**DELAYED CHOICE RESPONDING BY PIGEONS
WHEN THE CORRECT RESPONSE IS NOT
PREDICTABLE FROM THE SAMPLE STIMULUS**

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Food-deprived pigeons were presented with a row of four response keys situated above a grain hopper aperture. At the start of a trial, three of four keys were randomly selected and illuminated white for six seconds. After a variable blackout period, one of the three previously white keys and the previously dark key were illuminated green, and the remaining white keys were reilluminated as before. A response to the green key that was previously white was reinforced with three-seconds access to grain; a response to any other key resulted in a three-second blackout and the start of a new trial. Five of six subjects responded to the correct green key more often than chance at an interstimulus interval of 1.5 seconds, and they displayed maximal performance at different intertrial interval values ranging from 15 to 60 seconds. Choice accuracy decreased for all but one subject as the interstimulus interval was increased. For the range of interstimulus interval durations employed, decrements in choice accuracy were qualitatively similar to, but lower than those typically obtained from, delayed-matching-to-sample or delayed-pair comparison procedures.

Key words: delayed-choice responding, short-term memory, interstimulus interval, mediating response, key peck, pigeons

A number of delayed-choice procedures are currently used to investigate the short-term retention of visual information by pigeons. These include delayed-matching-to-sample, or DMTS tasks (Roberts & Grant, 1976); symbolic delayed matching-to-sample tasks (Zentall, Edwards, Moore, & Hogan, 1981); and delayed-pair comparison procedures (Shimp & Moffitt, 1977).

During a standard DMTS task, subjects are initially presented with a sample stimulus such as a uniformly colored keylight. Following a retention interval, two or more spatially distinct test stimuli are presented. One test stimulus is identical to the sample shown earlier, whereas the others are not. Only responses to the identical test stimulus are reinforced. The symbolic DMTS procedure is similar except that arbitrary relationships based on different

stimulus dimensions are scheduled between the sample and test stimuli. For example, a sample stimulus may consist of either a green or red keylight, whereas only horizontal and vertical lines are used as test stimuli.

A characteristic shared by these procedures is that the response to be reinforced during the presentation of the test stimuli is predictable from the value of the sample stimulus. In a standard DMTS procedure, the test stimulus identical to the sample will always be correct, whereas in the symbolic DMTS procedure, a red sample stimulus might immediately indicate that the correct choice will be to the key with a vertical line on it when the test stimuli eventually appear.

Data from standard and symbolic DMTS experiments are commonly cited as justification for stating that pigeons possess a short-term memory (Roberts & Grant, 1976; Shimp, 1976), often defined as the discriminative control of behavior by exteroceptive stimuli no longer present (Nelson & Wasserman, 1978). However, it is possible that behavioral mediators such as body orientations or key pecks (Blough, 1959; Eckerman, 1970; Urcuioli & Honig, 1980) could also account for retention of information during an interstimulus interval (ISI).

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Shimp and Moffitt (1977) used a variant of the DMTS procedure, which reduced the predictability of the correct response from the sample stimulus. Pigeons' responses on left or right keys were reinforced depending on whether a test stimulus was the same as or different from a sample stimulus presented earlier in the same trial. The correct side-key response could not be determined until both sample stimuli had been presented. Choice accuracy was lower than that often obtained from DMTS studies (Roberts & Grant, 1974), but it was well above chance levels.

The present experiment utilized a delayed-choice procedure¹ where the correct response to the test stimuli was neither defined by, nor predictable from, the configuration of the sample stimuli. Subjects were presented with a row of four response keys above a food hopper. During a trial, three of the four keys were randomly chosen and illuminated white for six seconds ("original stimulus array"). After a variable ISI during which all chamber functions were inoperative, one randomly chosen, previously white key, and the previously dark key were illuminated green, whereas the remaining white keys were reilluminated as before ("modified stimulus array"). Subjects received three-seconds access to mixed grain for pecking the green key, which was previously illuminated white, whereas a response to any other key resulted in a three-second blackout. Since the composition of both the original and modified stimulus arrays was randomly determined, the original stimulus array contained necessary, but not sufficient, information for a correct choice to be subsequently made to the modified stimulus array.

METHOD

Subjects

Six adult White King pigeons obtained from a local breeder served. They were individually housed and maintained on a 12-hour light, 12-hour dark schedule at 80% of free-feeding body weights. Grit and water were continuously available to subjects in their home cages. None had been previously employed in any type of delayed choice task.

¹Please refer to the article by Wilkie and Summers in this issue of *Journal of the Experimental Analysis of Behavior* for a report of work closely related to the present experiment.

