

MEMORY FOR SEQUENCES OF STIMULI AND RESPONSES

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Two experiments sought to determine if pigeons could discriminate and remember recent sequences of stimuli and responses. A variant of Konorski's short-term memory procedure involving successive presentation of sample and test stimuli was used. The samples were stimulus-response pairs of the form, (S-R)₁-(S-R)₂. Differential test responding disclosed memory of the two-item samples, with birds showing earlier and greater control by the second item than the first (Experiment 1). When the retention interval separating the second item of the sample sequence from the test stimulus was lengthened from .5 to 2.0 or 4.0 sec, a systematic loss of stimulus control resulted; however, when varied over the same temporal range, the interval between the two items of the sample sequence had a much smaller effect, or none at all (Experiment 2). These results support an account of response-sequence differentiation that stresses short-term memory of organized behavior patterns.

Key words: response differentiation, behavioral organization, stimulus-response memory, short-term memory, key peck, pigeons

When many responses precede a reinforcer, responses in addition to the last one may enter into association with the reinforcer (Cattania, 1971). This retrograde influence of reinforcement raises the possibility that functional operants may involve several responses that are organized into temporal and spatial groupings: a possibility for which empirical support has recently been gathered (e.g., Grayson & Wasserman, 1979; Hawkes & Shimp, 1975; Wasserman, 1977; Zeiler, 1977).

Consider the experiment of Grayson and Wasserman (1979). In this discrete-trial investigation, the illumination of two response keys signaled the availability of food reinforcement to hungry pigeons. Food delivery depended on the order in which the required two key pecks occurred. In different phases only one of the four possible two-peck sequences (left-left, left-right, right-left, and right-right) produced food. In each case the pigeons learned to perform the correct two-peck sequence more often than

the incorrect sequences. During those phases in which a response to each key was required (left-right and right-left), incorrect sequences most often involved repeated responses to the key temporally nearest to reinforcer delivery (right-right and left-left, respectively).

In accounting for these response-differentiation results, Grayson and Wasserman proposed that the concept of *short-term memory* could be valuable. If an organized sequence of responses is to become a functional operant, then the constituents of the response pattern and their temporal order (Weisman & Dodd, 1979) must be retained until reinforcement for response differentiation to take place. Thus, if we assume that pigeons remember their own recent behavior until the reinforcer is delivered (e.g., Lattal, 1975; Rilling & McDiarmid, 1965; Shimp, 1976; Shimp & Moffitt, 1974; Zirix & Silberberg, 1978),

we can appreciate how response differentiation is possible for behavioral units comprising two responses: an ordered sequence of two responses should still be available in the pigeon's short-term memory at the time of reinforcement or non-reinforcement. And we can understand why incorrect sequences often involve the response closest in time to reinforcement:

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memory for the second response of the positive sequence should exceed that of the first, thereby favoring association of the final response element of the sequence with reinforcement over association of the entire two-response sequence with reinforcement (Grayson & Wasserman, 1979, p. 28).

Of course, there is a danger in applying the concept of memory to these experimental outcomes: without an independent assessment outside the response-differentiation situation, properties of short-term memory that are *inferred* from the response-differentiation data might be used circularly to *explain* the characteristics of such learning. What is needed is an independent evaluation of the pigeon's memory for organized behavior sequences that would parallel the response-differentiation experiment. This was the intent of the present study. Specifically, Experiment 1 of this study sought to determine if organized sequences of stimuli and responses could serve as discriminable and rememberable samples in a delayed conditional-discrimination paradigm. Experiment 2 pursued the positive findings of the first experiment and examined in greater detail the characteristics of memory for organized stimulus-response sequences.

EXPERIMENT 1

To gather supportive evidence of memory for stimulus-response sequences, Konorski's (1959) delayed conditional-discrimination procedure was utilized (also see Nelson & Wasserman, 1978; Wasserman, 1976). In this procedure, one of several samples is presented, and some time after its termination one of several test stimuli is presented. For each sample only one test stimulus is regularly paired with reinforcement; the remaining test stimuli are never paired with reinforcement after that sample. Performance during the test stimulus provides evidence of memory for the sample; in order to respond discriminatively during the test stimulus in accord with the availability or unavailability of reinforcement, the prior sample must be remembered over the scheduled retention interval.

In our delayed conditional-discrimination procedure, shown in Table 1, the items to be remembered were stimulus-response pairs of

the form, (S-R)₁-(S-R)₂. Four sample sequences resulted (left-left, left-right, right-left, and right-right), each of which was uniquely paired with reinforcement after only one of four different test stimuli (Test 1, Test 2, Test 3, and Test 4). By monitoring the pigeon's rate of responding to the four test stimuli after the four sample sequences, it was possible to determine the degree to which the compound samples gained discriminative control over behavior at test. Specifically, if the two-item sample sequences gained control over test behavior, then response rates on positive (+) trials should exceed rates on all negative (-) trials. Also, to the degree that relative recency of the elements constituting a sample sequence controls behavior, highest response rates on negative trials should involve the sample sequences sharing the same terminal segment as the sample sequences on positive trials.

