MEMORY FOR TWO STIMULUS-RESPONSE ITEMS IN PIGEONS

MASAKO JITSUMORI AND SUKEO SUGIMOTO

HIROSHIMA UNIVERSITY

Six pigeons served in a discrete-trial experiment on short-term memory. Combinations of three key positions and two ordinal positions, yielding six possible sequences of stimulus-response pairs, were used as lists of items. A retention interval separated list presentation from the test phase in which two (for Group 1) or three (for Group 2) keys were illuminated with either red or green light. A reinforcer was delivered if a subject pecked the key of the first item on a red trial and the key of the second item on a green trial. When the retention interval was lengthened from one to five or nine seconds, a systematic loss of stimulus control resulted. Lengthening the interval between items from one to eight seconds had a much smaller effect for the birds in Group 1, whereas a systematic loss of stimulus control was found in red trials for the birds in Group 2. The functional relations between choice accuracy and delay provided an empirical basis for analysis of what relations among temporal events can become discriminative stimuli.

Key words: short-term memory, stimulus-response memory, stimulus control, discriminative stimulus, delay, temporal event, choice, key peck, pigeons

Shimp (1976a) argued for the necessity of a concept of memory to understand behavioral patterns comprising two or more different responses. Empirical support comes from studies of short-term memory in the pigeon (Grayson & Wasserman, 1979; Shimp, 1976b,c; Shimp & Moffitt, 1974, 1977; Wasserman, Nelson & Larew, 1980; Weisman, Wasserman, Dodd, & Larew, 1980), which revealed that behavioral patterns can be conditioned and that an ordered succession of responses can gain stimulus control in conditional discriminations. These studies of animal memory have been concerned specifically with the questions of whether a subject can remember recent sequences of stimuli and responses and how differentiation of an ordered sequence of responses develops.

Animals are continuously exposed to a succession of temporal-spatial events that include past stimuli and responses, but it may be assumed that only some of these events gain discriminative control over a terminal response

that precedes reinforcement, even if others remain in short-term memory for a time. Therefore, from a failure of stimulus control or differentiation of a response sequence one cannot conclude that a subject is incapable of remembering a particular sequence of stimuli and responses. The question of whether a subject *can* remember and discriminate a recent sequence of stimuli and responses should be differentiated from the question of whether the sequence *is* acting as a discriminative stimulus in a particular situation. The present study was an analysis of what relations among temporal events can become discriminative stimuli.

Wasserman et al. (1980) showed that a sequence of stimulus-response items could serve as a discriminative stimulus for key pecking. In this delayed-conditional-discrimination procedure, the extent to which the stimulus-response samples gained discriminative control over behavior was determined by monitoring rate of responding during 5-sec presentations of test stimuli after sample sequences. In our delayed-conditional-discrimination procedure, pigeons were required to choose one key among two (Group 1) or three (Group 2) keys during a test period that followed presentation of two successive stimulus-response items. The extent to which the items gained discrim-

The research was supported by a Grant-in-Aid for the Encouragement of a Young Scientist from the National Science Foundation. We are indebted to Hiroko Kurita, who assisted in conducting the experiment. Reprints may be obtained from M. Jitsumori, now at the Department of Psychology, Faculty of Humanities, Chiba University, 1-33, Yayoi-cho, Chiba-shi 260, Japan.

inative control was determined by the percentage of correct test responses.

The items-to-be-remembered were modeled after those used by Wasserman et al., stimulus-response pairs of the form, $(S-R)_1-(S-R)_2$, where S is lighting of a key and R is pecking that key. Wasserman et al. employed both homogeneous (left key-left key and right key-right key) and heterogeneous (left-right and right-left) sample sequences. In the present study, adding a third (center) key yielded a pool of six two-item heterogeneous sequences (left-center, left-right, center-left, center-right, right-center, and right-left), which could be presented as samples-to-be-remembered. In the test period, two of the keys (for Group 1) or all three keys (for Group 2) were illuminated, all with red light or all with green. The pigeons had to repeat the response of the first item on red trials and the response of the second item on green trials.