Apparatus

A standard Lehigh Valley pigeon chamber, with a modified intelligence panel described below, served as the experimental apparatus. A fan provided air circulation, and loud masking noise was continuously presented from two 8-cm speakers that were symmetrically mounted on the back of the intelligence panel. All experimental manipulations were controlled and all data collected by a TRS-80 microcomputer (Tandy-Radio Shack) located in an adjacent room. The interior of the chamber was painted flat black except for the translucent response keys.

The intelligence panel contained four response keys, two white noise speakers, a house-light, and a hopper aperture. The panel measured 48 cm wide and 40 cm tall. The row of four keys was located 27 cm from the bottom of the panel and 10 cm from each other. The first and the fourth keys were each 9 cm from the sides of the panel. Each key was 2.6 cm in diameter and could be illuminated with 28-V lightbulbs (GE 1820) behind translucent or green filters. A 28-V lightbulb partially surrounded by a metal housing served as a house-light and was centered 6 cm directly above the row of four keys. The center of each speaker was located 10 cm down from the center of each outside key.

Procedure

A five-phase training sequence was employed for all subjects prior to the experimental condition.

Phase 1. After hopper training, all subjects were autoshaped to peck the four response keys when they were illuminated green: three seconds access to mixed grain was scheduled every 60 seconds independently of responding. One of the four keys was randomly chosen, illuminated green for six seconds, and extinguished immediately prior to the hopper presentation. The houselight was illuminated at all times and a daily session consisted of 40 hopper presentations. Phase 1 was terminated when each subject was responding reliably to all green keys. This occurred within five sessions.

Phase 2. During Phase 2, subjects responded on a fixed-ratio one (FR 1) schedule to the randomly chosen green key to acquire access to grain. As in Phase 1, the intertrial interval

(ITI) was 60 seconds, and the houselight was continuously illuminated. A session comprised 40 trials. All subjects acquired the contingent response during the first session and Phase 2 was terminated after two sessions.

Phase 3. Phase 3 was identical to Phase 2 except that the randomly chosen key was illuminated white for six seconds prior to being illuminated green. Subjects were not required to respond to the white keylight at any time during the experiment. An ISI of 1.5 seconds was imposed between the white and green key illuminations. This phase did not disrupt responding to the green stimulus and it was terminated after five sessions.

Phase 4. Phase 4 was identical to Phase 3 except that two keys were illuminated green after a single white key illumination. One of the green keys was always the key that had been previously illuminated white, whereas the other green key was randomly chosen from the three which had been previously dark. Subjects were required to peck the green key that had been previously illuminated white. All subjects displayed near perfect choice responding after two sessions at which time Phase 4 was terminated.

Phase 5. During Phase 5, three of the four keys were randomly selected and illuminated white for six seconds. After an ISI of 1.5 seconds, the houselight came back on and two of the three originally white keylights were reilluminated as before. Simultaneously, the randomly selected, third white key and the initially dark key were illuminated green. The pigeons were required to peck the green key that had been previously illuminated white. The modified stimulus array remained unchanged until a subject responded to one of the keys. Responses to the correct green key were reinforced with three seconds access to grain, whereas a peck to any other key resulted in a three-second blackout period and the start of a new trial. A session again consisted of 40 grain presentations.

A six-second ITI was initially employed during which the houselight remained illuminated. This value was then systematically increased for each subject. ITI durations of 6, 9, 15, 24, 33, 42, and 60 seconds were introduced in ascending order until each subject reached a maximum level of accuracy in its choice responding. A specific ITI value was employed until the variance between the daily

percentage of total trials in which a correct response was made decreased to less than 10% of the mean. None was employed for less than eight sessions nor more than 15 sessions.

Experimental phase. During this phase, the ISI was increased by increments of 1.5 seconds until the accuracy of choice responding to the two green keys in the modified stimulus array decreased to chance levels. The ITI employed for each subject was that value at which maximal choice responding was obtained during Phase 4. All other procedural details were identical to those employed in Phase 5. Each 1.5-second increase in the ISI was maintained until the variance between the daily percentage of total trials in which a correct response was made decreased to less than 10% of the mean. However, a minimum of five daily sessions at any ISI value was always employed.

When random choice responding was obtained, the ISI was then decreased by 1.5 seconds to the previous value. If, after five sessions, nonrandom responding was not recovered, the delay was decreased by another 1.5 seconds. This procedure was repeated until the nonrandom choice responding was recovered. When nonrandom choice responding was recovered, the ISI value was again increased by 1.5 seconds. If responding again became random, the subject was terminated from the experiment. If nonrandom responding was obtained, the ISI duration was again increased. The one exception to this rule was Subject 1. It was terminated from the experiment after an ISI value of 19.5 seconds was reached without his choice responding dropping to chance levels.