METHOD

Subjects

The subjects were six domestic pigeons housed individually, with water and grit constantly available in their home cages. They were kept at approximately 80% of their free-feeding weights by postsession feeding in the home cage. The subjects had earlier received extended training under intermittent reinforcement schedules. Immediately prior to the present investigation, the birds were conditioned to peck the appropriate key stimuli described below.

Apparatus

Four three-key conditioning cubicles were used with interior dimensions of 29 by 38 by 38 cm. The three response keys in each cubicle were 2.5 cm in diameter, were positioned 13 cm above the grain hopper (BRS/LVE No.

Table 1
Experimental Design

Test Stimulus	Sample sequence			
	Left-Left	Left-Right	Right-Left	Right-Right
Test 1	+	-	-	-
Test 2	-	+	-	-
Test 3	-	-	+	-
Test 4	-	-	-	+

Note. The + sign denotes trial types involving reinforcement; the - sign denotes trial types involving nonreinforcement.

114-10), and required at least .15 N for activation. Key illumination was accomplished by applying 5 VDC to incandescent bulbs (GE 44) in display projectors located behind each clear plastic key. The left and right keys could be illuminated by red or green fields. The center key could be illuminated by red, violet, blue, or yellow fields and by white lines that bisected the response key and were oriented vertically or 60° from vertical. Each line stimulus was .2 cm wide and 2.5 cm long. Chamber illumination was provided by a houselight (5 VDC, GE 44 bulb) encased in a metal shield that directed the light toward the ceiling. In each chamber ventilation was provided by an exhaust fan; white noise was provided through an audio speaker. Experimental control and data collection were managed in an adjacent room by a DEC PDP 8/a computer using the SKED software system (Snapper, Stephens, & Lee, 1974) and a solid-state interface (Grisham & Frei, 1977).

Procedure

Each of 80 daily trials progressed through the following steps: intertrial interval, sample-sequence presentation, retention interval, test-stimulus presentation, and trial-outcome period.

Intertrial interval. During the 20.4-sec intertrial intervals, all keys were dark. The houselight was continuously illuminated during the first 20 sec of each intertrial interval; then two .1-sec off, .1-sec on cycles of the houselight signaled the beginning of a sample sequence.

Sample-sequence presentation. A left-left, left-right, right-left, or right-right sample sequence was scheduled during this step. With equal probability the left or the right key was illuminated. The first peck to the lighted key turned it off, and with equal probability .5 sec later, the left or the right key was illuminated. Again, the first peck to the lighted key turned it off. In the event that 10 sec elapsed without a peck to either the first or the second lighted key, the light was automatically extinguished and the program advanced to the next step. Trials lacking the required two sample responses were rare and data from these trials were excluded from analysis. The houselight was on during this step.

Retention interval. The retention interval immediately followed sample-sequence presentation and lasted .5 sec. The keys were

Table 2
Stimulus Assignments for Individual Pigeons

Bird	Side Keys	Test 1	Test 2	Test 3	Test 4
4122	Red	Slanted	Yellow	Blue	Vertical
4132	Red	Slanted	Yellow	Blue	Vertical
4113	Green	Red	Yellow	Blue	Violet
4123	Green	Yellow	Blue	Violet	Red
4133	Green	Blue	Violet	Red	Yellow
4143	Green	Violet	Red	Yellow	Blue

dark and the houselight was on during this interval.

Test-stimulus presentation. One of the four test stimuli (T1, T2, T3, or T4) was presented with equal probability on the center key during this step. Combining the four possible sample sequences with the four possible test stimuli yields the 16 possible and equiprobable trial types outlined in Table 1. Five blocks of 16 trials were scheduled each session, with each of the 16 trial types occurring once in each block. On negative (EXT) trials the test stimulus lasted 5 sec. On positive (FI) trials the first center-key peck after 5 sec turned off the test stimulus. Comparison of center-key response rates during the first 5 sec of test-stimulus presentation on positive and negative trials permitted evaluation of control by the preceding sample sequences. The houselight was on during this step.

Trial outcome. On both positive and negative trials, the trial outcome step lasted 2.5 sec during which the houselight was off. On positive trials the food hopper was lighted and elevated for the full duration of the trial-outcome period. On negative trials blackout was the outcome.

Stimulus assignment. The specific side- and center-key stimuli given to each subject are shown in Table 2.

Experimental training lasted 75 days for Birds 4122 and 4132, and 155 days for Birds 4113, 4123, 4133, and 4143.

RESULTS

Over the course of experimental training, test responding came under the discriminative control of prior stimulus-response sample sequences. Support for this conclusion comes from subproblem analysis of response rates to each test stimulus.

