MEMORY FOR RECENT BEHAVIOR IN THE PIGEON

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Variations of the symbolic delayed-matching-to-sample procedure were used to study a pigeon's memory for a small number of pecks. In the first experiment a choice of a left or right sidekey after a delay or retention interval was reinforced if a bird had not pecked at all or had pecked exactly once, before the delay, respectively. In the second experiment a choice of a red or green sidekey, regardless of its position, was reinforced if a bird had not pecked at all or had pecked exactly twice, respectively. In the first experiment a bird could orient toward the correct choice during the delay, whereas it could not in the second experiment. In a third experiment a feature-probing method was used to study a pigeon's memory for a number of pecks in the context of certain other pecks. The results showed that a pigeon can remember a small number of pecks for one-half to one minute or more and that the percent correct is a decreasing function of the log retention interval. When a second number of pecks is different from the first number, memory for the first number lasts only a few seconds. When a second number is the same, memory lasts considerably longer. The more recent number of pecks is remembered better. The results are interpreted in terms of a theory which holds that a reinforcer, in general, may act on a subjects' memory for recent behavior to generate patterns of behavior.

Key words: short-term memory, symbolic delayed-matching-to-sample, feature probing, bias, memory strength, behavioral patterns, key pecks, pigeons

Recent developments in the operant conditioning literature suggest a need for data on an animal's memory for its recent behavior. It appears that there is a relationship between a pigeon's memory for its behavior and patterns of behavior that are observed in a number of schedules of reinforcement (Hawkes & Shimp, 1975; Shimp, 1975).

According to Shimp (1975) the patterns of behavior (that is, the temporal distributions of responses) may be a direct result of the effects of reinforcers on behavior that is remembered when reinforcers are delivered. Several studies have examined memory for certain types of behavior such as number of responses, but the behaviors were confounded with other events such as duration of a stimulus light (Kojima, 1980; Lattal, 1975; Maki, Moe, & Bierley, 1977; Shimp, 1976). There are no data on a pigeon's short-term memory for its behavior. In order to extend or evaluate Shimp's findings several questions should be addressed: can it indeed be demonstrated that a pigeon can remember its recent behavior? If so, what are some properties of this memory? More specifically, how long does the memory last? What are some parameters and contingencies that improve or impair the memory? What is the significance of such properties for Shimp's theory and for the analysis of reinforcement contingencies?

The procedure selected to investigate memory for behavior is symbolic delayed-matching-to-sample (symbolic DMTS). Delayed-matching-to-sample (DMTS) and symbolic DMTS procedures have been used extensively to examine memory for colored lights (Carter & Werner, 1978; D'Amato, 1973; D'Amato & Cox, 1976; Roberts & Grant, 1976; Santi, 1978). In DMTS a sample stimulus is presented. After a delay or "retention interval," a subject chooses between two comparison stimuli. Reinforcement is delivered if the chosen comparison stimulus is identical to—i.e., matches—the

sample stimulus. When a subject is able to choose the identical comparison stimulus on a significant percentage of the trials, it may be said that the subject, to some extent, can remember the sample.

In symbolic DMTS the sample and comparison stimulus are not identical; a sample and its corresponding comparison stimulus are related only by an arbitrary rule (Carter & Werner, 1978; Maki et al., 1977; Santi, 1978). For each sample the rule specifies which comparison stimulus is correct—that is, the one to which a response will produce reinforcement. For example, a rule in symbolic DMTS might state that if the sample stimulus is red then a peck to a yellow comparison stimulus produces reinforcement, but if the sample stimulus is blue then a peck to a green comparison stimulus produces reinforcement. Stated another way, the rule specifies codes or associations of some kind (cf. Blough, 1959; Cohen, Looney, Brady, & Aucella, 1976; Roitblat, 1980; Urcuioli & Honig, 1980; Zentall, Hogan, Howard, & Moore, 1978), which are to be established between sample and comparison stimuli. When a subject is able to choose the correct comparison stimulus on a significant percentage of the trials in symbolic DMTS, one can assume that to some extent, the appropriate associations or codes have been established, and that the subject can remember the sample or code.

A variation of the latter procedure would permit an arbitrary activity to be used as the sample instead of colored lights. A rule in such a procedure would specify the arbitrary associations or codes that are to be established between a sample activity and a comparison stimulus. This symbolic DMTS procedure in which a sample is a pigeon's specific activity and the comparison stimuli are colored lights is used in the three experiments that follow. However, the possibility is considered that components of symbolic DMTS performance other than memory for the sample affect a subject's choices. (1) The possibility is considered that a subject's bias or preference for a comparison stimulus of a particular color or position affects the percentage of correct choices. (2) The possibility is considered that the rate of sample responses or some other uncontrolled aspect of the sample behavior affects the percentage of correct choices. Accordingly, some numbers other than the percentage

of correct choices are computed that may provide different information about memory for a sample.

GENERAL METHODS AND DATA ANALYSIS

METHODS

Subjects

Nine male White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. Three different birds were used in each of three experiments. The animals in Experiments I and II had experimental histories involving the reinforcement of behavioral patterning. The remaining animals were experimentally naive.

Apparatus

Six standard three-key Lehigh Valley Electronics pigeon chambers were interfaced to a Digital Equipment Corporation PDP-12/30 computer that arranged all of the experimental contingencies and recorded the data on magnetic tape for subsequent analysis. The chambers were located in a darkened room and white noise in each chamber attenuated sounds from the outside.

Procedure

Each session consisted of a number of discrete trials. Each discrete trial consisted of a *behavior phase* followed by a *retention interval* and then by a *test phase*.