In the study of Wasserman et al., relatively high rates of test responding occurred on negative trials in which the sample sequence ended in the same terminal segment as the corresponding positive-trial sequence (for example, where S^A was a left-left sequence and S^D was a right-left sequence). A systematic loss of stimulus control did not result, however, when the interval between the two items was lengthened. Therefore, it might be inferred that control by the first item was weak. Our procedure was designed so that the first item as well as the second item must gain discriminative control for the birds in Group 2 to reach criterion. On the other hand, the birds in Group 1 could reach criterion even if only the second item gained discriminative control. Systematic loss of stimulus control as a function of delay was assessed for the first item and the second item, respectively, and the accuracy of choice as a function of delay was compared between the groups.

METHOD

Subjects

Six experimentally naive homing pigeons, housed individually with water and grit constantly available in their home cages, were maintained at approximately 80% of their free-feeding weights throughout the experiment.

Apparatus

A three-key pigeon chamber (33.3 by 28.0 by 35.5 cm) contained a grain feeder and a house-light. The 2.0-cm-diameter keys were arranged in a row, 5.0 cm apart (center to center) and 15.0 cm above the opening to the food hopper. Each key could be transilluminated with either red or green light from a light-emitting diode (5V dc) behind each clear-glass key. The house-light (28 V dc) was mounted in the ceiling. An exhaust fan masked extraneous noises. Electromechanical equipment in an adjoining room controlled experimental procedures.

Procedure

Subjects were trained to peck keys and given at least three sessions in which 50 consecutive responses were reinforced. The birds were then divided randomly into two groups of three birds each. Daily sessions consisted of discrete trials that progressed through the following steps: presentation of the first item, interstimulus interval (ISI), presentation of the second item, retention interval (RI), presentation of the test stimulus, trial outcome. Trials were separated by an intertrial interval (ITI). Procedures were identical for both groups except for presentation of the test stimulus. Figure 1 schematically represents the procedure for Group 1.

Presentation of list of items. A trial began with onset of the houselight and illumination of one of the three keys with red light. When the red key was pecked once $(S-R)_1$, houselight and keylight were extinguished. After a 1-sec ISI, one of the other two keys was illuminated with green light and the houselight was again turned on. A single peck on the green key turned off the keylight and the houselight $(S-R)_2$.

Retention interval. The RI immediately followed presentation of the two items and lasted 1 sec. Keylights and houselight remained off during this interval, and key pecks had no scheduled consequences.

Test-stimulus presentation. When the RI ended, the houselight was turned on and two (for Group 1) or all three (for Group 2) keys were illuminated, all with red light (red trials) or all with green light (green trials). For Group 1, the keys illuminated in this step were the

Fig. 1. Schematic representation of procedure for Group 1. See text for details.

two that had been illuminated during presentation of the two list items (See Figure 1). A single peck on any lit key turned off all keylights and the houselight and started the trial-outcome period.

Trial outcome. On red trials, a single peck on the key that had been illuminated with red light for presentation of the first list item was correct. A single peck on the key that had been illuminated with green light for presentation of the second item was correct on green trials. Correct responses were followed by 3-sec access to grain and incorrect responses by a 3-sec blackout.

Intertrial interval. 10 sec of blackout intervened between the end of trial outcome for one trial and the beginning of the next trial. Key pecks during the ITI were ineffective.

Correction procedure. Following an incorrect response, the same problem was repeated on succeeding trials until the subject pecked the correct key and the reinforcer was delivered.

Stimulus assignment. The combinations of three key positions and two ordinal positions yielded six heterogeneous S-R sequences (list of items). Since each list could be followed by a red or by a green test phase, there were 12 types of trials in all. A daily session consisted of 54 trials: four randomized blocks of the 12 trial types and six additional trials. Over all trials, there were 27 green trials and 27 red trials; 18 reinforcements were arranged for correct responses on each of the three keys.