Figure 1 portrays group mean test-response rates from selected 5-day blocks of training in

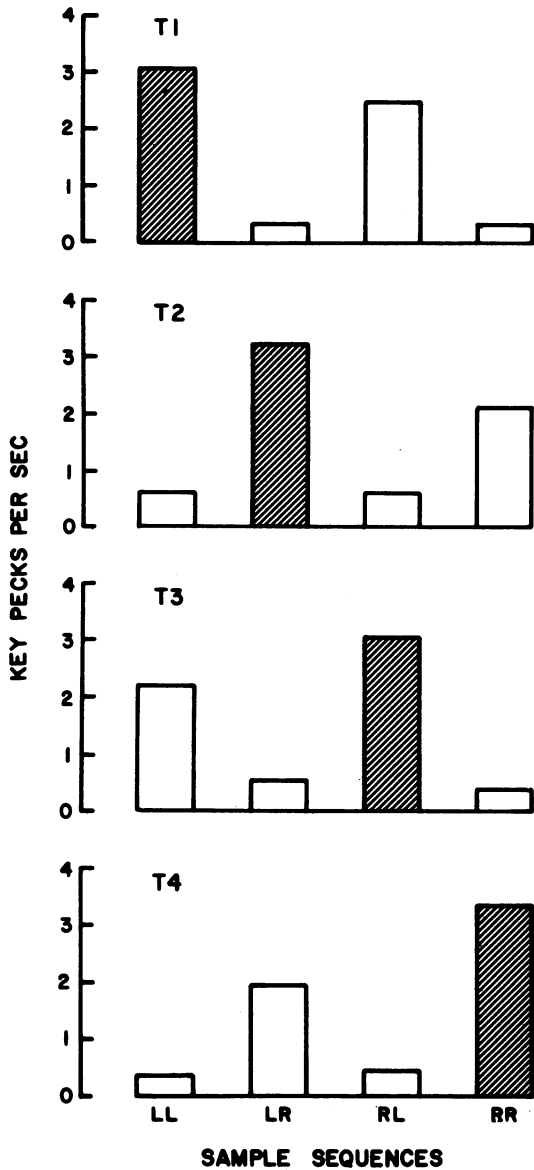


Fig. 1. Group mean key pecks per sec to each of the four test stimuli (T1, T2, T3, and T4) after each of the four sample sequences (LL, LR, RL, and RR) on selected 5-day blocks of training (see text and Table 3) in Experiment 1. Only LLT1, LRT2, RLT3, and RRT4 trials involved food reinforcement (shaded bars); the remaining trials involved nonreinforcement (open bars). The data of individual subjects are in Table 3.

a manner paralleling the design of the experiment depicted in Table 1.¹ Data for individual pigeons, in Table 3, testify to the representa-

tiveness of the group data in Figure 1. The data of Birds 4122, 4132, 4123, and 4133 come from the first training block in which test pecks on all negative trials in each subproblem constituted no more than 90% of the test rate on positive trials. Birds 4113 and 4143 never quite met this criterion; instead, their data come from the training block containing the fewest responses on negative trials, provided that the percentage of pecks on all negative trials in each subproblem was no more than 100% of the rate on positive trials.

Lowest rates of test responding occurred on negative trials in which the sample sequences ended in a different terminal segment than the corresponding positive-trial sequences. Intermediate rates of test responding occurred on negative trials in which the sample sequences ended in the same terminal segment as the corresponding positive-trial sequences. Table 3 further shows that discrimination learning proceeded more rapidly for pigeons (4122 and 4132) receiving two lines and two colors as test stimuli than for pigeons (4113, 4123, 4133, and 4143) receiving four colors as test stimuli.

Figure 2 gives a more detailed picture of the course of discrimination learning. This figure depicts the mean rate of responding in T1, T2, T3, and T4 after LL, LR, RL, and RR sample sequences for a representative pigeon, Bird 4133, over the first 21 5-day blocks of training. Test responding first declined after sample sequences ending in a different terminal segment than the sample sequences on positive trials. Later in training, test responding also declined on negative trials after sample sequences ending in the same terminal segment as the sample sequences on positive trials. Differential responding during each of the four test stimuli showed these trends.

Figure 3 shows the mean time for Bird 4133 to make the second peck of the sample sequence over the first 21 5-day blocks of training. This time was recorded in .10-sec units from onset of the second sample keylight. Over training time to respond to the second sample light decreased on left-right and right-left sequences from more than 4.50 sec on Block 1 to approximately 1.50 sec on Block 6, where it remained until the end of training. Time to respond to the second sample light on left-left and right-right sequences began at about .75 sec, rose to about 1.50 sec on Block

¹These scores represent the means and standard errors of daily rates of key pecking on selected 5-day blocks.

Table 3
Mean test pecks per sec and standard errors for individual pigeons on selected 5-day blocks of training in Experiment 1. (*Note.* Italicized scores come from positive trials.)

