p < .01$] supported this observation. Individual comparisons further revealed that false alarms significantly increased ($p < .05$) more to light than to tone S_1 , except at the 20-sec RI in the DMTS task.

S_1 Matching or Mismatching Scores, $P(\bar{A})$

Figure 7 shows $P(\bar{A})$ scores from baseline (1-sec RI) and delay test blocks (5-, 10-, and 20-sec RIs). Within each task, $P(\bar{A})$ s declined from baseline levels more to the light than to the tone S_1 . A significant interaction between S_1 modality and blocks [$F(1,12) = 67.58, p < .01$] and individual comparisons ($p < .01$) supported this observation. No significant effects due to task were found.

Discussion

Aside from two minor differences in changes in hits and false alarms, animals in each task behaved similarly by increasing false alarms and decreasing hits and $P(\bar{A})$ scores more from baseline levels to light than to tone S_1 . These results clearly support a retrospective rather than a prospective interpretation of the S_1 modality effect in DMTS observed in the first two experiments. These findings also replicate and extend those of Wallace et al. (1980), who found better simultaneous delayed symbolic

Figure 7. Mean signal sensitivity scores [$P(\bar{A})$] for delayed matching (DMTS group) or mismatching (DMmTS group) to the visual (VS_1) and auditory (AS_1) sample stimuli during baseline (1-sec RI) and delay test (5-, 10-, 20-sec RIs) blocks in Experiment 3.

matching to sample for a tone than for a light S_1 (Experiment 1). In their experiment, however, the animals had to choose between two discrete visual stimuli (steady vs. flashing light). The global visual S_1 may have proactively interfered with choices between the discrete, localized visual stimuli. Our design, which used the same test as sample stimuli in both an actual matching and a symbolic matching (mismatching) procedure, eliminated the possibility of differential S_1 proactive interference.

GENERAL DISCUSSION

Findings from the first two experiments are consistent with Honig and Thompson's (1982) dual-process theory of working memory. In DMTS, the animal must generally retrospect the nature of S_1 to perform correctly to S_2 , but in DD, S_1 provides the animal with all the information to respond correctly to S_2 , so that the animal only has to prospect or rehearse the instruction about responding signaled by S_1 . Therefore, differences in the ability to retrospect different S_1 s in DMTS should disappear in DD. Rats in the present study appeared to retrospect a visual sample stimulus less well than an auditory sample stimulus, but prospected the response rules indicated by each equally well or poorly over increased retention intervals. Prospection may lead to either better or poorer performance than retrospection, however, depending upon the complexity of information to be retained under each process.

Findings from the third experiment indicate that the S_1 modality effect observed in DMTS cannot be accounted for by prospection—that is, animals having more difficulty

remembering to press on a light S_2 than on a tone S_2 as signaled by S_1 . In Experiment 3, rats were equally less able to delay matching or mismatching to a visual than to an auditory S_1 .

Even though retrospection appears to be dominant in DMTS and prospection appears to be dominant in DD, each process may not be exclusively associated with each task. Some evidence for retrospection in DD was observed in Experiment 2, in which rats increased false alarms more to the visual than to the auditory S_1 . Perhaps such an S_1 modality effect indicates residual retrospection, initially used in early acquisition, but not yet completely supplanted by prospection. A similar idea was proposed by Weisman, Wasserman, Dodd, and Larew (1980), who found that control by S_2 declined in favor of control by stimulus order in later training on stimulus sequence discrimination in pigeons. Some residual retrospection of S_1 during increased retention intervals also may have been maintained by our rats in Experiment 2 to retrieve complex instructions initiated by that stimulus. In other words, retrospection may serve as an aid for prospective retention or rehearsal in DD tasks.

In a rather obvious way, prospection must also occur in DCD tasks. Although the subject may have to retrospect S_1 until S_2 occurs, when S_2 is presented, the rat, for accurate performance, will have to prospect the response instruction and outcome associated with the stimulus sequence. Evidence of this type of temporal sequencing of each process is found in greater disruption of matching accuracy by increased RIs following S_1 than following S_2 (Honig & Wasserman, 1981; Weisman & DiFranco, 1981). If the rule to be prospected during post- S_2 RIs is

sufficiently complex, however, such general differences in performance would not always occur. In our preparation, for example, increasing RI only after S_1 rather than after S_2 should produce poorer matching to visual than to auditory S_1 . If, as Honig (1978) suggests, a response to terminate a present trial and advance to the next trial indicates prospective anticipation of a negative outcome, then when the subject chooses to make an advance response within a DCD task should also indicate possible retrospection. Weisman, Gibson, and Rochford (1984) found that pigeons would advance to the next trial at S_1 when it signaled a negative outcome, but waited to advance on S_2 when such outcomes were codetermined by both stimuli. Delaying advance responding until S_2 may require some retrospection of S_1 .

A more difficult question arises if prospection as well as retrospection occurs to S_1 in DCD tasks. The design of the present study was not suited to assess such possible simultaneous processing. Enhancing prospection of S_1 by having it differentially predict some aspect of reinforcement, as discussed earlier, or by requiring subjects to respond differently to each S_1 to produce test stimuli (Shimp & Moffitt, 1977, Experiment 3; Urcuioli & Honig, 1980; Zentall, Hogan, Howard, & Moore, 1978) improves delayed actual or symbolic matching in the pigeon. The general interpretation of these findings has been that such improvements represent a usurpation of a less efficient retrospective process by a prospective one. As we have shown, however, prospection does not necessarily guarantee better retention but will eliminate differential retention based on stimulus modality. Therefore, a better indication of reduction of retrospection by such experimentally induced prospection would be a decline of the stimulus-modality effect. Such a demonstration still does not determine if prospection of S_1 occurs naturally in DCD tasks. If prospection represents slower instructional set learning and retrospection represents an initial memory process, then our techniques of differentiating retention to light and tone S_1 could be used to assess the development of acquiring response rules. We might expect that the stimulus modality effect should diminish or possibly disappear (if prospection takes over completely) with continued DCD training.

The preceding discussion offers some possible ways to study the relative contribution of retrospective and prospective processes in short-term retention. Those ideas rest upon the demonstration that some kinds of stimuli will be retained better than others. Although humans share with rats a similar characteristic of being able to retain information presented auditorily better than they can information presented visually (Conrad & Hall, 1968; Murdock, 1968; Murdock & Walker, 1969; Watkins, Watkins, & Crowder, 1974), pigeons fail to display such a distinction (Kraemer & Roberts, 1984). Perhaps the demonstration of differential short-term retention of sample stimuli based on other orthogonal dimensions may have to be established before similar investigations are carried out on pigeons. Kraemer and Roberts's (1984)

findings do raise the possibility that separate modality-specific memory areas, each possessing different decay, interference, and retrieval characteristics, may be more a mammalian than an avian trait. Finally, we note that Kraemer and Roberts's (1984) procedures differed from ours in that they trained and tested their pigeons with stimuli exclusively on one modality and then exclusively on the other. We presented both types of stimuli within the same task. A replication of their work should be carried out with rats to determine if modality-specific effects on S_1 retention are influenced by training and testing procedures.

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