Behavior Phase

During the behavior phase the center key was illuminated and on a random half of the trials, a number of pecks was required that was different from the number required on the other trials. The color of the center key and the required number of pecks were different in each experiment. In Experiments I and II, failure to emit the required number of pecks on a particular trial was counted as a *behavior-phase error*. An error was followed by a *behavior-phase correction interval* of several seconds, after which the behavior phase was recycled. Recycling continued until the required number of responses was emitted. In Experiment III, the behavior-phase correction procedure would have been too cumbersome and therefore was omitted.

Retention Interval

The interval between the behavior phase and the test phase defined the retention interval. It was initiated when the required number of pecks was emitted in the behavior phase. The duration of the retention interval was varied across conditions as shown in Table 1. A peck to any darkened key during the retention interval recycled the behavior phase. This contingency was intended to discourage pecks during the retention interval.

Test Phase

The sidekeys were illuminated in the test phase with different colors in different experiments. The test phase required a choice of a key of a particular color or position. Whether a particular choice was reinforced depended upon the behavior emitted in the recently completed behavior phase. A correct choice was reinforced with 2.0-sec access to mixed grain. Reinforcement was followed by an *intertrial interval*. An incorrect choice initiated a *test-phase correction interval* after which the trial was recycled from the behavior phase. Recycling continued until a correct choice response was made. A peck to any darkened key during either a behavior-phase or a test-phase correction interval reset the corresponding correction interval timer.

Other Arrangements

All lights in the box were turned off during the retention interval, the intertrial interval, and during the test-phase correction interval; but the houselight remained on during the behavior-phase correction interval. Sessions, which were usually conducted six days a week, were varied in duration across conditions to maintain comparable number of reinforcers delivered per session (see Table 1).

Pretraining

An extensive period of pretraining with a short retention interval was conducted before the first experimental condition in each experiment. Data were unavailable to aid in the selection of some parameter values. Consequently these parameters were varied until birds reached nearly perfect retention levels on their respective schedules. The number of pretraining sessions and the parameters that were varied are summarized in Table 2.

DATA ANALYSIS

Retention Curves

For each experiment the percentage of correct test-phase choices was calculated by dividing the number of reinforced sidekey pecks, correction responses excluded, by the total

Table 1
Experimental Conditions

Condition	Subject Number	Number of Sessions	Mean Trials Per Session	Duration of Sessions (min)	Retention Intervals (sec)
			Experiment 1		
1	1	26	128	30	1, 3, 5, 7
	2	30	98		
	3	30	135		
2	1	28	53	30	9, 11, 13, 15
	2	28	58		
	3	28	72		
3	1	27	44	45	17, 21, 25, 29
	2	27	50		
	3	27	52		
4	1	50	22	60	33, 41, 49, 57
	2	49	35		
	3	49	37		
5	1	—	—	60	73, 89, 105, 121
	2	38	24		
	3	24	19		
6	1	—	—	60	1.5, 2.5 min,
	2	20	11		3 min, 3.5 min
	3	—	—		

Table 1 (Continued)

Condition	Subject Number	Number of Sessions	Mean Trials Per Session	Durations of Sessions (min)	Retention Intervals (sec)
			Experiment 2		
1	4	25	191	30	.5, 1, 2, 4
	5	26	108		
	6	33	105		
2	4	33	118	30	5, 6, 7, 8
	5	33	61		
	6	31	69		
3	4	31	84	45	9, 11, 13, 15
	5	32	59		
	6	32	70		
4	4	23	62	60	17, 21, 25, 29
	5	23	69		
	6	23	61		
5	4	28	30	60	33, 41, 49, 57
	5	28	26		
	6	28	45		
6	4	15	37	60	10, 1.5 min,
	5	15	21		2 min, 2.5 min
	6	15	25		
			Experiment 3		
1	7	60	167	30	0.1
	8	61	192		
	9	60	187		
2	7	29	166	30	0.5
	8	32	164		
	9	32	157		
3	7	50	148	30	1.0
	8	50	154		
	9	50	156		
4	7	33	148	45	2.0
	8	33	158		
	9	33	135		
5	7	20	144	45	4.0
	8	20	154		
	9	20	128		
6 (replication)	7	16	143	30	1.0
	8	16	153		
	9	16	150		
7 (control)	7	2	64	30	1.0
	8	2	51		
	9	2	66		

number of reinforcements or trials. The mean percentage over the last five days of each condition is presented with one exception. In Experiment I the mean is calculated over nine days for the last condition for Bird 2. In this case the number of trials in five days would have been too small. The percentage of correct test-phase choices for each bird plotted against the log retention interval gives a "retention function." Semilog coordinates were used as a matter of convenience because of the wide range of retention interval values. The standard error of each mean estimates the variability within the days. A vertical line through each point represents plus and minus two standard errors. A point was considered above chance if it was at least two standard errors above .50.

TSD Analysis

Earlier it was noted that it is possible for bias or preference for a particular comparison stimulus or response to affect the percentage of correct choices. Indeed, systematic fluctuation in bias might confound the retention interval. Thus, the Theory of Signal Detect-

ability (TSD) was used to provide separate measures of memory strength and bias (Kintsch, 1967; Loftus & Loftus, 1976; Swets, 1964; Wickelgren & Norman, 1966). An ROC (Receiver Operating Characteristic) and a curve that relates d' to the retention interval were plotted for each subject with mean curves for each experiment. Because of the large amount of data, the curves are not shown but the results are discussed.