Bird	Block	T1				T2				T3				T4			
		LL	LR	RL	RR	LL	LR	RL	RR	LL	LR	RL	RR	LL	LR	RL	RR
4122	11																
	mean	<i>3.84</i>	.32	3.38	.31	1.06	<i>4.45</i>	1.27	3.21	4.07	1.60	<i>4.50</i>	.32	.18	2.39	.22	3.72
	se	.09	.13	.10	.14	.26	.21	.47	.43	.11	.34	.16	.11	.05	.45	.12	.20
4132	11																
	mean	2.66	.25	1.75	.56	.11	2.22	.15	1.91	1.66	.38	<i>2.64</i>	.42	.71	1.15	.77	3.07
	se	.05	.16	.24	.24	.07	.03	.12	.38	.26	.17	.03	.11	.45	.56	.48	.08
4113	17																
	mean	.77	.14	.75	.10	.19	<i>1.07</i>	.14	.99	.82	.46	<i>.91</i>	.45	.14	.85	.09	.98
	se	.03	.08	.07	.03	.10	.11	.06	.10	.06	.14	.08	.09	.03	.07	.04	.11
4123	31																
	mean	<i>2.08</i>	.06	1.05	.02	.42	<i>1.65</i>	.52	1.42	.80	.15	2.22	.62	.12	1.97	.78	<i>2.64</i>
	se	.17	.04	.29	.01	.13	.28	.25	.33	.31	.11	.19	.19	.10	.16	.41	.29
4133	16																
	mean	<i>3.10</i>	.35	2.61	.25	.54	<i>3.21</i>	.51	2.68	1.18	.15	2.76	.06	.08	2.25	.10	2.97
	se	.07	.13	.20	.04	.18	.08	.13	.24	.25	.05	.06	.03	.03	.18	.02	.05
4143	26																
	mean	<i>5.78</i>	.84	5.34	.59	1.34	<i>6.69</i>	.99	2.30	4.75	.62	<i>5.33</i>	.44	.92	3.19	.82	6.79
	se	.07	.17	.14	.04	.36	.10	.27	.24	.13	.05	.13	.03	.30	.30	.21	.10

3, and thereafter returned to approximately the .75-sec value for the remainder of training. These latency data bear no strong relation to the discrimination data of Figure 2.

EXPERIMENT 2

Experiment 1 showed that a two-item stimulus-response sequence could serve as a discriminative stimulus for the later key-pecking behavior of hungry pigeons: test-response rates on positive trials exceeded those on all negative trials. The results further showed that in such conditional discriminations, control by the second item of the sample sequences exceeded control by the first—a recency effect.

As noted earlier, the elaborate conditional-discrimination method of Experiment 1 was a modification of one originally designed for the study of short-term memory (Konorski, 1959; Wasserman, 1976). Given the main finding of Experiment 1—that a prior two-item stimulus-response sequence can control the later test responding of pigeons—it was of interest to determine how time influences such discriminative control. In Experiment 2, the retention interval between the second item of the sample sequence and the test stimulus was lengthened, as was the interval between the items of the sample sequences.

While we expected that increasing either

the interitem interval or the retention interval would impair discriminative control of test responding, it was not obvious whether one interval would influence performance more than the other. If one interval were to have a greater effect than the other, then different accounts of memory performance would gain or lose credence. For example, if the discrimination and retention of the sample sequences depend on the subject's organizing the two temporally-separate S-R pairs of a sample sequence into one perceptual unit or gestalt (Kohler, 1947), then the interitem interval might be predicted to be a more potent parameter than the retention interval. From a different perspective, if short-term memory is limited in its capacity to hold prior sample events (Atkinson & Shiffrin, 1968), then lengthening the interitem interval (over which only one sample item must be retained) should have a much smaller effect than lengthening the retention interval (over which both sample items and their temporal order must be retained).

METHOD

Subjects

Birds 4123, 4133, and 4143 continued as experimental subjects. The present experiment began after 40 sessions of additional training like that described in Experiment 1. During this time the interitem and retention intervals

