PIGEONS' SPATIAL MEMORY: II. ACQUISITION OF DELAYED MATCHING OF KEY LOCATION AND TRANSFER TO NEW LOCATIONS

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Five hungry pigeons first received delayed matching of key location training. Trials began with a "ready" stimulus (brief operation of the grain feeder). Then one (randomly chosen) of a set of four keys from a three-by-three matrix was lit briefly as the sample. After a short delay (retention interval), the sample key was lit again along with one of the other eight keys. A peck at the key that had served as the sample produced grain reinforcement, whereas a peck to the other key produced only the intertrial interval. After delayed matching of key location was learned, the remaining five key locations were introduced as samples. Four of the five birds performed at considerably above-chance levels on the novel sample trials during the first as well as subsequent sessions. These results suggest that pigeons sometimes learn the single rule—"choose the location that matches the sample." The relevance of these results to the issue of whether pigeons learn a generalized matching rule (i.e., a concept of "sameness") is discussed.

Key words: delayed matching to sample, key location as samples, transfer to novel samples, rule learning, "sameness" concept, remembering, key peck, pigeons

In delayed matching to sample (DMTS), a sample stimulus is presented and then terminated, after which choice or comparison stimuli, one of which is identical to the sample, are presented. Choice of the comparison that matches the sample is reinforced, whereas choice of a nonmatching comparison is not. The subject must remember the sample to choose the matching comparison; however, it is advantageous for it to forget the sample once the trial is over. For this reason, DMTS performance is often characterized as "working memory" (Honig, 1978).

The nature of the learning that occurs during DMTS is a long-standing issue. A widely held position (e.g., Carter & Werner, 1978) is that pigeons solve DMTS problems by learning a set of "if . . . , then . . . " rules (e.g., if red is the sample, then choose the red comparison; if green is the sample, then choose green) rather than a single, generalized matching rule ("choose the stimulus that matches the sample").

The major purpose of the present study was

to examine the effects of introducing novel samples on pigeons' delayed matching of key location performance (Wilkie & Summers, 1982; see also Smith, Attwood, & Niedorowski, 1982). The single- and multiple-rule models make different predictions about the effects of such a manipulation. According to the multiple-rule model, a bird that had learned a set of sample-specific rules would perform no better on novel sample trials than it did during the first session of original training. The single-rule model, on the other hand, predicts as good performance on novel as on old samples.

The design of the study was as follows. We employed a three-by-three matrix of pecking keys, one of which was lit briefly as a sample at the start of a trial. After a delay (retention interval), the previously lit key and one of the remaining keys were lit. A peck to the key that had been lit as the sample was reinforced, whereas a peck to the other key produced only the intertrial interval. During acquisition four key locations were used as samples. Then, the remaining five key locations were introduced as novel samples.

METHOD

Subjects

Five Silver King pigeons, reduced to about 85% of their free-feeding weights, served. Each bird previously had been trained to peck keys

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lit red or green. All birds were naive about delayed matching to sample.

Apparatus

Nine clear Plexiglas pecking keys (3.25 cm in diameter) were mounted (5 cm apart, center to center) on one wall of a ventilated, light-proof, sound-attenuating chamber. The center key of the matrix was about 20 cm above the floor. Behind each key was a microswitch, which sensed key pecks having a force greater than about 15 g (.15 N), and a FLV117 red light-emitting diode. The key locations from the pigeons' perspective were numbered as follows:

3	2	1
6	5	4
9	8	7

A BRS/LVE grain feeder was mounted on either the same wall as the key matrix (one chamber) or on a wall at right angles to the wall on which the keys were mounted (two chambers). Data collection and experimental control were carried out by a Data General NOVA 3 computer, BRS/LVE interface, and the MANX language (Gilbert & Rice, 1979).

Procedure

Preliminary training. Because the birds were unaccustomed to the chambers and the nine-key matrix, all birds first underwent training to eat from the grain feeder. Next, the birds received autoshaping training to establish key pecking. After a 20-sec intertrial interval (ITI), a randomly selected (without replacement) key was illuminated for 10 sec or until the key was pecked, whichever occurred first. Key illumination offset was followed by 5-sec access to mixed grain. This training, consisting of 45 trials per daily session, continued until each bird pecked on a substantial proportion of trials. The final stage of preliminary training consisted of illuminating Key Location 1 until it was pecked. This peck turned off Key 1 and produced 5-sec access to grain, which was followed immediately (i.e., no ITI) by the illumination of Key 2. A peck to this key produced grain and lit Key 3. This sequence continued until all nine keys were pecked; then the sequence was repeated (for a total of five times per daily session). This training lasted between two and six sessions for the different birds.