Testing 1. On the next day after birds had reached a criterion of at least 80% correct responses for two successive days, Testing 1 started. Each test session began with 18 trials including a block of 12 trials and six additional trials. These first 18 trials served as an "assessment" period with RI and ISI remaining at the standard of 1 sec. The purpose of the assessment was to determine whether the subjects' accuracy was high enough to permit testing or whether additional training was needed. If the subject's accuracy was less than 80% (i.e., more than three errors) during the assessment period, the RI for the remainder of the session was not lengthened and the session was recorded as a training session. If the bird performed at 80% or better in the assessment period, testing was conducted on the following 36 trials, which were made up of three randomized blocks of the 12 trial types. Therefore, standard training days sometimes intervened between test days. The correction procedure was not employed during test trials. Two test sessions were carried out at a given RI, which was then incremented by 1 sec for the next two test sessions, and so on until the bird was performing nearly at chance level. The ISI remained at 1 sec throughout Testing 1. After the test series was completed, the entire sequence was repeated. Therefore, the total number of test trials at each RI was 144 (36 test trials in each of four daily sessions).

Testing 2. After completing Testing 1, the birds were trained again until the criterion of 80% accuracy was reached for two successive days. Testing 2 started the next day. The ISI was successively lengthened in the same way as the RI had been in Testing 1, while the RI was held constant at 1 sec.

Testing 3. Following Testing 2, the birds in Group 1 were given training sessions with the same procedure employed for Group 2,

namely, all three keys were lit in the test step of each trial, rather than just two.

RESULTS

The number of daily sessions required to reach criterion ranged from 9 to 16, with a mean of 12.7, for subjects in Group 1. Two birds in Group 2 reached criterion in a mean of 68.5 sessions, but one (Bird 23) did not reach criterion after more than 90 sessions. Bird 23 showed about 80% correct responses in green trials but only about 60% correct responses in red trials at the end of standard training. The RI and ISI were decreased to .3 sec for Bird 23 and training was continued. After 28 sessions of the additional training, Bird 23 reached criterion.

Correct performance in green trials (testing for the more recent item) developed much more rapidly than in red trials (testing for the more remote item). Birds in Group 1 and in Group 2 (except Bird 23) took a mean of 4.3 and 6.5 sessions, respectively, to reach criterion in green trials. Green trials entailed two pecks in succession on the key of the second item rather than a switch from the key of the second item to another key. Better performance in green trials is consistent with the findings of Grayson & Wasserman (1979), who showed that learning of homogeneous left-left and right-right sequences was much more rapid than learning of heterogeneous left-right and right-left sequences. This might be partly due to the tendency of pigeons to peck repeatedly on the same key, rather than switching from one key to another. Better performance on green trials in Group 2 could also be due to the shorter retention interval from item presentation to test-stimulus presentation.

Although the performance levels to be expected by chance differed between the groups (50% for Group 1 and 33.3% for Group 2), the response sequences that were followed by reinforcement on a given problem were identical for the two groups. Hence, if the pigeons learned a set of stimulus-response chains based on specific lists, then the tasks should have been about equally difficult for the two groups. In fact, the prominent difference between the groups in the number of sessions needed to reach criterion suggests that choice performances were controlled by more general fea-

tures shared by the lists. These features must have differed between the groups. Support for this conclusion comes from analysis of time influences on the discriminative control of choice performance.

The percentage of correct responses is plotted as a function of RI in Figure 2 for Group 1 and in Figure 3 for Group 2. The ISIs were all equal to 1 sec except for Bird 23, for which it was .3 sec. For Group 1, curves for green and red trials overlap, which indicates that for this group the RI had the same effect on green trials as on red trials. In Group 2, on the other hand, correct responses in green trials exceeded those on red trials over all RIs, which resulted in the generally parallel courses of the curves in Figure 3. The parallel courses of the curves should correspond to the constant 1-sec (.3-sec for Bird 23) difference between the intervals separating the first and second items, respectively, from the test stimulus.

