

*SHORT-TERM MEMORY IN THE PIGEON:
DELAYED-PAIR-COMPARISON PROCEDURES
AND SOME RESULTS¹*

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A discrete-trials, delayed-pair-comparison procedure was developed to study visual short-term memory for tilted lines. In four experiments, pigeons' responses on left or right keys were reinforced with food depending on whether a comparison stimulus was or was not the same as a standard stimulus presented earlier in the same trial. In Experiment I, recall was an increasing function of the exposure time of the to-be-remembered stimulus and was a decreasing function of the retention interval. In Experiment II, retroactive interference was investigated: recall was poorer after a retention interval during which was presented either a tilted line or contextual stimuli in the form of the illuminated experimental chamber. In Experiment III, a subject was required to engage, throughout the retention interval, in one or the other of two different behaviors, depending on which of two stimuli a subject was to remember. This mnemonic strategy vastly improved recall after 15- and 20-second retention intervals. In Experiment IV, the opposite end of the performance continuum was studied: by combining the effects of a larger stimulus set and the effects of what presumably was an increased memory load, performance was reduced to approximately chance levels after retention intervals shorter than 1 second.

Key words: short-term memory, exposure time, retroactive interference, encoding strategy, limited processing capacity, key peck, pigeons

Short-term memory has significant implications for our understanding of fundamental issues in the analysis of reinforcement contingencies in general (Shimp, 1975, 1976*a, b, c*). Most research on short-term memory has been conducted with human subjects, but a comparative approach may be essential if we are to understand fully the results obtained with any given species, including humans (Medin and Cole, 1975). Most of the research on short-term memory in infra-human organisms has used a delayed-matching-to-sample technique (Blough, 1959; Cumming and Berryman, 1965; D'Amato, 1973; Jarvik, Goldfarb, and Carly, 1969; Roberts and Grant, 1976). The present

experiments were designed to develop more fully an alternative experimental method for the behavioral analysis of short-term memory in infra-humans. This alternative method consists of the successive presentation to an organism of two stimuli that are either the same or different. The contingency, a delayed-pair-comparison procedure, arranges reinforcement for one response if the two stimuli are the same and for a second response if the two stimuli are different. This method might be particularly useful in situations where the delayed-matching-to-sample procedure would be inapplicable, as with olfactory or auditory stimuli. In such cases, successive rather than simultaneous stimulus presentations might be required. Konorski (1959) advocated the use of this method, and available data suggest that it is not beyond the capability of infra-humans and merits additional attention (Stepien, Cordeau, and Rasmussen, 1960; Wasserman, 1976). This fact, combined with the proven utility of this method in studies on human short-term memory and attention (Massaro, 1970; Posner and Klein, 1973; Wickelgren, 1969), motivated the present experiment involving four variations on the basic delayed-pair-comparison theme.

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GENERAL METHOD FOR EXPERIMENTS I, II, AND III

Apparatus

Four standard Lehigh Valley Electronics three-key pigeon chambers were equipped with Industrial Electronics Engineers one-plane readouts mounted behind each of the clear plastic keys. General Electric 1829 bulbs were mounted both in the one-plane readouts and in the standard houselight. Tilted lines could be projected onto the keys. Each line was 1-mm wide, was a diameter of the circular key, and appeared white on a dark background. A Digital Equipment Corporation PDP 12/30 laboratory computer arranged all experimental events and recorded the data. A minimum force of 0.15 to 0.20 N was required to operate the keys and white noise helped to mask background noises.

Procedure

Each experimental session consisted of a number of discrete trials, and each discrete trial included two phases: a presentation phase and a test phase. During the presentation phase, a houselight was turned on and a stimulus was presented on the center key. This "standard stimulus" was randomly selected from a vertical and a horizontal line. The first response on the center key, after a short time (varied in Experiment I) after the onset of the standard stimulus, turned off the standard stimulus and initiated the retention interval (varied in Experiments I and II). Different visual stimuli were presented during the retention interval in different experiments, as described below in the separate procedure sections. Responses on any of the three keys during the retention interval had no scheduled consequences. When the retention interval timed out, the test phase of the trial began and the houselight was turned on, along with either the vertical or the horizontal line, one of which was randomly selected and presented on the center key. The test stimulus presented on the center key was equally likely to match or not to match the standard stimulus. That is, on a random half of the trials, the test stimulus was the same as the standard stimulus, and on the other trials, the test and standard stimuli were different. If the test stimulus was a nonmatching stimulus, the line that was not presented during the presentation phase of

the trial was presented during the test phase. That is, if the vertical line was the standard stimulus, the horizontal line was the nonmatching test stimulus. A response on the center key after the onset of the test stimulus simultaneously terminated the test stimulus on that key and displayed the same stimulus on each of the two side keys.

The response requirement on the center key during the presentation and test phases of a trial was to help to ensure that the pigeon attended to the standard stimulus and to the test stimulus when they were presented, and to help to ensure that a subject was positioned approximately midway between the side keys at the beginning of the test phase. The stimulus was displayed on each of the two side keys to ensure that the pigeon continued to attend to the test stimulus when the choice response was made.