The experiment proper. The experiment consisted of two phases. In the Baseline Phase the pigeons were trained to match key locations with four key locations serving as samples. In the Transfer Phase the remaining five key locations also served as samples.

Baseline Phase. Daily sessions had 36 trials. Each trial began with a 1-sec operation of the feeder (too brief to permit eating of the grain) as the "ready" stimulus. Then, .6 sec later, one of a set of four key locations was randomly selected (without replacement) as the sample and illuminated for 2 sec. The key locations serving as samples for the different birds were: 1, 2, 8, and 9 for Subjects NN and Peter; 3, 5, 6, and 7 for Subject Perry; 2, 3, 4, and 9 for Subjects RR and Captain.

Sample presentation was followed by a 1-sec delay (retention) interval, with all keys dark. After the delay the sample key again was lit along with one (randomly selected) of the remaining eight keys. These comparison keys remained lit until the pigeon pecked one of them. If it pecked the comparison that had been the sample, the bird received 5-sec access to mixed grain followed by a 20-sec ITI; if it pecked the other alternative, the bird received a 25-sec ITI.

These conditions were in effect for 17 (NN), 19 (Perry), 18 (RR and Peter), or 29 (Captain) sessions.

Transfer Phase. The procedures were identical to those in the Baseline Phase except that samples were randomly chosen (without replacement) from all nine possible locations. This phase lasted for 14 sessions for each bird.

Data recording. On each trial a record was made of which key location had served as sample and whether the matching location was chosen. This permitted calculation of matching accuracy for each key location. Late in the Baseline Phase (early Transfer Phase for Bird NN), I noticed that the pigeons occasionally pecked the sample when it was illuminated and sometimes pecked this key location during the retention interval. From this point onwards the number of such pecks per session was recorded.

RESULTS

Figure 1 shows the percentage of trials on which the birds pecked the comparison key that had been the sample. In the Baseline

Fig. 1. Percentage of trials with correct matches during each session of the Baseline and Transfer Phases. Chance performance is 50%.

Phase (left-hand panel) all birds matched at greater than 85% correct at asymptote and all reached this level quickly. An incidental observation regarding acquisition of delayed matching of key location was that performance during initial sessions began at or above chance, not below as often is the case with other matching procedures (e.g., Holmes, 1979).

When the five novel samples were introduced (Transfer Phase—right-hand panel),

each bird continued to match at above-chance levels on trials with both the old and new samples (except Bird RR on early novel-sample trials).

Table 1 shows details of first session and first week of the Transfer Phase. Two birds (NN and Captain) performed at above-chance levels on all five samples during the first transfer session; two birds (Perry and Peter) were above chance on four of the five novel-sample trials. Three birds (NN, Peter, and Captain)

Table 1
Percent Correct before (Two Left-Hand Columns) and after (Two Right-Hand Columns) Transfer to Novel Samples

Bird	NN			Perry			RR			Peter			Captain		
Key	Last Week	First Day	First Week	Last Week	First Day	First Week	Last Week	First Day	First Week	Last Week	First Day	First Week	Last Week	First Day	First Week
1	76	100	100	96	—	75	61	—	50	68	86	67	100	93	86
2	89	100	100	96	—	75	79	86	100	96	86	78	75	86	89
3	—	—	100	100	95	100	100	92	78	82	—	—	100	96	89
4	—	—	75	93	—	100	100	84	78	86	—	—	100	93	93
5	—	—	100	100	87	89	75	79	—	50	79	—	100	89	96
6	—	—	100	100	87	89	100	93	—	75	64	—	75	79	96
7	—	—	75	89	95	100	75	93	—	50	46	—	25	75	79
8	98	100	100	100	—	—	75	86	—	25	29	78	100	100	86
9	97	100	100	96	—	50	86	94	89	75	93	90	100	93	93
Novel-sample average on first day	90			75			50			80			90		
First day of original training	78			50			56			53			58		

made no errors during the first transfer session on three novel-sample trials. Bird RR performed at above-chance level on only one of the five novel-sample trials (Key Location 6).

Table 1 (bottom) also shows a comparison of average matching accuracy on novel-sample trials during the first day of Transfer Phase and matching accuracy during the first day of original training. In all cases (except bird RR) the subjects performed with more accuracy on the novel-sample trials than they did during the first session of delayed matching of key location training.

Over the first week of the Transfer Phase (28 trials for each of the five novel samples), performance on all novel-sample trials for all subjects except Bird RR clearly exceeded chance. Although Bird RR in this period matched at above chance on three of the novel-sample trials, its performance on one sample (Key Location 7) remained at about chance and performance on another (Key Location 8) for some inexplicable reason remained consistently below chance. [First-day Transfer Phase performance for Bird RR excluding Key 7 and Key 8 trials was 58.3%, slightly better than the first day of original training (56%). However, performance during the ensuing 13 sessions with Key 7 and Key 8 trials excluded differed little from the acquisition rate in the Baseline Phase.]