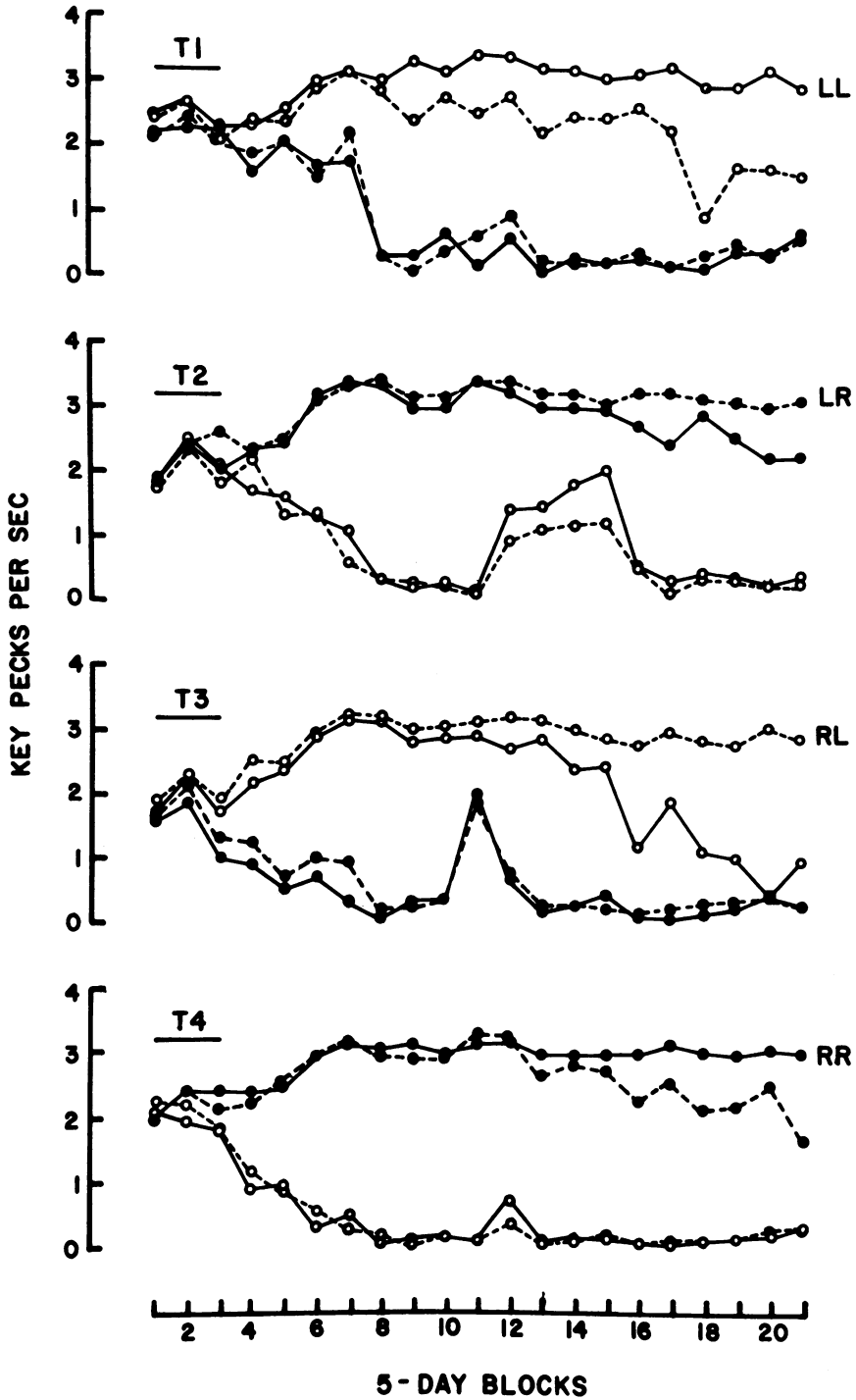


Fig. 2. Mean key pecks per sec of Bird 4133 to each of the four test stimuli (T1, T2, T3, and T4) after each of the four sample sequences (LL, LR, RL, and RR) on the first 21 5-day blocks of training in Experiment 1.