If the stimulus presented during the test phase of the trial matched the standard stimulus, a peck on the right side key was defined as the correct response and was followed by reinforcement. If the test stimulus did not match the standard stimulus, a peck on the left side key was defined as the correct response and was followed by reinforcement. An incorrect response, *i.e.*, a peck on the left key when the test stimulus matched the standard stimulus, or a peck on the right key when the test stimulus did not match the standard stimulus, was followed by a timeout. During this timeout, the houselight remained on, but there was no stimulus presented on any of the three keys. When the timeout had elapsed, a correction trial was initiated, *i.e.*, the same standard and test stimuli were presented as in the preceding trial on which the error was made. If an error was made on the correction trial, the timeout and correction trial were repeated until the correction response was made. A correct response on the correction trial was followed by reinforcement. During reinforcement, the houselight was turned off, a light above the food hopper was turned on, and the food hopper was operated. To provide more trials for each session and yet maintain a pigeon's proper weight, the food hopper was operated on some trials for only 0.25 sec, a time too brief to allow a pigeon to obtain food. The probability that the food hopper was operated for 0.25 sec (conditioned reinforcement) was slightly different in different experiments, as described

below in the separate procedure sections. Sessions were conducted seven days a week. An experiment was terminated when the probability of a correct response appeared stable over several days.

EXPERIMENT I

The exposure time of a to-be-remembered visual stimulus intuitively ought to affect the likelihood of a subject's recall of that stimulus. Not all data from infra-humans support this expectation. In delayed-matching-to-sample tasks, the performance of monkeys remains invariant over exposure times ranging from about 0.075 sec to about 0.450 sec (D'Amato and Worsham, 1972). In such delayed-matching-to-sample tasks, the performance of pigeons can be seen to improve over the wider range of exposure times from 0.5 to 8.0 sec (Roberts and Grant, 1974). Experiment I was designed to explore the effects of exposure time on performance in a delayed-pair-comparison procedure.

METHOD

Subjects

Four experimentally naive homing pigeons were maintained at approximately 90% of their free-feeding weights.

Procedure

The procedure was the same as described in general above, with the following numerical values for the various parameters. There were eight equally-likely, randomly-selected programmed exposure times of 0.05, 0.10, 0.50, 1.00, 2.00, 4.00, 8.00, and 16.00 sec. A peck to the lighted center key turned off the standard stimulus and the houselight and initiated a retention interval. There were three equally-likely, randomly-selected, retention intervals of 0.1, 2.0, and 8.0 sec. The correction interval after an error was 3.0 sec and the intertrial interval was 1.0 sec. Conditioned reinforcement was presented on a randomly-selected 80% of the trials. This percentage permitted an average of 200 trials per 1-hr session without interfering with the 90% deprivation level. Reinforcement consisted of 1.75 sec access to mixed grain. The experiment continued for 70 sessions.

Pretraining began with standard magazine training and key-peck training on all three

keys. The subjects were then placed on the delayed-pair-comparison procedure with a very short retention interval of 0.1 sec and no conditioned reinforcement. The number of retention intervals was then slowly increased and their durations were slowly lengthened. Whenever another retention interval was added, it initially appeared on only a small fraction of trials and then slowly was made to occur equally often with the other retention intervals. At the same time, the percentage of trials on which conditioned reinforcement was presented was slowly increased, until parameter values used in Experiment I were reached. Pretraining lasted approximately three months.

RESULTS

Figure 1 shows the percentage of trials, for a given exposure time and after a given retention interval, on which a subject chose the correct side key. These probabilities are plotted as a function of the logarithm of the mean obtained exposure time of the to-be-remembered stimulus. The calculations omitted the first two trials of a day in an effort not to include warmup effects. They also omitted any side-key pecks after an initial error, *i.e.*, after an unreinforced choice, because these subsequent responses could have been under the control of different contingencies; that is, they might have been controlled in part by a subject's memory for the most recent side-key response. The data in Figure 1 are averages over the last 10 days of a condition.

Two major outcomes are apparent in Figure 1. First, recall was very clearly better with shorter retention intervals than with longer ones, thereby demonstrating that the delayed-pair-comparison procedure is qualitatively consistent with other short-term memory procedures. Second, recall tended to be better with longer exposure times than with shorter ones. However, recall was so high for Birds 2, 3, and 4 with a retention interval of 0.1 sec that a ceiling effect obscured any potential effect of exposure time. A tendency for longer exposure times systematically to produce better recall is most clearly revealed in Figure 1 for Bird 1 at retention intervals of 2.0 and 8.0 sec, and for Bird 3 at a retention interval of 2.0 sec. For every bird, at retention intervals of 2.0 and 8.0 sec, recall was higher for the longest