During each session over a period of about a week before and a week after the start of the Transfer Phase, a record was kept of the number of times sample keys were pecked (mean pecks per trial for Birds NN, Perry, RR, Peter, and Captain were 3.67, 1.62, .86, 3.35, and .93, respectively), the number of times these keys were pecked during the delay interval (mean

pecks per trial for Birds NN, Perry, RR, Peter, and Captain were .00, .11, .06, .27, and .05, respectively), and the number of correct choices made. Pearson correlation coefficients were calculated for these three variables for each bird (Table 2). The correlation between pecking the sample and pecking during the delay was inconsistent across birds. All birds showed a positive correlation between the number of sample pecks and the number of correct choices. This relationship was strongest for Bird RR, but even for this subject sample pecking accounted for only 29% of the variability in correct responding. The relationship between delay pecking and correct responding was inconsistent between subjects.

The association between the presence or absence of sample pecking and successful transfer to novel samples also was examined. For each of the first seven (six for Bird NN) sessions of the Transfer Phase a record was kept of whether or not a novel sample was pecked one or more times and whether or not the correct comparison was chosen on a particular novel-sample trial. A significant association ($\chi^2_{.05}$ for 1 df = 3.84) was found for Birds NN ($\chi^2 = 9.54$), Perry ($\chi^2 = 12.32$), and RR ($\chi^2 = 5.17$) but for neither Peter ($\chi^2 = .03$) nor Captain ($\chi^2 = .51$).

DISCUSSION

When one key serves as the sample in the delayed matching of key location procedure, it is possible to invoke the mediation hypothesis (e.g., Meltzer & Nobbe, 1980) to explain how pigeons match key location. According to this hypothesis the pigeon may have pecked at the sample location when it was illuminated and during the delay. Then, after the delay the pigeon simply pecked the sample yet another time. Although it is never clear if such behavior is the actual mechanism of remembering or only collateral behavior (e.g., Stonebraker & Rilling, 1981), the fact that sample- and delay-interval pecking was observed in the present study indicates that this hypothesis merits consideration.

Three predictions can be derived from the mediation hypothesis. First, there should be a high positive correlation between sample pecking and matching accuracy. Second, there should be a high positive correlation between delay-interval pecking at the sample location

Table 2

Correlation coefficients between number of pecks to sample (S), number of pecks during delay (D), and number of correct choices (C).

Bird	r_{SD}	r_{SC}	r_{DC}
NN	*	.35	*
Perry	-.15	.45	.57
RR	.75**	.54**	.47
Peter	.50	.17	-.01
Captain	-.14	.20	-.31
Overall	.37	.43	.10

*no delay pecks

** $p < .05$, two-tailed

and matching accuracy. Third, during the Transfer Phase there should be an association between the presence of novel-sample pecking and correct matching on novel-sample trials. Although the correlation between sample pecking and correct choices was positive for all subjects as predicted by the hypothesis, the correlation was significant for only one subject (Bird RR) and in all cases accounted for less than 30% of the variance in matching accuracy. The correlation between delay-interval pecking at the sample location and correct choices was positive for only two subjects (Birds Perry and RR) and both these coefficients were insignificant and again accounted for no more than about 30% of matching accuracy variance. During the Transfer Phase a significant association between the presence or absence of novel-sample pecking and correct choices on novel-sample trials was found for only three of the five subjects (Birds NN, Perry, and RR). This overall pattern of results provides weak support at best for the mediation hypothesis.

The mediation hypothesis received most support from Bird RR's data. A significant positive correlation between sample pecks and correct choice, a positive (but insignificant) correlation between delay-interval responding to the sample location and correct choice, and a significant association between the presence or absence of pecks at the novel samples and correct choice of these samples was found in Bird RR's data. It is interesting to note that this bird performed no better on novel-sample trials during the Transfer Phase than it did during the original acquisition in the Baseline Phase.

At another level the mediation hypothesis is more difficult to reject. It is possible that the pigeons learned to respond not to sample-key position but to their own body orientation (itself, a response to the lit sample key). Although this version of the hypothesis cannot be rejected here, and indeed would be difficult to evaluate given the obvious technical difficulties of measuring body orientation, data from our previous study of delayed matching of key location seems to be inconsistent with this notion. Wilkie and Summers (1982, Experiment 4) lit three keys as samples. After the delay one of these keys (randomly chosen) and one of the remaining six locations were presented as choices. Each of the four pigeons in the experiment matched at levels exceeding

that expected had the pigeons been simply orienting (or pecking) to one sample location during sample presentation and delay.