Table 2

Pretraining Condition

Experiment	Subject Number	Number of Sessions	Parameters Varied*
1	1	90	a e f h i
	2	84	
	3	75	
2	4	109	a b d e f h
	5	109	
	6	94	
3	7	58	b c d g i
	8	58	
	9	58	

*Parameters Varied Key
  a = behavior-phase duration
  b = behavior-phase correction interval
  c = inter-stimulus interval
  d = inter-trial interval
  e = number of sample pecks
  f = reinforcement duration
  g = retention interval
  h = single and variable retention-interval procedure
  i = consequence of pecks in the retention interval

Behavior-Phase Performance

It was noted earlier that it is possible for some uncontrolled aspect of the sample behavior to affect the percentage of correct choices. For example, the number of behavior-phase errors or the mean response rate might vary over conditions as the retention interval is changed. Thus, systematic changes in behavior-phase performance might be confounded with the retention interval. Accordingly, a measure of the sample behavior is computed for each subject to see if changes over conditions are systematic. In Experiments I and II, the mean number of behavior-phase errors per component is computed. This number may be taken as an index of the time per component and of the mean response rate. In Experiment III the mean response rate is computed be-

cause the behavior-phase correction procedure is omitted.

EXPERIMENTS I AND II

Experiments I and II take up some of the questions raised by Shimp's perspective (1975, 1978). The first experiment attempts to demonstrate a subject's memory for a small number of responses. A symbolic DMTS task was used in which the association or code was between a sample behavior and a comparison stimulus of a particular position. Because the correct choice was a particular position, the task was very similar to a delayed-response procedure (e.g., Kojima, 1980; MacCorquodale, 1947). That is, the procedure permitted a subject to orient during the retention interval toward the correct comparison stimulus. In the second experiment a correct choice was a particular color, the position of which was varied randomly so that a subject could not orient toward the correct choice key. A recent study suggests that the positional orientation of a subject during the retention interval is an important variable in delayed-response tasks (Kojima, 1980). Thus, the present studies examine memory for behavior where a subject may or may not orient toward the correct choice key.

In two recent studies that used a behavioral event as the sample in symbolic DMTS, the time interval during which the sample behavior was emitted was permitted to vary, so that memory for stimulus duration was confounded with memory for behavior (Lattal, 1975; Maki et al., 1977). In the studies that follow, the presence or absence of a small number of pecks (one or two) is the sample behavior that is required during a sample component of fixed duration. That is, a keylight is turned on in the behavior phase for a time interval that is the same regardless of which behavior is required. In this way memory for behavior is not confounded with memory for stimulus duration.

A variable retention-interval procedure is used in the present experiments to maintain a higher density of reinforcement and, accordingly, a higher response rate than if only the longest retention interval were used. In this procedure shorter, easier retention intervals are programmed with longer, more difficult

retention intervals within a session. It was felt that the procedure would be beneficial with lengthy retention intervals when the density of reinforcement might have been otherwise too low to maintain responding.

METHOD

Procedure: Experiment I

During the behavior phase in Experiment I, a single peck to the illuminated center key was required on a random half of the trials, and on the other half it was required that the subject not peck at all. The center key was transilluminated with white light for .5 sec. This center-keylight duration was selected during pretraining as a duration that produced few behavior-phase errors. An error occurred if a number of pecks other than that required on a trial was emitted during the .5-sec interval. An error initiated a 3.0-sec behavior-phase correction interval during which only the houselight remained on. The retention interval began if the correct number of pecks was emitted. Four different retention intervals were used in each condition (see Table 1). Each retention interval was in effect on a random one-fourth of the trials.

After the retention interval, two white sidekeys appeared in the test phase. A peck to the left or right key was reinforced if a bird had not pecked at all or had pecked exactly once during the behavior phase, respectively. The intertrial interval was 2.0 sec and the test-phase correction interval was 2.0 sec.

Procedure: Experiment II

During the behavior phase in Experiment II, two pecks to the lighted center key were required on a random half of the trials, and on the other half it was required that the subject not peck at all. The center key was transilluminated with white light for .65 sec, a duration selected during pretraining as one which produced few behavior-phase errors. The behavior-phase correction procedure was identical to that in Experiment I. As in Experiment I, there were four different retention intervals (see Table 1).

In the test phase, red and green sidekeys were turned on, with the position of a given color alternating randomly over trials. A peck to the red or green key was reinforced if a bird had not pecked at all or had pecked exactly twice during the behavior phase, respec-

tively. The intertrial interval and the correction interval were the same as in Experiment I.

RESULTS

Experiment I

The individual retention curves and the mean retention curve shown in Figure 1 (Panels A to D) are decreasing functions of the log retention interval. The curves show that retention remained at least two standard errors above chance (.50) through the 49-sec, 121-sec, and 73-sec retention intervals for Birds 1, 2, and 3, respectively. The mean curve remains above chance through the 49-sec retention interval.