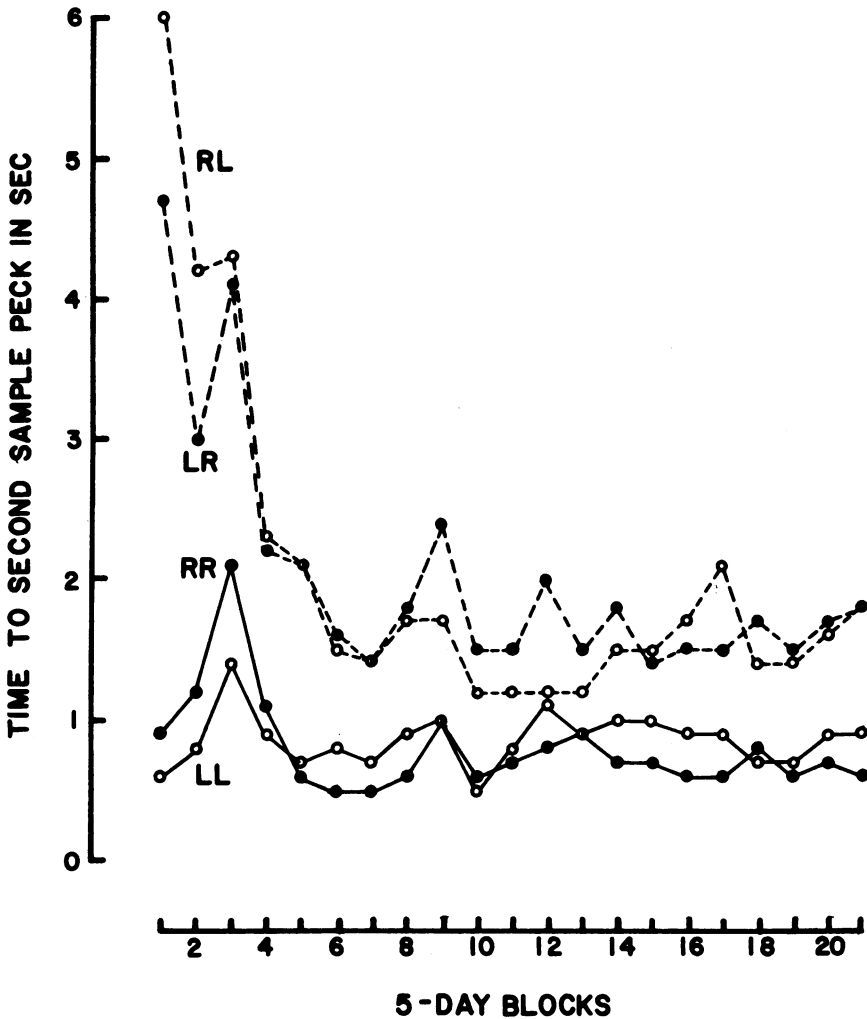


Fig. 3. Mean time (in sec) from onset of the second sample light until the required peck on LL, LR, RL, and RR samples for Bird 4133 on the first 21 5-day blocks of training in Experiment 1.

were occasionally varied so that reasonable values might be selected for the present experiment.

Apparatus

The apparatus was the same as in Experiment 1.

Procedure

Except for the manipulation of interitem and retention intervals, training was identical to that described in Experiment 1. These parameters were manipulated in a random-blocks design, with each day of a 5-day block involving a different combination of interitem interval and retention interval. For Birds 4123

and 4143, these combinations were: .5-.5 (the first number being the length in sec of the interitem interval, the second the length of the retention interval) as in Experiment 1, 1.0-.5, 2.0-.5, .5-1.0, and .5-2.0. For Bird 4133, whose performance surpassed that of the other two birds, these combinations were: .5-.5, 2.0-.5, 4.0-.5, .5-2.0, and .5-4.0. Training lasted 25 days.

RESULTS

As in Experiment 1 the mean rate of responding to the test stimuli on all 16 trial types was obtained for each of the five combinations of interitem interval and retention interval. To minimize the burden of examining the data from all 16 types of trials, these

Table 4

Mean test pecks per sec and standard errors for individual pigeons at each combination of interitem interval and retention interval in Experiment 2. (*Note.* Scores from Condition .5-.5 are repeated for ease of comparison.)

Bird	Condition	Sample sequence			
		SS	DS	SD	DD
4123	.5-.5	mean: 1.90	1.31	.40	.44
		se: .19	.16	.08	.08
	1-.5	mean: 1.98	1.62	.47	.38
		se: .18	.14	.09	.08
	2-.5	mean: 1.97	1.24	.48	.42
		se: .21	.15	.09	.09
	.5-.5	mean: 1.90	1.31	.40	.44
		se: .19	.16	.08	.08
.5-1	mean: 2.12	1.69	.75	.62	
	se: .19	.16	.09	.09	
.5-2	mean: 2.52	2.09	1.17	1.05	
	se: .23	.21	.16	.15	
4133	.5-.5	mean: 2.73	1.59	.60	.37
		se: .05	.11	.08	.05
	2-.5	mean: 2.69	1.69	.61	.49
		se: .06	.10	.07	.06
	4-.5	mean: 2.83	1.82	.60	.60
		se: .05	.11	.07	.07
	.5-.5	mean: 2.73	1.59	.60	.37
		se: .05	.11	.08	.05
	.5-2	mean: 2.59	1.78	.93	.77
		se: .06	.10	.10	.09
.5-4	mean: 2.63	2.17	1.29	1.16	
	se: .06	.08	.11	.10	
4143	.5-.5	mean: 4.32	3.42	1.82	1.30
		se: .09	.15	.18	.15
	1-.5	mean: 4.41	3.40	1.67	1.23
		se: .11	.14	.18	.15
	2-.5	mean: 4.66	4.26	2.30	1.88
		se: .12	.10	.20	.19
	.5-.5	mean: 4.32	3.42	1.82	1.30
		se: .09	.15	.18	.15
.5-1	mean: 4.34	3.16	2.30	1.97	
	se: .09	.15	.18	.17	
.5-2	mean: 3.87	3.49	3.52	3.31	
	se: .08	.10	.11	.13	

scores were reduced to four categories: tests on negative trials in which only the last sample segment was the same as in positive trials (Different-Same or DS; from LLT3, LRT4, RLT1, and RRT2 trials), tests on negative trials in which only the first sample segment was the same as in positive trials (Same-Different or SD; from LLT2, LRT1, RLT4, and RRT3 trials), tests on negative trials in which both sample segments were different than in positive trials (Different-Different or DD; from LLT4, LRT3, RLT2, and RRT1 trials), and tests on positive trials (Same-Same or SS; from

LLT1, LRT2, RLT3, and RRT4 trials). These categorized response-rate data are shown in Table 4.² Response rates were generally ordered: SS > DS >> SD > DD. As the interitem interval was lengthened, there was little systematic change in the rates of test responding; however, lengthening the retention interval tended to increase the rate of response on all categories of negative trials—DS, SD, and DD.