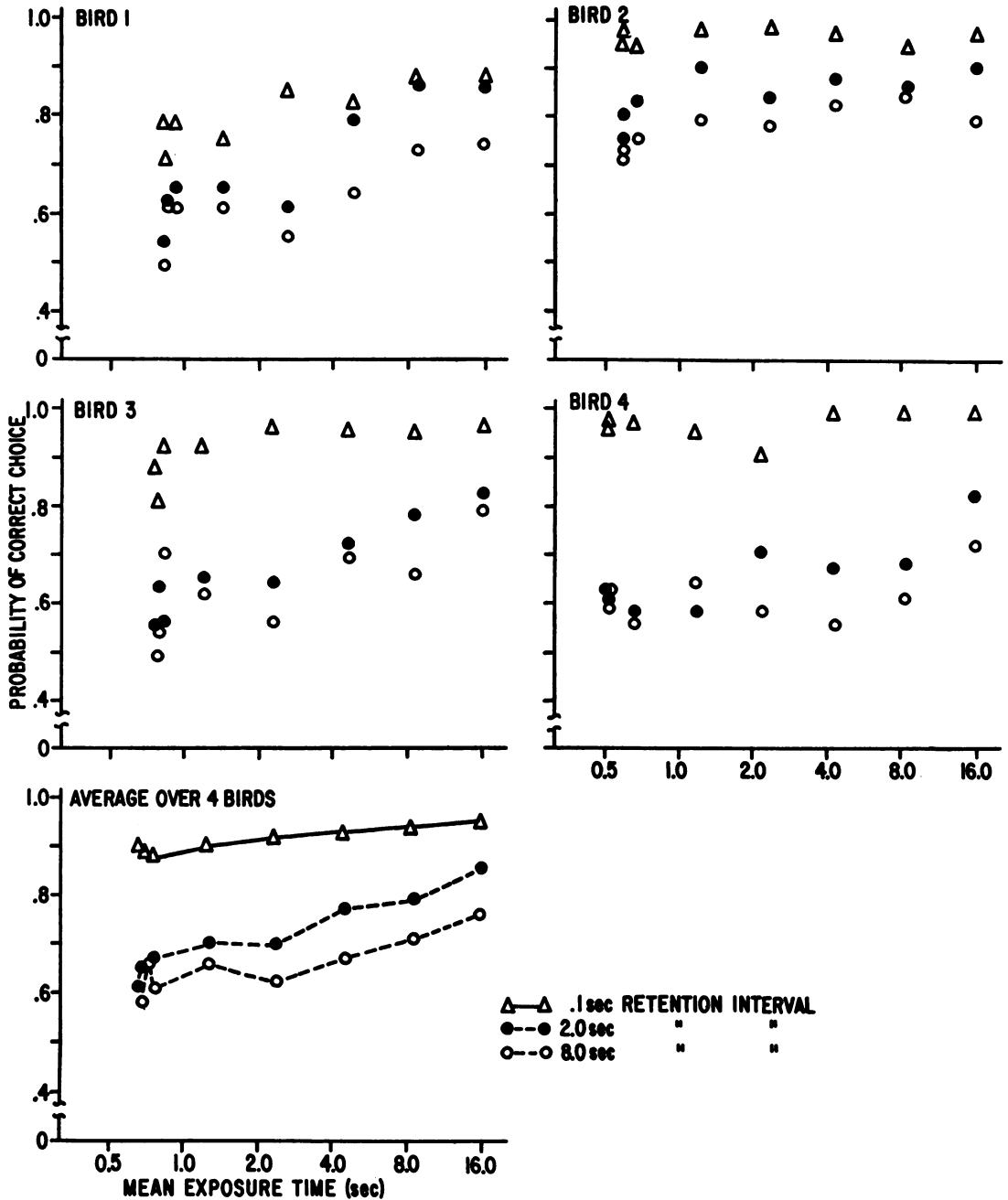


Fig. 1. The probability of a correct choice as a function of the mean exposure time of the to-be-remembered stimulus.

than for the shortest exposure times. For these two retention intervals, Figure 1 reveals that a number of ways of averaging performance over the several shortest *versus* longest exposure times all produce the same result: for each subject, longer exposure times of a to-be-

remembered stimulus clearly improved subsequent recall. The exact shape of the function relating recall to exposure time varied, however, from subject to subject, suggesting that as-yet-undetermined and uncontrolled variables also played a role.

DISCUSSION

Experiment I extends to the delayed-pair-comparison paradigm results obtained earlier with pigeons in two other experiments on visual short-term memory. Roberts and Grant (1974) obtained qualitatively the same effect with a delayed-matching-to-sample technique and Shimp (1976a) obtained a similar effect with a feature probing technique studying short-term memory for the order of recent events. Exposure time of a stimulus apparently has the power in a wide variety of situations to determine the extent to which the memory of that stimulus can control behavior at some later time (see also Experiment IV below). These various results obtained with pigeons may seem to disagree with those obtained by D'Amato and Worsham (1972) with monkeys, but none of the exposure times in the experiments with pigeons was varied over quite the same range as in the monkey study, so that the difference in results may be attributable to methodological differences, rather than species differences.

The effect of exposure time on short-term memory may provide an alternative explanation of various phenomena in the literature. For example, Sacks, Kamil, and Mack (1972) found that performance is improved on a delayed-matching-to-sample task when a subject is required to emit more responses in the presence of the sample stimulus. Similarly, Williams (1972) found that the structure of behavior more closely matched a required win-stay, lose-shift strategy when an element in the response pattern consisted of longer ratios of responses, rather than a single response. One way to interpret these results is that "complex learning is facilitated by larger work requirements" (Williams, 1972). But longer ratios generally produce longer exposure times to the event a subject must remember for optimal performance. Thus, available data do not permit us to discriminate between the work-requirement hypothesis and the hypothesis that longer ratios may improve accuracy simply because they lengthen exposure to a to-be-remembered event.