The individual subject ROCs roughly resemble the mean curve (no curves shown). On the mean curve the points cluster near the isobias line, with some preference for the right key in Condition 4 where the retention interval was 33, 41, 49, or 57 sec. Thus the ROCs show relatively little preference for either sidekey. As the retention interval increases points are increasingly distant from point (.00, 1.00) and nearer point (.50, .50). A curve that relates d' to the retention interval shows that
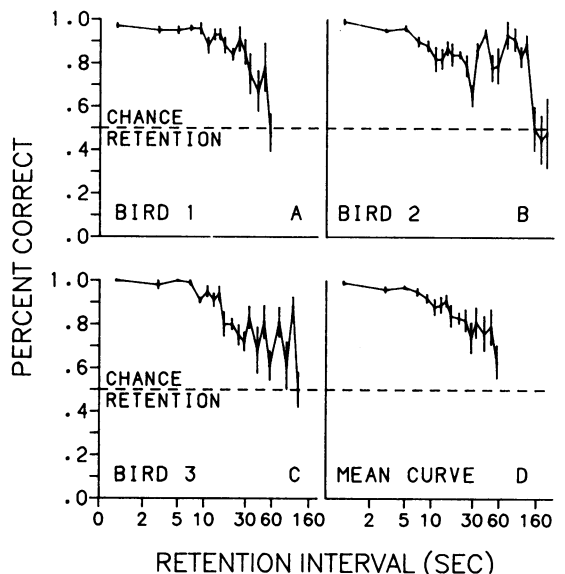

Fig. 1. Retention curves for the individual subjects of Experiment I are shown in Panels A to C. Panel D is a mean curve for the three subjects. Each point reflects data from the last five sessions of each condition except for the last three points for Bird 2, which reflect data from the last 9 days of the condition. The vertical line through each point represents plus or minus two standard errors.

the mean d' is a decreasing function of the log retention interval.

The number of errors per behavior-phase component was substantially unchanged across conditions: for Bird 1 the mean number of behavior-phase errors across all conditions is 5.66, and the mean number of errors for Conditions 1 and 6 (the conditions with the shortest and longest retention intervals, respectively) is 7.46 and 4.92, respectively. The overall mean and the mean number of errors for Conditions 1 and 6 and Bird 2 are 4.25, 5.23, and 6.11, respectively. For Bird 3 the mean numbers are 3.04, 2.95, and 3.07, respectively. The number of behavior-phase errors may be taken as an index of the time per component and the response rate so that, in these respects, the behavior-phase performance did not systematically change as the retention interval increased.

Experiment II

Retention was a decreasing function of the log retention interval as shown in the mean retention curve and in each individual subject curve in Figure 2 (Panels A to D). Retention remained at least two standard errors above chance through the 49-sec, 41-sec, and 57-sec retention intervals for Birds 4, 5, and 6,

respectively. The mean curve remains above chance through the 57-sec retention interval.

The individual subject ROCs are similar to the mean curve (no curves shown). The mean curve shows no systematic color bias, although variability in color bias seems to increase as the retention interval increases. As the retention interval increases, data points are increasingly distant from point (.00, 1.00) and nearer (.50, .50). A curve which relates d' to the retention interval shows that the mean d' is a decreasing function of the log retention interval.

Individual subject ROCs that show position bias are very similar to a mean curve (curves not shown). The mean curve shows that performance was unbiased with respect to position except for a slight left-key bias with the longest retention interval of the last condition.

Behavior-phase performance did not systematically change across conditions. The mean overall number of errors per behavior-phase component for Bird 4 is 2.30, and the mean number of errors for Conditions 1 and 6 (the conditions with the shortest and the longest retention intervals, respectively) is 2.32 and 2.47. respectively. The overall mean and mean number of errors for Conditions 1 and 6 for Bird 5 are 1.53, 2.36, and 1.62, respectively; and for Bird 6 are 3.30, 3.54, and 3.62, respectively.

DISCUSSION

Experiments I and II demonstrate that recent behavior or an association or code between behavior and color or position can be remembered in a symbolic DMTS situation. The retention curves show that the memory may last for one-half to one minute or more. The analysis of bias and sample behavior provides some additional information on the duration of the memory. That is, the analysis provides some insight into the question of whether the relation of the retention interval to the percentage of correct choices is confounded by a change in an uncontrolled component of performance.

The analysis of behavior-phase performance shows little or no change across conditions. The number of errors per component did not systematically vary, which indicates that the time per component and the response rate
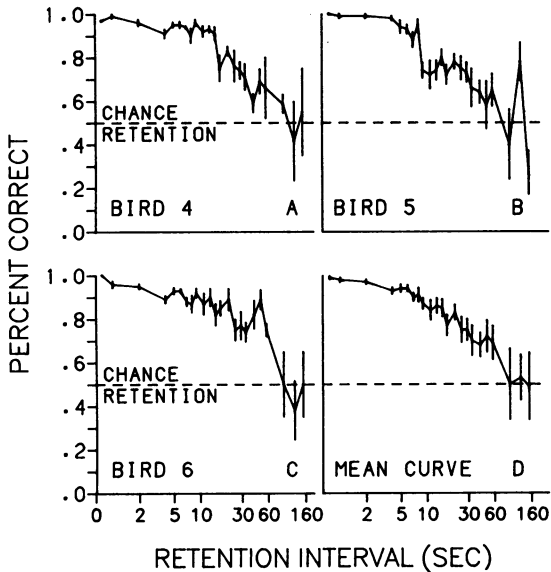

Fig. 2. Retention curves for the individual subjects of Experiment II are shown in Panels A to C. Panel D is the mean curve for the three subjects. Each point reflects data from the last five sessions of each condition. The vertical line through each point represents plus or minus two standard errors.

also did not systematically vary. Thus, changes in behavior-phase response rate do not appear to correlate with the decreased percentage of correct choices. The analysis of the bias component of performance also shows little or no systematic change across conditions. That is, sustained preference for a particular comparison stimulus or response does not appear to have developed; so that change in a subject's bias does not seem to correlate with the decreased percentage of correct choices. On the other hand, d' shows similar results to the percentage of correct choices. Therefore, it does not appear that the relation of increased retention interval to decreased percentage of correct choices is confounded either by changes in the rate of sample responses or by changes in bias. Rather, it appears that the decreased percentage of correct choices defines a subject's inability to remember the sample behavior or an association or code between the behavior and the color or position.