Definition of nonrandom choice accuracy. Probability theory dictates that random responding to the two white and two green keys in the modified stimulus array would result in subjects choosing the correct green key on 25% of the trials during a session. If subjects tended to respond only to the green keys, random responding would result in an average of 50% of the responses being correct. This latter behavior would produce a distribution of choice outcomes that approximates a binomial distribution, and thus allows derivation of a criterion beyond which it can be inferred that random responding is not occurring.

If we define nonrandom behavior as choosing the correct alternative more often than would occur 5% of the time with random re-

sponding, threshold accuracy satisfying that criterion would consist of a session comprising 63 trials: 40 reinforced and 23 incorrect. Dividing 40 reinforced trials by 63 total trials reveals that a subject must choose the correct green key on 63% of the trials in a single session for $p \leq .05$.

This 63% criterion was used to change conditions on a session-by-session basis. However, the percentage correct associated with the $p \leq .05$ criterion is lower than 63% if choice responding over multiple sessions rather than a single session is considered. This is due to a reduction in the variance of the binomial distribution as n increases. For example, if behavior over five sessions is considered, the threshold for nonrandom responding would be 54% correct, derived from 367 total trials: 200 reinforced and 167 incorrect.

RESULTS

Intertrial interval. During Phase 5, accuracy of choice responding by five of six subjects exceeded the 63% nonrandom criterion discussed above as the ITI duration was increased. However, maximum choice accuracy was attained at different ITI values by different subjects. Subjects 1, 2, and 3 displayed maximum accuracy at an ITI of 43 seconds, where they responded correctly on an average of 67.3, 72.0, and 71.5% of the trials. Subject 4 displayed maximum accuracy at an ITI of 15 seconds, responding correctly on an average of 67.2% of the trials, and Subject 6 did so at an ITI of 60 seconds responding correctly on an average of 71.3% of the trials. The choice accuracy of Subject 5 did not reach or exceed the 63% criterion during training and its data are excluded from analysis. All of the percentages reported above are based on the performance of each subject during the last eight sessions of training.

Interstimulus interval. As the ISI was increased, choice accuracy decreased for four of the five subjects. These data are shown in Figure 1.

As can be seen from Figure 1, maximum ISI values that supported nonrandom responding ranged from three seconds for Subject 6 to at least 19.5 seconds for Subject 1 (see Procedure Section). Between these extremes were maximum ISI values of 7.5 seconds for Subject 4 and 4.5 seconds for Subjects 2 and 3. Except for

Subject 1, the maximum ISI that would support nonrandom responding was inversely related to the optimal ITI employed for that subject.

Responses to the original stimulus array. During training, subjects developed a transitory tendency to peck one or more of the white keys comprising the original stimulus array, both while they were illuminated and into the ISI, despite no scheduled consequences for doing so. The patterning of such responses changed often, but subjects tended to peck center rather than side keys. These white key responses extinguished for all subjects before, or as the ISI was increased. Observation failed to detect off-key substitutes, and no responses were recorded to dark keys in the original stimulus arrays during the experiment.

Error patterns. Subjects 2, 3, 4, and 6 tended to make more errors to incorrect green center keys than to incorrect green side keys, whereas Subject 1 tended to distribute its (fewer) errors more evenly among all keys. All subjects made an occasional error to a white key in the modified stimulus array, but these errors never comprised more than 4% of a subject's total errors during a session. Neither of these tendencies changed systematically as the ISI was varied.

The proportion of errors made during all phases of the experiment on green center keys to the proportion of errors made on all incorrect green keys are as follows for each subject: Subject 1, .52; Subject 2, .69; Subject 3, .71; Subject 4, .80; and Subject 6, .64. Although these center-key biases accounted for many of the errors committed by subjects during the experiment, these biases did not prevent the five subjects from responding consistently above chance.

DISCUSSION

The data clearly demonstrate that five of six subjects were able to retain information about the original stimulus array which was no longer present for at least several seconds, and to then use that information to respond correctly to the identical green keys in the modified stimulus array. They were able to do so despite the fact that the configuration of the original stimulus array did not allow for the a priori determination of the subsequent correct response.