The percentage of correct responses in Testing 2 (ISI varied) is plotted as a function of the ISI in Figure 4 for Group 1 and in Figure 5 for Group 2. For all birds, the RI was 1.0 sec¹. Although varied over the same temporal range

Fig. 2. Percentage of correct responses as a function of retention interval in Group 1.

Fig. 3. Percentage of correct responses as a function of retention interval in Group 2.

as was the RI, increasing the ISI had a much smaller effect on performance in Group 1 or none at all. More than 70% correct responses were obtained in both green and red trials at the longest ISI of 8 sec. In contrast, increasing the ISI for Group 2 impaired discriminative control on red trials, as shown by the clear and ordered decrements in Figure 5. On green trials, a systematic loss of stimulus control was not found except in Bird 23, but even Bird 23 showed better than 70% correct responses in green trials at the longest ISI of 8 sec.

Figure 6 shows the session-by-session course of Testing 3 with a transfer-of-training procedure for Group 1. The birds in Group 1 showed 80% correct responses or better in green trials when they were initially exposed to the procedures used for Group 2. Performance on red trials, on the other hand, was characterized by excessive errors to the key on which no item had been presented on that trial ("nonlist key").

Fig. 4. Percentage of correct responses as a function of interstimulus interval in Group 1.

DISCUSSION

The data from Testing 1 and Testing 2 represent a remarkable difference in time influence between the groups, which suggests that choice behavior in the two groups was controlled by different features of the sequential stimuli. Results from Testing 3 with Group 1 suggest that the second item gained discriminative control of choice behavior but that the birds had not needed to learn to refrain from pecking the nonlist key so long as only two keys were lit as the test stimulus. The overall results for Group 1 (Figure 2, Figure 4, and Figure 6) support the inference that these birds simply learned to peck twice on the key of the second item on green trials and to switch to the other key on red trials. Hence, only the second item gained discriminative control. On the other hand, data for Group 2 (Figure 3 and Figure 5) suggest that in this group the first item controlled test choices on red trials just as much as the second item controlled choices on green trials. Both stimulus-response items of the lists gained discriminative control

Fig. 5. Percentage of correct responses as a function of interstimulus interval in Group 2.

for the birds in Group 2, whereas only the more recent item gained discriminative control for the birds in Group 1. The experimental arrangement for Group 2, which required the pigeons to refrain from pecking the nonlist key (rather than simply switching from one lit key to the other), enabled both items to gain discriminative control.

Several studies of short-term memory in pigeons have shown a strong recency effect (Roberts & Grant, 1976; Shimp, 1976b; Shimp & Moffitt, 1974, 1977; Wasserman et al., 1980; Weisman et al., 1980). In the present study, the recency effect was so strong that subjects in Group 1 showed discriminative control only by the second item. Yet the data of Group 2 indicate that the first item must have been in short-term memory at the time of the retention test (at least at the shortest ISI and RI), since it functioned as the discriminative stimulus controlling choice responses on red trials. The findings suggest that experimental arrangements that do not induce the pigeons to learn to refrain from pecking a nonlist key do not make the first item a discriminative stimulus for choice behavior.

The curves for green and red trials in Group 2 fell in parallel when the RI was lengthened (Figure 3). If the memory of the first item were weakened by presentation of the second item, the curve for red trials should have dropped faster than the curve for green trials. On the contrary, the results obtained from Group 2

Fig. 6. Transfer data obtained from birds in Group 1 on red trials (top panel) and green trials (bottom panel) during training sessions with three lit keys as the test stimulus.

support theories (Atkinson & Shiffrin, 1968) which hold that traces of items within the span of short-term memory decay independently of one another and none is modified in strength by the presentation of others. Of course, the trace of the first item had a longer decay interval than the second item (the constant 1-sec difference); the theory of trace independence explains why, therefore, the percentage of correct responses in green trials fell in parallel with those in red trials over all RIs.