Let us briefly consider the significance of these results for the Shimp theory (1975, 1978). An important component of that theory is the proposal that a reinforcer may act on a subject's memory for behavior. Stated another way, a reinforcer may act on behavior that is noncontiguous with its delivery if the behavior can be remembered. The present results appear to be consistent with this component of the theory to the extent that (1) they demonstrate that a subject can remember whether or not it emitted a small number of responses, (2) they demonstrate how memory depends on different retention intervals.

EXPERIMENT III

Experiments I and II provided data that are consistent with one component of Shimp's theory (1975, 1978), and they identified one property of memory for behavior. They showed that the retention interval is one variable that affects memory for behavior. The experiment that follows explores the question, what are some other variables that affect a subject's memory for its recent behavior?

Data from a number of sources suggest that memory for one type of behavior emitted to a stimulus should be affected by a second type of behavior emitted to a different stimulus (e.g., Patrick, 1971; Peterson & Peterson, 1959; Shimp, 1976). The present experiment exam-

ines memory for behavior emitted to a stimulus before or after other behavior emitted to a different stimulus.

The procedure used is a variation of symbolic DMTS called a "feature probing method." Shimp and Moffitt (1974) and Shimp (1976) developed this procedure to probe a pigeon's memory for a sequence of stimulus-response events. In the experiment by Shimp (1976), a bird was required on a given trial to peck three sample stimuli that were successively illuminated randomly alternated sidekeys. Thus, a pattern of left or right sidekey pecks was emitted. After a retention interval, comparison stimuli were turned on which consisted of one of these randomly selected colors. A reinforcer was delivered if the bird pecked the same sidekey as one sample stimulus that it had recently pecked. The color of the comparison stimuli determined which peck of the pattern of sample pecks a subject was to replicate. The results showed that a pigeon can remember several recent stimulus-response events when the events are pecks to randomly alternated sidekeys. It was found that retention in this context may last for several seconds or more.

The present experiment is an application of the feature-probing method to memory for one or another number of responses emitted on a sequence of two colored keys. That is, on a given trial two sample stimuli of different colors were presented in succession on the center key, and a smaller or larger number of pecks was required to each color. After a retention interval, comparison stimuli were turned on which were the same color as one recently pecked sample stimulus. If the smaller or larger number of pecks had been emitted to this sample stimulus, then a reinforcer was delivered for a peck to the left or right comparison stimulus, respectively. Thus, depending on its color a comparison stimulus probed a pigeon's memory for the number of pecks emitted to the first or second sample stimulus. On a random half of the trials, memory was probed for a number of responses emitted before or after an identical number of responses. On the other half of the trials, memory was probed for a number of responses emitted before or after a different number of responses. With this procedure it is therefore possible to examine memory for the number of responses emitted to a stimulus that has been preceded

or followed by the same number or a different number of responses emitted to a different stimulus.

In order to compare memory for behavior emitted in each of the above contexts, a subject's comparison stimulus choices are analyzed separately for each context or kind of trial. The percentage of each kind of trial on which a subject chooses the correct comparison stimulus is taken to indicate how well the subject remembers a sample behavior emitted in a certain context. Thus, a retention curve plotted for each kind of trial provides an estimate of the relative duration of memory for behavior emitted in the context of certain other responses.

The bias and behavior-phase components of performance that were analyzed in Experiments I and II are analyzed in the present experiment. As in the earlier experiments, the analysis provides information on the extent to which the relation between retention interval and percentage of correct choices is confounded by changes in an uncontrolled aspect of performance. Such an analysis in the present experiment is viewed as important to the development of a conception of how long memory for behavior lasts in the context of other behavior.

METHOD

Procedure

The *behavior phase* in Experiment III consisted of two successive components, each with its own response requirement. In the first component, either one or three pecks were required on a red center key, and in the second component either one or three pecks were required on a green center key. In either component the requirement to peck one or three times occurred on a random half of the trials. The first and second components were separated by a .25-sec interstimulus interval of darkness during which pecks to any darkened key initiated recycling of the behavior phase. The red and green center keylights remained on until the appropriate response requirement was satisfied. Four equiprobable sequences of color-coded pecks were therefore required: one peck on the red center key followed by one peck on the green center key; three pecks on the red key followed by three pecks on the green key ("homogeneous trials"); one peck followed by three pecks; and three pecks followed by one peck ("heterogeneous trials"). The time interval during which the behavioral ratios were emitted was permitted to vary to avoid a cumbersome correction procedure for behavior-phase errors. A control condition was conducted at the end of the experiment to determine to what extent the component duration rather than the number of pecks was remembered (see below).

The retention interval began after the behavior phase was completed. The duration of the retention interval across conditions followed a progression shown in Table 1, which was the same as the progression used by Shimp and Moffitt (1974).

Two types of tests were equiprobable in the *test phase*. Sidekeys were transilluminated with a color that was the same as the key color of one of the recently completed components of the behavior phase. If red sidekeys were turned on in the test phase, then a peck to the left or right key was reinforced if a single peck or three pecks had been emitted during the first (red) component of the behavior phase, respectively. If green sidekeys were turned on in the test phase, then a peck to the left or right key was reinforced if one or three pecks had been emitted during the second (green) component of the behavior phase, respectively. Thus, a bird was required to remember the number of pecks it had most recently emitted in the presence of the test color. Each of the four sequences of behavior-phase pecks was followed by both red and green tests for a total of eight possible different kinds of trials. The test-phase correction interval was 2.0 sec, and the intertrial interval was 4.0 sec.