Although the ITI values employed in Phase 5 of training were not manipulated in a sys-

Fig. 1. Percentage of correct green key choices at each ISI value for each subject. Dashed lines indicate non-random response criterion. See text.

tematic manner, the general tendency for choice accuracy to increase as the ITI was increased is consistent with data from other delayed-choice experiments. Roberts (1980) demonstrated that choice accuracy in a standard DMTS task was higher for an ITI of 20 seconds than it was for an ITI of one second when a single ITI value was used during a session. Nelson and Wasserman (1978) showed that choice accuracy in a go/no go DMTS task increased as the ITI was increased from 1 to

50 seconds and the ISI duration ranged from 1 to 25 seconds.

All subjects developed an initial tendency to peck one or more of the white keys comprising the original stimulus array and to continue pecking when the keys were dark even though such pecks had no scheduled consequences. Subjects were more likely to peck the two center keys as opposed to the two peripheral keys. This position bias may have developed because the two side keys were situated

farther from the center of the hopper than were the center keys. These responses may have been initially directed at a predictor of potential food delivery or they may have commemorated the location of a white key. The early extinction of these dark-key responses may have been due to the higher risk of inadvertently pecking an incorrect white key (.67) rather than a correct green key (.33) as the modified stimulus array was presented.

Data obtained from the present experiment may be compared to those obtained from other delayed-choice procedures. Data from DMTS experiments have shown that choice accuracy is a function of several variables including ITI duration (Roberts, 1980), sample stimulus duration (Roberts & Grant, 1974), and ISI duration (Roberts, 1972). For pigeons, there appears to be little difference between performance on symbolic and standard DMTS tasks both in terms of speed of acquisition and asymptotic level of performance (Carter & Eckerman, 1975; Cohen, Looney, Brady, & Aucella, 1976).

When a sample stimulus is presented during a DMTS task for four to eight seconds and the ISI is approximately one or two seconds, pigeons display choice accuracy that can range from approximately 95% (Roberts, 1980) to 77% (Roberts & Grant, 1974). Typically, performance declines as a negatively accelerating function of delay (Grant, 1975; Roberts, 1972). With sample durations comparable to those used in the present experiments, Roberts and Grant (1974) found a significant decline in performance with an ISI of one second or more, whereas Roitblat (1980) demonstrated that choice accuracy on a three-key symbolic DMTS task decreased with ISI's of .7 seconds or more. However, Grant (1975) showed that DMTS choice accuracy could remain well above chance as ISI durations reached 60 seconds or more.

Shimp and Moffitt (1977) have demonstrated that, with a four- to eight-second sample stimulus presentation and a near zero ISI, choice accuracy in a delayed-pair comparison task is approximately 95%. This value is equal to, or greater than, the DMTS accuracies reported by Roberts (1980) and Roberts and Grant (1974). As with DMTS performance, delayed-pair comparison choice accuracy decreases as the ISI increases. Shimp and Moffitt report choice accuracies of 75% to 78% as the ISI was in-

creased to two seconds and of 67% to 71% when the ISI was increased to eight seconds. This decrease in accuracy is similar to that reported by Roberts and Grant (1974) for DMTS performance with a comparable sample stimulus duration and ISI, but was larger than that reported by Roberts (1980) or Grant (1975).

In the present experiment, choice accuracy for Subjects 2, 3, 4, and 6 decreased to chance levels as the ISI was increased to values ranging from 4.5 to 9.0 seconds. The data from the present experiment are more similar to those obtained from delayed pair comparison tasks than to those from DMTS tasks, both in terms of the level of choice accuracy and in the duration of the ISI that would still support nonrandom responding. The exception to this rule is the performance of Subject 1. His responding remained well above chance and even improved as the ISI duration was increased. The reason for this is not clear from the data obtained.

Taken together, these data indicate that increasing the amount of time pigeons must retain information leads to decrements in choice accuracy and that slightly larger decrements are obtained as the predictability of the correct choice from the sample stimulus decreases. This finding may indicate that pigeons employ behavioral mediators to retain information about a sample during an ISI when the predictability of the correct choice from the sample makes it possible to do so. However, the accurate choice performance displayed by five of six subjects in the present experiment indicates that pigeons can make accurate delayed choices when the opportunity to utilize behavioral mediators is greatly diminished. This, in turn, is consistent with the contention that pigeons store information about a sample stimulus in short-term memory (Shimp, 1976).

The ability of pigeons to make delayed choices when the correct choice is not predictable from the sample stimulus has been demonstrated. What has yet to be precisely determined, however, is the means by which this is accomplished. Research to date has failed to adequately discern the roles of behavioral mediation and short-term memory in the pigeon's ability to retain information over time. More research using a variety of delayed-response procedures is clearly indicated.

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