It is possible also to phrase the mediation hypothesis in terms of "looking" or even more "central" mediators. However, when this tactic is adopted the hypothesis becomes essentially incapable of being proven wrong and has no advantages over simply assuming that pigeons perform delayed matching of key location by remembering the location of the lit key.

The performance of four of the five subjects (Bird RR being the exception) on novel-sample transfer trials provided support for a single-rule model of DMTS. There are two measures of transfer (cf. Premack, 1978). In the weaker case, there will be savings in learning to match the new samples. In the stronger case, the subjects will perform as accurately on the novel-sample trials as on the training ones. All four birds transferred successfully to novel-sample trials according to the weaker criterion: Each bird's performance on novel-sample trials during the first session of the Transfer Phase exceeded its performance during the first session of the Baseline Phase. However, too much should not be made of successful transfer according to the weak criterion. Pigeons certainly must learn about things besides delayed matching during original training (e.g., position discriminations) and have the benefit of this learning during the transfer phase.

With the possible exception of Bird Perry, the birds also transferred successfully to novel samples according to the stiffer criterion: There was little if any difference over the course of the Transfer Phase between old- and new-sample trials, especially for Birds NN, Captain, and Peter.

There are only a handful of studies claiming to show successful transfer of matching to novel samples and hence evidence for single-rule learning in the pigeon, and all of these (e.g., Honig, 1965; Urcuioli & Nevin, 1975; Zentall & Hogan, 1974) have been criticized on various grounds (e.g., Premack, 1978). The present results seem clear cut and may prove to be the most unambiguous evidence showing that single-rule learning sometimes occurs in pigeons as it commonly does in primates and dolphins (Premack, 1978).

The success of the present study in showing successful transfer of matching to novel samples undoubtedly has something to do with the

fact that the samples were spatial cues rather than the colored fields and geometric forms typically used in previous transfer of matching experiments (e.g., Holmes, 1979). Animals learn very rapidly about spatial cues (e.g., Olton & Samuelson, 1976). As well, animals may have a "natural concept" (Herrnstein, Loveland, & Cable, 1976) for "same place" and "different place" such as they appear to have for "trees" and "water." Further, animals may have had considerable extra-experimental practice at "matching locations." Although it is easy to imagine a predator foraging for prey in the wild with a "win-stay" (or "win-shift") strategy (cf. Olton, Handelman, & Walker, 1981) receiving practice on problems resembling spatial matching (or oddity), it is more difficult to envisage situations in which an animal would have an opportunity to practice color or form matching in the wild.

Other factors as well may have contributed to the successful transfer to novel samples. Two features of our procedure differed from that employed in previous studies. First, the stimuli to be used as novel samples in the Transfer Phase appeared occasionally as incorrect comparisons during the Baseline Phase. The influence of this factor is difficult to gauge. However, it should if anything have produced a negative effect on successful transfer because choice of these key locations in the Baseline Phase was never reinforced, and this should have mitigated against the choice of these keys when they appeared as novel samples. Second, again unlike several other studies, "old" as well as "new" samples appeared during the Transfer Phase. This factor may be important in maintaining a definition of the task for the animal. When only novel stimuli appear, errors may arise because of ambiguity about the task rather than the absence of single-rule learning.

One last issue merits discussion. What is the nature of the single rule acquired by pigeons during delayed matching of key location training?

When a pigeon pecks a key whenever a picture of a tree (or part thereof) is shown and withholds pecks when there is no tree present, even though the pigeon never before has seen these pictures (Herrnstein et al., 1976), we say that the pigeon has an abstract "tree" concept. We say that this concept is abstract because the class of stimuli called trees contains an un-

countably large number of exemplars or is "open-ended." The concept of tree is absolute; a stimulus is categorized as a tree without comparison to other stimuli. The present results suggest that pigeons are also capable of forming an abstract relational concept: Generalized matching to sample of location suggests a concept of "same location as." Still, however, it is probably the case that the pigeon's concept of "sameness" is much more primitive than that of primates: There is little evidence in the literature that the pigeon's concept of "sameness" extends beyond the spatial domain. It may be the case that pigeons can acquire a "same as" concept only for biologically important stimuli, such as spatial location.

Yet undoubtedly some will argue that "sameness" cannot be anything but a general concept, that it cannot be restricted only to a particular set of stimuli. Adherents to this position may argue that a limited form of generalized matching (limited to key location) does not really exist. Perhaps body orientation or direction of looking rather than key location was the controlling stimulus. If this was the case, and our previous discussion indicates that it is difficult to prove otherwise, then the single rule learned during delayed matching of key location would not be "sameness" but rather something akin to "nearest lit key."

Although there may be debate about the specifications of the single rule that characterizes delayed matching to sample of key location, there can be little doubt that a single rule is sometimes learned by pigeons in DMTS procedures.

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