After the final experimental condition, a *control condition* was conducted with a 1.0-sec retention interval. The termination of the first and second behavior-phase components was made dependent on time rather than upon any response requirement. The number of responses per component was permitted to vary; but the duration of each behavior-phase component for a particular subject was equal to the mean of the actual durations produced by that subject in completing either one or three responses over the last five sessions of the last experimental condition. In either component, the longer duration was used on a random half of the components, and on the other half the shorter duration was used. Four equiprobable sequences of color-coded compo-

nent durations were therefore presented: a short red component followed by a short green component, a long red component followed by a long green component, a short followed by a long, and a long followed by a short. A test of either the red or green component duration followed the retention interval.

RESULTS

Figure 3 shows retention curves for the individual subjects (Panels A to C) and a mean curve (Panel D) in which results for each kind of *red-key test* are plotted separately. Retention on the heterogeneous trials (triangles) was substantially poorer than homogeneous trials (circles). This relation held for all of the subjects in all conditions except for Bird 9 in Conditions 3 and 5 where retention was poorest for three pecks followed by three pecks. Figure 4 shows retention curves for individual subjects (Panels A to C) and a mean curve (Panel D) in which results for each kind of *green-key test* are plotted separately. Retention of the heterogeneous trials (triangles) was poorer than the homogeneous trials (circles).

This relation held for all subjects and conditions except for Bird 8 in Condition 1 and Bird 9 in Condition 5. Mean retention across subjects and heterogeneous trials was above chance through the 2.0-sec retention interval. With a 4.0-sec retention interval performance was not two standard errors above .50. Retention across homogeneous trials with a 4.0-sec retention interval remained high (.804). On heterogeneous trials when memory for the first (red) component behavior was tested, retention was .665 compared with .905 for homogeneous trials, a difference of .24. On heterogeneous trials when memory for the second (green) component behavior was tested, memory was .715 compared with .925 for homogeneous trials, a difference of .21. Thus, it appears that the retroactive interference effect was slightly greater than the proactive interference effect (cf., Patrick, 1971; Stelmach, 1969). The difference was .03.

Figure 5 (Panels A to D) shows the individual subject and mean retention curves collapsed separately across *red-key* and *green-key tests* to show a primacy or recency effect (e.g.,
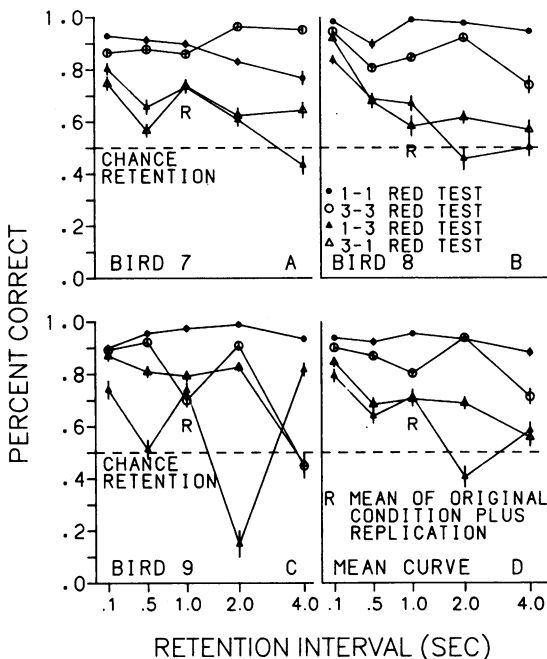

Fig. 3. Retention curves for the individual subjects of Experiment III are shown in Panels A to C. Panel D is a mean curve for the three subjects. All points are for trials in which red (first) component behavior was tested. Circles show retention on homogeneous trials. Triangles show retention on heterogeneous trials.
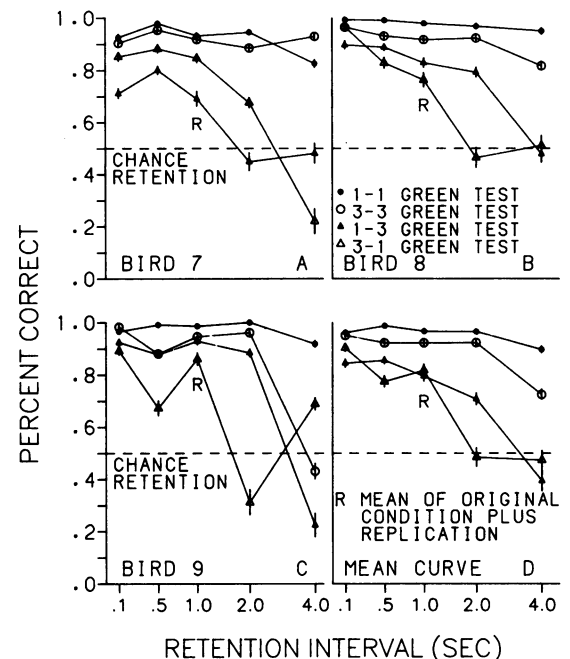
Fig. 4. Retention curves for the individual subjects of Experiment III are shown in Panels A to C. Panel D is a mean curve for the three subjects. All points are for trials in which green (second) component behavior was tested. Circles show retention on homogeneous trials. Triangles show retention on heterogeneous trials.