EXPERIMENT II

A subject's recall of an earlier event can in general be expected to depend heavily on the

nature of intervening events. In particular, one can expect a pigeon's memory for a visual stimulus to depend on the subsequent visual environment. Two kinds of visual interference have been identified in animal short-term memory. Zentall (1973) demonstrated that an interpolated color could degrade performance of pigeons in a delayed-matching-to-sample task with colors. The source of this kind of interference, an interpolated stimulus from the same dimension as used in the short-term memory task, has been called "specific", and has been found in monkeys as well as pigeons (Jarvik, Goldfarb, and Carly, 1969). In addition, recall of a visual stimulus can be degraded by "nonspecific" sources, such as contextual cues provided by illuminating the experimental chamber during the retention interval. This effect has been demonstrated with monkeys in a delayed-matching-to-sample task (D'Amato and O'Neil, 1971). The purpose of the present Experiment II was to explore possible specific and nonspecific sources of retroactive interference in the delayed-pair-comparison procedure with pigeons.

METHOD

Subjects

Four male homing pigeons were maintained at approximately 90% of their free-feeding weights.

Procedure

The basic procedure was the same as that described in general above, with the following specific arrangements. There were eight equally-likely retention intervals: 0.1, 1.0, 2.0, 4.0, 8.0, 16.0, 24.0, and 32.0 sec. On any one trial, one of four events occurred during the retention interval: (1) there was a blackout, *i.e.*, the houselight was off and there was no stimulus presented on any of the three keys; (2) the houselight was on and there was no line presented on any of the three keys; (3) the houselight was off and a line was presented on the center key, and, (4) the houselight was on and a line was presented on the center key. These four events occurred equally often. With eight different retention intervals and four different events possible during the retention interval, there were $8 \times 4 = 32$ different trial types.

When a line was presented during the retention interval, it was selected from a stimulus-

set consisting of a 45-degree line and a 135-degree line, each of which occurred equally often. Note that each of these two lines was equally distant from the lines in the stimulus-set for the standard and test stimuli, *i.e.*, the horizontal and vertical tilted lines. Either the 45-degree line or the 135-degree line was presented during the entire retention interval, from the offset of the standard stimulus to the onset of the test stimulus. The exposure time of the standard stimulus was 2.0 sec, the correction interval was 5.0 sec, conditioned reinforcement was delivered on 60% of the trials, and each session lasted 2 hr. Primary reinforcement was a 1.75-sec access to mixed grain. The experiment continued for 70 sessions.

Pretraining for Experiment II resembled that for Experiment I. The subjects first were magazine and key-peck trained. Then, the number of retention intervals was increased, their durations were slowly lengthened, and conditioned reinforcement was delivered more frequently. This pretraining took place with the houselight off during the retention interval and lasted approximately four months.

RESULTS

Figure 2 shows the probability of a correct response as a function of the logarithm of the length of the retention interval for each of the four possible events during the retention interval. The probabilities shown in Figure 2 are averaged over the last 30 sessions. The correct responses were summed over the last 30 sessions to compensate for the low frequency of occurrence of each of the 32 different trial types during a single session. Responses on correction trials and the two warmup trials were not included in any of these computations.

The functions for the individual subjects show that recall on the whole was best after a retention interval that was a blackout and was worst after a retention interval during which both contextual cues and an irrelevant line tilt were present. The two other types of retention intervals led to intermediate performance, with a suggestion in the average curves that an irrelevant line tilt was more disruptive than were contextual cues.

DISCUSSION

Experiment II demonstrates both specific and nonspecific sources of retroactive interfer-

ence on visual short-term memory in pigeons. These effects are qualitatively similar to those obtained with humans in a similar, auditory, delayed-paired-comparison task (Massaro, 1970) and with monkeys in visual delayed-matching-to-sample (D'Amato and O'Neil, 1971; Etkin, 1972; Jarvik *et al.*, 1969). Specifically, retroactive interference was demonstrated with both contextual cues provided by a houselight and an irrelevant tilted line. The effects of the two classes of interfering stimuli tended to combine, so that recall was poorer when the two appeared together than when either was presented alone.

In an earlier demonstration of a specific source of retroactive interference in the pigeon, Zentall (1973) found that the effect tended to decrease in magnitude over the few sessions in the experiment. Such data suggest that a specific source of retroactive interference may be limited to fairly novel stimuli. The present experiment demonstrates that not all retroactive interference in short-term memory with pigeons is attributable to novel stimuli: interference was demonstrated here even after the irrelevant line tilts were thoroughly familiar through exposure in 40 to 70 sessions.