A similar but possibly clearer picture emerges when performance on negative trials is expressed relative to performance on positive trials. To do this the rate of responding on SS trials was separately summed with the rate of responding on each of the three categories of negative trials. Then, the rate of responding on SS trials was divided by each of these subtotals (DS + SS, SD + SS, and DD + SS) to yield three discrimination ratios expressing the degree to which subjects discriminated DS from SS trials, SD from SS trials, and DD from SS trials, respectively. As these discrimination ratios rise from .5 to 1.0, increasingly better discrimination is seen; forgetting is manifested by lowered discrimination ratios as either the interitem or the retention interval is lengthened from the original training values of .5 sec (also see Nelson & Wasserman, 1978).

Figure 4 illustrates the resulting scores. Discrimination ratios were much less affected by changes in the interitem interval than by changes in the retention interval; increasing the retention interval produced clear and ordered decrements in the discrimination of negative from positive trials, whereas increasing the interitem interval did not yield such marked and regular reductions. Relative to SS performance, discrimination ratios were generally ordered: DD > SD >> DS. However, even at the longest interitem and retention intervals studied, the discrimination of DS from SS trials yielded ratios above the chance level of .5.

GENERAL DISCUSSION

The central aim of this study was to discover if pigeons can discriminate and remem-

²These scores represent the means and standard errors of rates of key pecking from individual trials during a 5-day period, unlike the scores given in Experiment 1 (see Footnote 1).

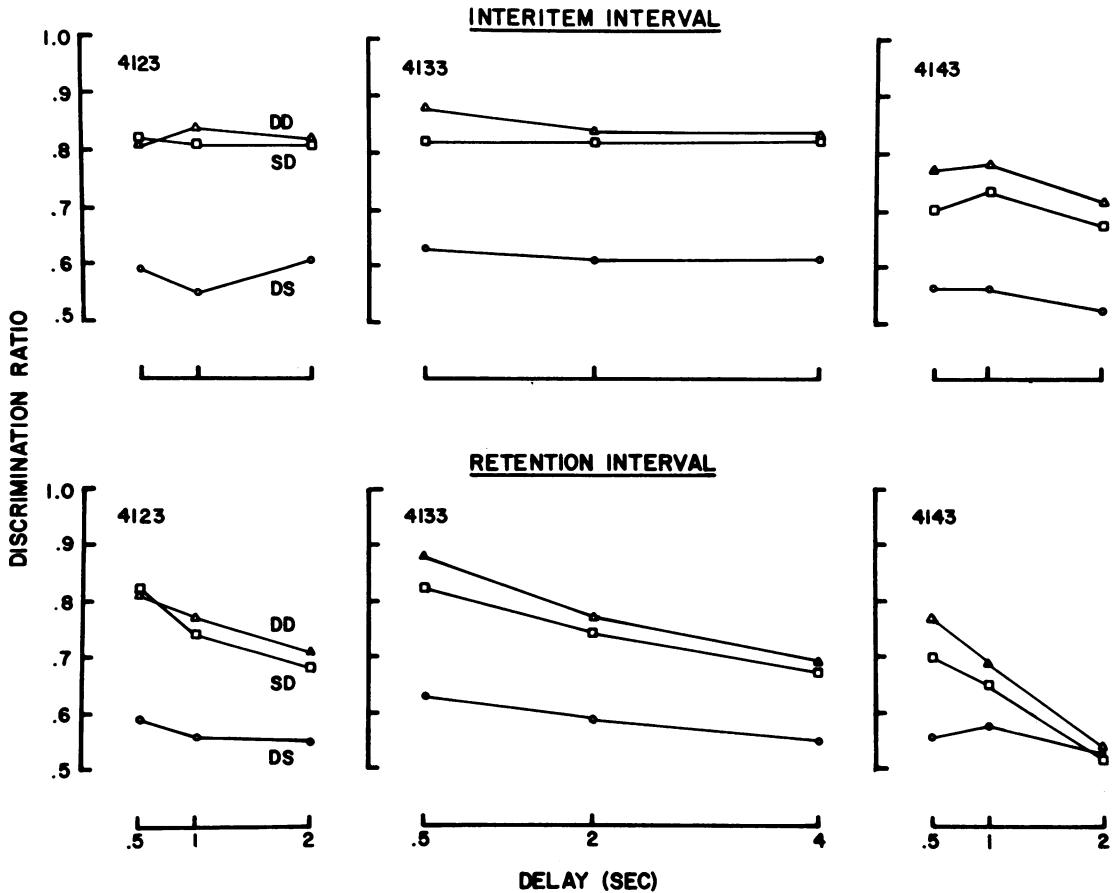


Fig. 4. Discrimination ratios of Birds 4123, 4133, and 4143 at each combination of interitem interval (top) and retention interval (bottom) in Experiment 2. Separately depicted are discriminations between positive (SS) trials and each of the three categories of negative trials (DS, SD, and DD). The .5-.5 values are replotted in the top and bottom portions of the figure so that delay gradients for the interitem interval and the retention interval might be separately portrayed.