Shimp, 1976). Twelve of the fifteen data points in Panels A to C show better performance when behavior in the second component (green keys) was tested (unfilled circles). Performance was better in only three conditions when behavior in the first component (red keys) was tested (filled circles). If the two outcomes are considered equally likely, then the hypothesis that this result arose from chance may be rejected with a binomial distribution ($p < .05$, $n = 15$, two-tailed test). Thus, there appears to be a small recency effect. Averaged over all subjects and conditions, the difference between the retention for second and first component behavior is .035.

Averaged over subjects and conditions, the results for each context or kind of trial are as follows: on heterogeneous trials retention for one peck to a red key was .64 and for three pecks to a green key was .72. Retention for three pecks to a red key was .69 and for one peck to a green key was .71. On homogeneous trials retention for one peck to a red key was .93 and for one peck to a green key was .96. Retention for three pecks to a red key

was .88 and for three pecks to a green key was .89. Collapsed across test-key color, over all subjects and conditions except one, performance was better on trials in which one peck was followed by one peck than on trials in which three pecks were followed by three pecks. A binomial distribution shows that the likelihood of such a result arising from chance is very small ($p < .001$, $n = 15$, two-tailed test). Across all conditions and subjects, the difference in retention between the one-one and the three-three trials was .061.

Behavior-phase performance was examined to see if a decrease in response rate was correlated with the decreased percentage of correct choices. The changes across conditions of the mean response rate were nonsystematic. The mean response rate across conditions for Bird 7 was 1.20/sec, and the rates in Conditions 1 and 5 (the conditions with the shortest and longest retention intervals, respectively) were 1.13/sec and 1.23/sec, respectively. For Bird 8, the mean rate and the rates in Conditions 1 and 5 were 1.73, 1.55, and 1.63/sec, respectively. Bird 9 pecked at a mean rate of 1.23/sec and at the rate of 1.51 and 1.43/sec in Conditions 1 and 5, respectively.

The individual subject ROC curves are very similar to a mean curve (no curves shown). The points on the latter curve cluster around the isobias line. Thus, there is little or no bias for either sidekey. As the retention interval increases across conditions, data points are increasingly distant from point (.00, 1.00) and nearer (.50, .50). A curve that related d' to the retention interval shows the d' is a decreasing function of the log retention interval.

The results of the control condition show that all of the birds performed at or near chance (.50). The percentage of correct test-phase responses for all trials was .50, .59, and .51 for Birds 7, 8, and 9, respectively.

DISCUSSION

The results demonstrate that a pigeon can remember, for at least several seconds, the number of pecks recently emitted to a red (first) or green (second) sample stimulus. That is, a pigeon can remember the number of responses to each of two successive stimuli. The obtained retention, which is a decreasing function of the log retention interval, is consistent with the results of Experiments I and II. How-
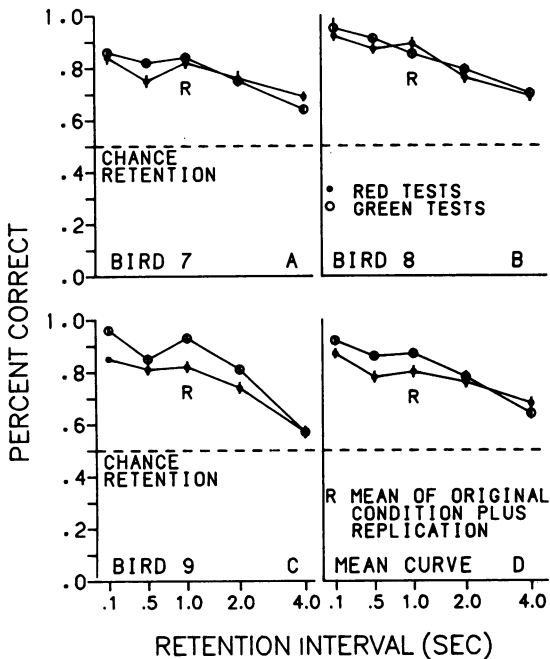

Fig. 5. Retention curves for the individual subjects of Experiment III are shown in Panels A to C. Panel D is a mean curve for the three subjects. Filled circles show retention across all red (first) component tests of a condition. Unfilled circles show retention across all green (second) component tests of a condition.

ever, the results of the present experiment also show that memory for one type of behavior may be affected by another type of behavior as well as by the passage of time.

Figures 3 and 4 show that a bird can remember which number of responses it recently emitted in the presence of a stimulus even when that number of responses is preceded or followed by a different number of responses to a different stimulus (heterogeneous trials). The retention lasts for only a few seconds, however. When a number of responses is preceded or followed by the same number of responses retention lasts much longer (homogeneous trials). Thus, when homogeneous and heterogeneous trials are compared, it appears that memory for a number of responses emitted to a stimulus is impaired considerably by a different number of responses recently emitted to a different stimulus. The retroactive effect is slightly greater than the proactive effect.

Some other properties of memory for one type of behavior in the context of another type were also identified in the present results. Figure 5 shows that there was a slight recency effect; that is, retention was better for the more recent (green component) activity than for the earlier (red component) activity. This result may be interpreted in terms of the effective retention interval on red-key tests compared with green-key tests, or in terms of the interference effects, or in terms of both retention interval and interference. The retention interval was increased, when red-component behavior was tested, by the interstimulus interval (.25 sec), plus the time taken for the green-component behavior to be emitted (a mean of 1.44 sec). Thus, the mean effective retention interval was shorter on green-key tests by 1.69 sec. It is well-established in a variety of situations that retention decreases as a retention interval is increased (e.g., Adams & Dijkstra, 1966; D'Amato, 1973; Roberts & Grant, 1976; Peterson & Peterson, 1959). Based on the retention decrements in Figure 5 of the present experiment, it appears that at least quantitatively the difference in effective retention interval between red- and green-key tests could account for some or all of the recency effect of .035. However, on homogeneous trials alone the recency effect was only .02, where there is presumably no interference. Thus, the recency effect may be only .02 rather than .035, with

the interference effect providing the additional difference in retention between the red- and green-key tests.