The demonstration of retroactive interference in short-term memory has an interesting implication in the context of response-reinforcer pairings. A reinforcing stimulus is an even more salient stimulus than the most powerful interfering stimulus used here, the combined line-tilt-houselight stimulus. Accordingly, one may expect that short-term memory for an event, such as a response, will be *less* after the response has been followed by a reinforcing stimulus (Shimp, 1976c). That is, the present results make the prediction, somewhat counterintuitive from the perspective of the Law of Effect, that a pigeon's short-term memory for a reinforced response is less than that for an unreinforced response. Thus, we have the seemingly contradictory result that a reinforcer in some sense strengthens a response and at the same time lessens the chance that a subject will remember having emitted the response. It will be noted that the latter property of a positive reinforcer resembles an inhibitory property. As such, it may be related to diverse phenomena. For example, Medin (1976) found that a predelay reinforcement may lower, rather than improve, performance in a delayed-matching-to-sample task (Medin,

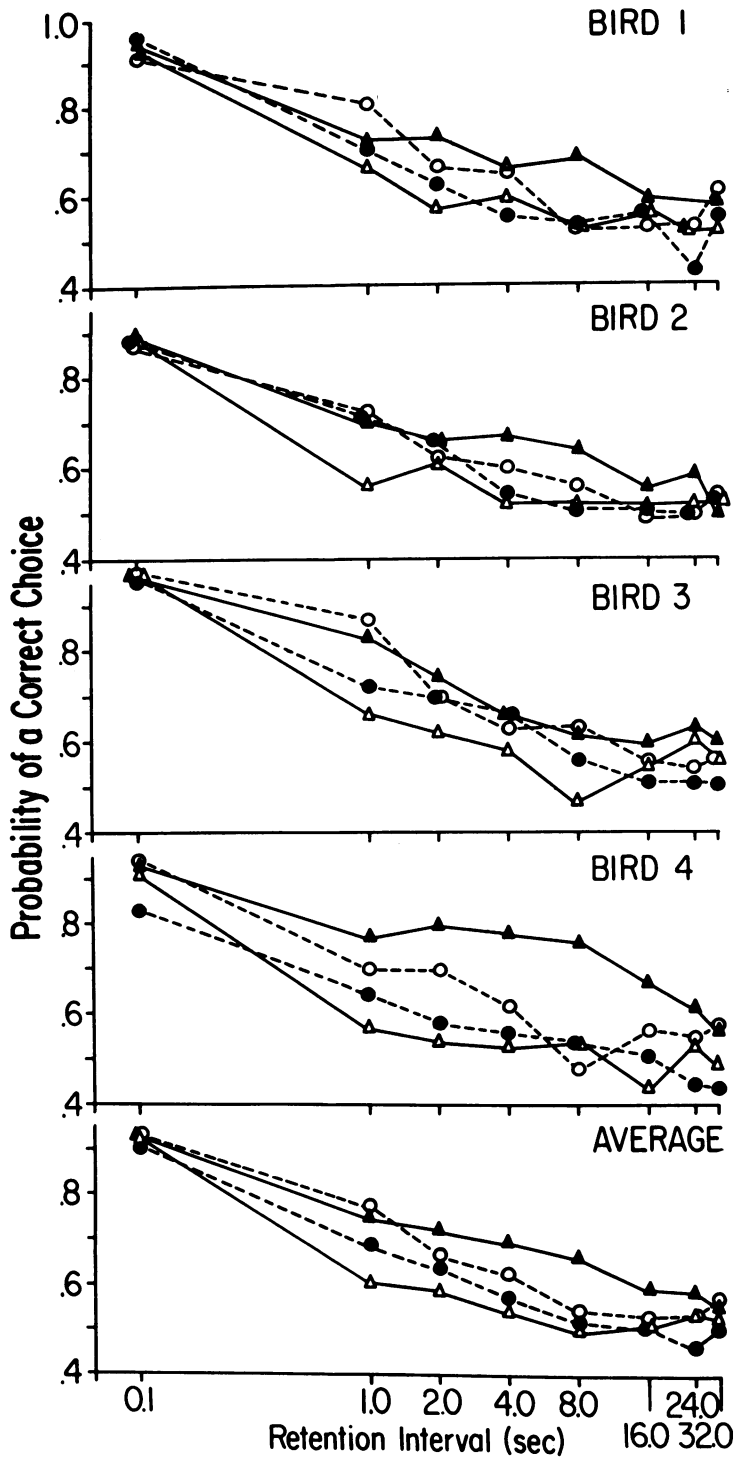


Fig. 2. The probability of a correct choice as a function of the length of the retention interval for each of four different events during the retention interval: a blackout (filled triangles); the houselight on with no irrelevant line tilt (filled circles); the houselight off with an irrelevant line tilt (open circles), and the houselight on with an irrelevant line tilt (open triangles).

1976). This finding is clearly consistent with interference properties of reinforcement. Also, Catania (1973) discussed various schedule phenomena that seemingly require for their explanation some inhibiting property of a positive reinforcer. The fact that the stimulus properties of reinforcement retroactively interfere with memory for recent behavior (Shimp, 1976c) appears to offer one mechanism in terms of which an inhibitory property of positive reinforcement might be explicable.