An alternative theory of trace-strength limitation holds that there is a limit on the total amount of trace strength contributed by several stimuli that can be stored in memory. This theoretical position asserts that lengthening the ISI should allow the trace of the first item to decay and thus remove the limitation it had placed on the strength of the trace of the second item. Therefore, performance on green trials in Group 2 and on all trials in Group 1 (for which only the second item served as a discriminative stimulus) should have improved when the ISI was lengthened. However, there was no support in our findings for the theory of trace-strength limitation. It could be argued that a ceiling effect prevented the improvement in performance from being manifested. However, Bird 23 and Bird 12 showed clear and ordered decrements rather than improvement. Furthermore, close correspondence can be found between the present findings and Grant and Roberts' (1973) study of the interaction of traces in pigeons' short-term memory. Their findings from a delayed matching-to-sample task supported a theory of trace independence and provided no support for the trace-strength-limitation theory.

Although the first item as well as the second item was shown to serve as a discriminative stimulus for the birds in Group 2, just what features of the items controlled choice behavior is not clear, because the first item was always red and the second item was always green. Thus, color and ordinal position of an item were confounded, and the procedure did not strictly require the subjects in Group 2 to remember the temporal order of items. The subjects might have discriminated and remembered associations between specific keys and specific colors, or the order of pecking specific keys, or both. With the data in hand, it is not possible to choose among these alternatives.

In summary, differences in the way longer RIs and ISIs affected the performance of the two groups provided an extensive empirical basis for inferring something about the stimuli controlling choice behavior. Comparisons between the groups suggested that short-term memory of a stimulus and the function of that stimulus as a discriminative stimulus must be differentiated. Although the dangers associated with postulating the construct of memory to explain behavior are clear, and some would take issue with the construct as discussed here, analysis of systematic changes in stimulus control as a function of delay can illuminate what relations among temporal events can become discriminative stimuli.

REFERENCE NOTE

1. Bird 23 reached criterion with RI and ISI of 1 sec during additional training conducted after Testing 1.

REFERENCES

- Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (Vol. 2). New York: Academic Press, 1968.
- Grant, D. S., & Roberts, W. A. Trace interaction in pigeon short-term memory. *Journal of Experimental Psychology*, 1973, **101**, 21-29.
- Grayson, R. J., & Wasserman, E. A. Conditioning of two-response patterns of key pecking in pigeons. *Journal of the Experimental Analysis of Behavior*, 1979, **31**, 23-29.
- Roberts, W. A., & Grant, D. S. Studies of short-term memory in the pigeon using the delayed matching to sample procedure. In D. L. Medin, W. A. Roberts, & R. T. Davis (Eds.), *Processes of animal memory*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1976.
- Shimp, C. P. Organization in memory and behavior. *Journal of the Experimental Analysis of Behavior*, 1976, **26**, 113-130. (a)
- Shimp, C. P. Short-term memory in the pigeon: Relative recency. *Journal of the Experimental Analysis of Behavior*, 1976, **25**, 55-61. (b)
- Shimp, C. P. Short-term memory in the pigeon: The previously reinforced response. *Journal of the Experimental Analysis of Behavior*, 1976, **26**, 487-493. (c)
- Shimp, C. P., & Moffitt, M. Short-term memory in the pigeon: Stimulus-response associations. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 507-512.
- Shimp, C. P., & Moffitt, M. Short-term memory in the pigeon: Delayed-pair-comparison procedures and some results. *Journal of the Experimental Analysis of Behavior*, 1977, **28**, 13-25.
- Wasserman, E. A., Nelson, K. R., & Larew, M. B. Memory for sequences of stimuli and responses. *Journal*

of the Experimental Analysis of Behavior, 1980, 34, 49-59.

Weisman, R. G., Wasserman, E. A., Dodd, P. W. D., & Larew, M. B. Representation and retention of two-event sequences in pigeons. *Journal of Experimental*

Psychology: Animal Behavior Processes, 1980, 6, 312-325.

Received July 10, 1981

Final acceptance December 28, 1981