On both red-key and green-key tests, memory for one peck followed by one peck was found to be significantly better across conditions than memory for three pecks followed by three pecks. The reason for this result on the red-key tests may be a difference in the effective retention interval. That is, when memory for one peck to a red key was tested on a homogeneous trial, the effective retention interval was shorter than when memory for three pecks to a red key was tested. The elapsed time for the interpolated green-component behavior was shorter on the former trials. The reason for the superiority of memory for one peck over three pecks to a green key on homogeneous trials is unclear. However, the latter result in the final analysis may not be reliable because a similar result was not obtained on the heterogeneous trials.

The analysis of the bias and behavior-phase components of performance provides an estimate of the extent to which uncontrolled aspects of performance contributed to the decreased percentage of correct choices. The control condition provides an estimate of the extent to which a subject remembered the duration of the sample stimulus rather than the sample behavior. There were no systematic changes across conditions in the rate of behavior-phase responses, so that changes in behavior-phase performance do not appear to correlate with the decreased percentage of correct choices. There was little or no increase in bias across conditions, so that the development of sidekey preferences does not appear to correlate with the decreased percentage of correct choices. Decreased d', however, does appear to correlate with the decreased percentage of correct choices. Thus, the decreased percentage of correct choices appears to define a subject's inability to remember the sample behavior and not a confound with some uncontrolled aspect of performance. In the control condition the retention was near chance, so that it indeed appears that the animals remembered the number of pecks emitted to a sample stimulus rather than the duration of a sample stimulus.

In Experiments I and II, one property of memory for recent behavior was identified that is relevant to the theory of Shimp (1975,

1978). That is, it was shown that one variable that affects the likelihood that behavior will be remembered is the retention interval. In Experiment III another relevant property of memory for recent behavior is identified. That is, it was shown that memory for one activity is affected by another activity.

More specifically, other behavior that is the same improves memory compared to other behavior that is different. Other behavior that is different impairs memory compared to other behavior that is the same. Retroactive interference is greater than proactive interference. The more recent of two types of behavior is remembered better; and there is some indication that a small number of responses is remembered better than a larger number.

GENERAL DISCUSSION

Let us consider the questions related to Shimp's theory that were raised earlier in view of the present results. It has been demonstrated that recent behavior can indeed be remembered; and some of the properties of the memory have been explored. It has been shown that memory for a small number of responses may last one-half to one minute or more. It has been shown that memory for one number of responses may be affected by a second number. When the second number of responses is different from the first, memory may last only a few seconds. However, when the second number of responses is the same, memory may last considerably longer. The interference effect of a different number of responses is greater on earlier responses than later responses. The more recent number of responses should be remembered better, and a small number of responses may be remembered better than a larger number.

It remains to discuss the significance of the properties of memory for behavior for the theory presently under consideration and for the analysis of reinforcement contingencies. An important component of Shimp's theory is the proposal that a reinforcer may act on behavior that is noncontiguous with its delivery to the extent that the behavior can be remembered. Such a memory-based theory permits one to easily incorporate results such as the present ones to generate predictions of patterns of behavior that may or may not develop based on remembered behavior.

Based on the results of the first two experiments one might predict that it should be possible to produce patterns that contain an interresponse time (IRT) of thirty to sixty seconds if all of the parameters of a situation were similar to those of Experiments I and II. In such a situation one might also predict that it should be difficult to produce patterns that contain a considerably longer IRT. The "differential-reinforcement-of-long IRT (DRL)" is an example of a schedule of reinforcement to which predictions based on the present results might apply. In the DRL, a parameter specifies the minimum amount of time that must elapse between two instances of a response in order for a reinforcer to be delivered. The bulk of the DRL literature shows that performance can be brought under control of DRL contingencies with parameter values of up to 30 to 60 seconds (e.g., Gray, 1976; Harzem, Lowe, & Davey, 1975; Richardson & Clark, 1976). Catania (1971) reported that with short parameter values, many IRTs were emitted that met the specifications for reinforcement; but with values of 36.4 to 48.0-sec, the temporal control was not comparable. There are two seeming anomalies in the literature in which DRL parameter values of four to fifteen minutes were used (Richardson & Loughead, 1974; Skinner & Morse, 1958). However, in the Skinner & Morse study, it is unclear that performance was brought under control of the DRL contingency. That is, the relative frequency of required IRTs may not have been higher than the relative frequencies of other emitted IRTs. In the other study (Richardson & Loughead, 1974) the explanation is less clear. The authors reported that in contrast to small DRLs, there was very little activity during the IRT of their schedule. They concluded: "perhaps DRL behavior under large DRL values is a different 'kind' than DRL behavior under small DRL values," or perhaps small and large DRLs are controlled by different sets of variables.

Based on the results of the third experiment, one might predict that it should be possible to produce patterns that contain different numbers of responses emitted to different stimuli followed by a shorter IRT; and that it should be possible to produce patterns that contain identical numbers of responses followed by a longer IRT. However, there do

not appear to be any data in the literature to which these predictions might apply. Before a theory of patterns based on memory can be used to produce more general predictions, it will be necessary to explore other properties of memory that may determine the general extent to which a reinforcer may act on behavior which is noncontiguous.

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