EXPERIMENT III

Performance in Experiments I and II was not overly impressive, declining to chance levels after only a few seconds. The purpose of Experiment III was the practical one of improving short-term memory for visual stimuli significantly above the levels obtained in Experiments I and II. In the literature on human short-term memory, one vehicle for improving performance is to provide a subject with a more effective "mnemonic strategy" (Bower, 1975). Such strategies may involve mental imagery (Bower, 1972), higher-order encodings (Miller, 1957), or other kinds of transformations of the to-be-remembered stimuli. The present experiment made use of a related encoding idea that has appeared in various guises. It has often been assumed or suggested that animal performance in a variety of contexts depends on a coding response that mediates performance (Blough, 1959; Cumming, Berryman and Cohen, 1965; Eckerman, 1970; Farthing and Opuda, 1974; Lawrence, 1963; Lydersen and Perkins, 1974). The present experiment provided a separate, presumably highly discriminable, coding response for each of the two to-be-remembered stimuli. In short, a subject was required to engage in one behavior when it was to remember one stimulus, and to engage in a different behavior when it was to remember the other stimulus.

METHOD

Subjects

Three experimentally naive homing pigeons were maintained at approximately 90% of their free-feeding weights.

Procedure

The procedure was as described above for Experiments I and II, with the following nu-

merical values for the parameters and with additional contingencies. The programmed exposure time for the standard stimulus (vertical or horizontal line tilt) was 2.0 sec. The inter-trial interval was 1.0 sec, the correction interval was 3.0 sec, and conditioned reinforcement was delivered on a random 60% of the trials. Primary reinforcement consisted of 3.0-sec access to mixed grain. During the retention interval, the houselight was off but the center key was illuminated by a white light.

During the retention interval, if the standard stimulus had been a horizontal line, a subject was required not to peck the illuminated center key. Any center-key peck initiated a 3.0-sec blackout, after which the trial was begun anew. If the standard stimulus had been a vertical line, a subject was required to peck the lighted center key during the retention interval. This pecking was maintained by the following contingency. When the retention interval timed out, the computer required that at least two key pecks had occurred during the interval and that the most recent peck had occurred no more than 0.5 sec previously. If these two requirements were not satisfied, a 3.0-sec blackout was started, after which the trial began anew. These contingencies were sufficient to produce an absence of pecking the center key after a horizontal standard stimulus and an abundance of pecking after a vertical standard stimulus.

The retention interval was set initially at a value of 2.0 sec for 22 days and then was progressively lengthened to 4.0 (14 days), 6.0 (30 days), 8.0 (13 days), 10.0 (46 days due to apparatus problems and an illness of a subject), 12.0 (26 days), 15.0 (22 days), and 20.0 sec (9 days). The present method provided an insufficient number of trials per session with intertrial intervals longer than 20.0 sec. Each session was 31.7 min in duration.

Pretraining was as described above for Experiments I and II, with the simplification that here only a single retention interval was employed.

RESULTS

Table 1 shows the average probability of a correct choice, averaged over the last five sessions of a condition. The probability of a correct response was not less than 0.96 for any subject for any retention interval up to and including 12.0 sec, and was not less than 0.80

Table 1

Probability of a Correct Response in Experiment III

Retention Interval (sec)	Bird Number	Probability of a Correct Choice	Average Number of Trials per Session
2.0	1	0.997	134
	2	1.000	188
	3	0.995	233
4.0	1	0.989	115
	2	0.997	123
	3	0.994	159
6.0	1	0.996	108
	2	0.979	57
	3	0.962	82
8.0	1	1.000	71
	2	0.995	59
	3	0.964	73
10.0	1	0.976	61
	2	1.000	47
	3	0.984	101
12.0	1	0.973	49
	2	1.000	25
	3	0.999	84
15.0	1	0.977	37
	2	0.796	22
	3	0.962	60
20.0	1	0.990	18
	2	0.808	22
	3	0.924	19

for a 20.0-sec retention interval, when Bird 1 was still responding almost perfectly. When these values are contrasted with those in Experiments I and II, one finds a dramatic improvement in Experiment III. Even performance at the shortest retention interval, 2.0 sec, was vastly superior for all three subjects in Experiment III to that of any of the subjects in Experiments I and II with an exposure time and retention interval of 2.0 sec.

DISCUSSION

The idea behind Experiment III, an encoding-strategy notion, suggests that short-term memory can be improved if we provide different coding responses for the to-be-remembered stimuli. The results show that performance in short-term memory experiments can indeed be vastly improved by requiring that an organism engage in different behaviors after different to-be-remembered stimuli. This method is obviously an extremely powerful way to bridge the temporal gap between the occurrence of an event and its subsequent control of behavior.

EXPERIMENT IV

It seems advisable, when developing a new method, to explore procedural variations that produce very poor as well as very good performance. In a sense we are obliged, that is, to study the method's boundary conditions. Experiment III explored a procedural variation by means of which performance in a delayed-pair-comparison task can be kept at a high level with what are otherwise, for pigeons, unusually long retention intervals. Experiment IV was designed to explore the other end of the continuum—a variation of the basic method that produces recall only over very short retention intervals.