ber recent sequences of stimuli and responses. To this end, two-item sequences of the form $(S-R)_1-(S-R)_2$ were used as samples in a delayed conditional-discrimination procedure. Our pigeon subjects did indeed learn to respond discriminatively after prior stimulus-response sequences (Experiment 1) and later showed a systematic loss of a stimulus control when the retention interval separating the second item of the sample sequence from the test stimulus was lengthened from .5 to 2.0 or 4.0 sec (Experiment 2). Although varied over the same temporal range, the interval between the two items of the sample sequence had a much smaller effect on performance, or none at all (Experiment 2). Relative recency of the individual elements of the two-item sequences also influenced the acquisition (Experiment

1) and maintenance (Experiment 2) of stimulus control, with the second sample item exerting control sooner and more strongly than the first.

Close parallels can be drawn between the present study of memory for stimulus-response sequences and the prior investigation of response-pattern differentiation by Grayson and Wasserman (1979). The successful differentiation of two-response patterns of key pecking in the prior study led us to expect that pigeons could discriminate and remember two-item stimulus-response sequences. The present results confirmed this expectation. Further, because in the response-differentiation investigation many pattern errors involved responses closest to reinforcement, we anticipated that in the present study stimulus control by the

second item of the sample sequences would exceed the first. This too proved to be the case.

While these parallels encourage us to pursue the usefulness of a memory-based account of operant behavior, some problems with the present results and procedures merit consideration. The first problem is that the present research disclosed no notable differences in the stimulus control exerted by homogeneous (left-left and right-right) and heterogeneous (left-right and right-left) sample sequences, whereas Grayson and Wasserman found that the homogeneous response patterns were differentiated much faster than the heterogeneous patterns. One might have predicted that memory of homogeneous sample sequences would surpass that of heterogeneous sequences; homogeneous sequences should entail shorter intervals from termination of the first stimulus-response item until test-stimulus presentation because heterogeneous sequences entail travel from one key to the other. Experiment 1 showed that such item 1-test interval differences did exist but that they were unrelated to control by the different sample sequences. In addition, Experiment 2 revealed little effect of the item-1-item-2 interval (and correspondingly of the item-1-test interval).

Given the present failure to find differential stimulus control by homogeneous and heterogeneous sample sequences, how can the disparate differentiations of these patterns observed by Grayson and Wasserman be explained? A good possibility is that the homogeneous behavior patterns have a higher likelihood of occurrence than the heterogeneous patterns. Unpublished work in our laboratory has shown that, under nondifferential reinforcement, left-left and right-right patterns are emitted more than five times as often as left-right and right-left patterns. Indeed this fact led Grayson and Wasserman to include in their preliminary training a phase in which only heterogeneous response patterns were reinforced so that the frequencies of heterogeneous and homogeneous patterns might be more nearly equal. With homogeneous patterns being much more likely than heterogeneous patterns (possibly because of their lesser effort), perhaps it is not too troubling that they are also more rapidly differentiated.

A second problem in drawing parallels between the earlier investigation of response-

pattern differentiation and the present study of memory for stimulus-response sequences is that the differentiation study involved responses to simultaneously illuminated pecking keys, whereas the present memory investigation constructed stimulus-response sequences by the successive illumination of response keys. In the present study it is possible that subjects discriminated and remembered the sequence of key illuminations or the sequence of key pecks or both. Our inability to choose among these alternatives is a possible shortcoming. However, the response-differentiation experiment encounters the same problem: even there, the subject was exposed to a succession of lighted keys as it moved from one key to another or as it struck the same key twice. Successions of stimulus events may thus play a significant role in response-pattern differentiation as in memory for stimulus-response sequences.

Therefore, we conclude that the two problems discussed above do not pose serious difficulties for a memory-based account of operant behavior.

We wish to end this paper with a brief historical note, so that due credit might be given for many of the ideas we have entertained. Although others might be mentioned, we cite the early investigator of animal learning, L. T. Hobhouse, as one of the first to study the acquisition of complex sequences of manipulative behavior. His researches were not only many and varied, but they also involved rather more unusual subjects than are customarily found in today's laboratories, including several species of monkeys, an otter, and an elephant. From his work Hobhouse concluded that elaborate sequences of responses were conditionable. Commenting on the learning of a heterogeneous two-response sequence, Hobhouse conjectured that, "To learn this . . . implies a certain measure of articulateness in experience. Two things must be . . . known, and their order kept in mind" (1901, p. 165). Noting the course of mastery of a heterogeneous two-response sequence, Hobhouse observed that "this was a double movement learnt *regressively*—i.e., the act to be done last was learnt first" (1901, p. 165). The reader will recognize the similarity of these notions to our own ideas of response-sequence memory and relative recency of the elements in a response sequence.

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