Experiment IV modified the basic delayed-pair-comparison method in two ways. First, we simply expanded the set of standard and comparison stimuli from two to four tilted lines. Second, we modified the function in the reinforcement contingency of a stimulus interpolated between the presentation of a stimulus and its subsequent recall test. This function was modified to make the second, interpolated tilted line presumably more interfering than it was in Experiment II. There, reinforcement did not depend in any way on the interpolated stimulus. This stimulus was simply an incidental stimulus. Here, this stimulus was correlated with reinforcement: the correct response on a trial depended on *both* the first and second stimuli. In short, in Experiment IV, the second stimulus, as well as the first, was a to-be-remembered stimulus. It is well documented in the "directed forgetting" literature on human short-term memory that recall of one of several items is poorer when the contingency requires a subject to try to remember all the items than when it is necessary only to remember that one item (Bower, 1975; Bjork, LaBerge, and Legrand, 1968; Reed, 1970). Another way to refer to this reduction in level of recall is to say that a to-be-remembered event imposes a greater load on memory than does an incidental event, everything else being the same.

METHOD

Subjects

Two experimentally naive White Carneaux pigeons were maintained at approximately 90% of their free-feeding weights.

Procedure

The procedure for Experiment IV was generally similar to that for Experiments I, II, and III, except that now the stimulus set for the standard stimuli was expanded to include 45-degree and 135-degree lines, as well as horizontal and vertical lines. The standard stimulus now consisted of a pair of these lines presented successively one at a time. With a total of four lines, a total of 12 pairs was available. One of these pairs was randomly selected for each trial. The exposure time for each line was varied as shown in Table 2. A 0.1-sec blackout separated the end of the first from the beginning of the second. The retention interval, a blackout, was varied as shown in Table 2. The comparison stimulus was randomly selected from the four stimuli, so that on a random half of the trials it was one of the standard stimuli and on the remaining half of the trials it was not one of the standard stimuli. If the comparison stimuli matched one of the standard stimuli, a subsequent peck on a lighted left key delivered a reinforcer. If the comparison was neither of the standard stimuli, a subsequent peck on the right key delivered a reinforcer. The correction interval was 5.0 sec, conditioned reinforcements were delivered on 80% of the trials, primary reinforcement consisted of 3.0-sec access to mixed grain, and each session lasted 90 min.

Pretraining for Experiment IV began as described above for Experiments I, II, and III. Initial exposure to the contingencies of Experiment IV involved 2-sec exposure times to the first and second stimuli with a 0.1-sec retention interval. Initial performance showed

no recall of the first item that was above the chance level. Therefore, an additional feature was incorporated into the procedure: temporal cues were provided that increased the exposure time to the to-be-tested item (Shimp and Moffitt, 1974). If the first or second stimulus on a trial was to be tested, that stimulus was presented for 2.0 sec and the other was presented for only 0.1 sec. If neither the first nor second stimulus was to be tested, the exposure time for each was 2.0 sec. An attempt was then made to equalize these temporal cues by simultaneously lengthening the not-to-be-tested stimulus and shortening the to-be-tested stimulus. After a total period of pretraining lasting approximately seven months, sufficient information had been collected to permit us to identify an appropriate range of parameter values for Experiment IV.

RESULTS

Figure 3 shows the probability of a correct choice as a function of several experimental parameters. Like Figures 1 and 2, Figure 3 is based on choice responses only and excludes the first two trials of a session. The data are averages over the last five days of a condition. The results are presented separately for those trials on which the comparison stimulus was the same as the first standard, was the same as the second standard, or was neither of these. The general shapes of the two sets of functions for the individual subjects are in gratifyingly close agreement. In the top panel, recall is plotted as a function of the retention interval for exposure times for the first and second standard stimuli fixed at 1.0 and 0.1 sec, respectively. Recall is above chance for all three types of comparison stimuli at least for delays up to 1.0 sec. The middle panel plots recall as a function of the exposure time of the first standard stimulus, with both the exposure time of the second standard and the retention interval fixed at 0.1 sec. Recall of the first item increases with longer exposure times but varies relatively little and unsystematically for comparison stimuli equal to the second item or to neither item. The bottom panel plots recall as a function of the exposure time of the second item, with the exposure time of the first item fixed at 1.0 sec and the retention interval fixed at 0.1 sec. Recall of the first item decreased as the exposure time of the second item in-

Table 2
Experimental Conditions in Experiment IV

Condition	Number of Days	Programmed Exposure Times (sec)		Retention Interval (sec)
		First Item	Second Item	
1	8	0.1	0.1	0.1
2	11	0.5	0.1	0.1
3	11	1.0	0.1	0.1
4	13	1.0	0.1	0.5
5	28	1.0	0.1	1.0
6	9	1.0	0.5	0.1
7	13	1.0	1.0	0.1
8	15	1.0	0.1	2.0
9	11	2.0	0.1	0.1

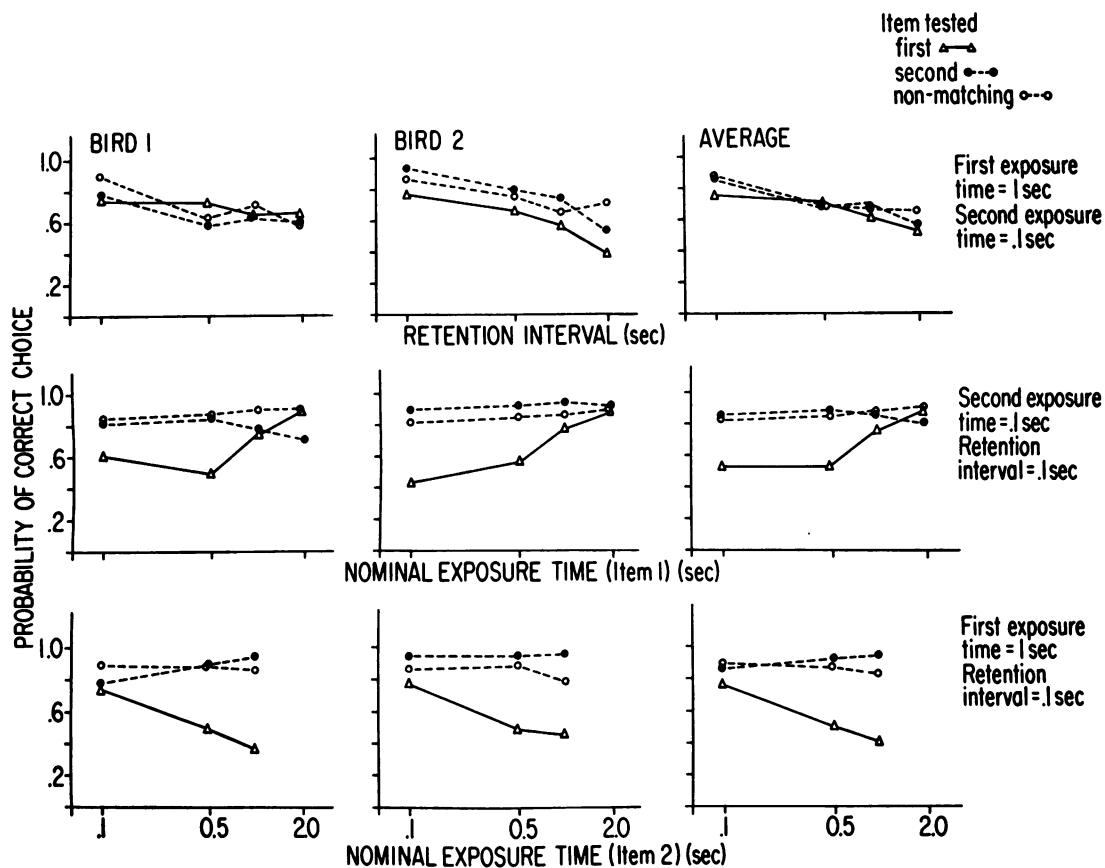


Fig. 3. The probability of a correct choice as a function of the nominal exposure time of the first or second item or of different retention intervals.

creased. Recall on the other trials varied unsystematically and remained moderately high to high.

DISCUSSION

Experiment IV successfully reduced the memory span in a delayed-pair-comparison task to what may be a practical minimum: recall of a stimulus was reduced to approximately chance levels after retention intervals shorter than 1 sec. Thus, we can modulate recall in a delayed-pair-comparison task over a very wide range by employing an encoding strategy to maintain recall at high levels after long retention intervals (Experiment III) or by expanding the stimulus-set size and increasing the memory load to reduce recall to low levels after short retention intervals (Experiment IV). The reader should carefully note that Experiment IV does not by itself allow us to measure the separate contributions to recall of the two procedural modifications intro-

duced there. It simply shows that their combined effects can appreciably shorten a pigeon's memory span for a visual stimulus in a delayed-pair-comparison procedure.

GENERAL DISCUSSION

A delayed-pair-comparison procedure was developed in four different ways in order to provide an alternative to the delayed-matching-to-sample method for the study of short-term memory in animals. The two experimental paradigms seem to be qualitatively similar in several different ways. Longer exposure times to a to-be-remembered stimulus improve recall of that stimulus with both methods. Also, both specific and nonspecific sources of retroactive interference can be identified with both procedures. Beyond demonstrating these qualitative similarities between methods, the present experiments also explored some boundary conditions of the delayed-pair-com-

parison procedure: an encoding strategy substantially lengthened the memory span for visual stimuli and the combined effects of an expanded stimulus set and an increased memory load substantially shortened it. Various theories of animal short-term memory are at present available (D'Amato, 1973; Medin, 1976; Roberts and Grant, 1976) but it is not clear how any of them can handle the range of empirical phenomena obtained here. It would seem in particular that greater theoretical attention may have to be devoted in the future to empirical phenomena related to encoding and perhaps to the memory load associated with a stimulus by virtue of the role of that stimulus in the reinforcement contingency. There are, of course, theories developed for human memory that have sufficient scope to handle, at least qualitatively, all of the phenomena obtained here (Bower, 1975). Such theories assign more important roles to "cognitive" variables than has generally been fashionable in analyses of animal behavior (Shimp, 1976b).

A close relation has been hypothesized to obtain between a behavioral pattern functioning as a unitized behavioral chunk or operant, on the one hand, and the memory span of an organism for the recent events preceding reinforcement, on the other hand (Hawkes and Shimp, 1975; Shimp, 1975, 1976b). That is, it has been hypothesized that the repeated delivery of a reinforcer after the same remembered pattern of behaviors may establish that pattern as a new behavioral unit. This hypothesis, taken along with the results of the present Experiments III and IV, suggests that a fundamental unit of behavioral analysis may, in various contexts, have either very abbreviated or rather extended temporal duration, depending on how a context discourages or encourages short-term memory for recent events, respectively.

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