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SHORT-TERM MEMORY IN THE PIGEON: RELATIVE RECENCY[1]

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Three pigeons pecked for food in an experiment in which each trial consisted of two phases. The first phase consisted of a pattern of three successively illuminated, randomly selected left or right keys. A subject was required to peck each of the lighted keys as they appeared. Thus, in the first phase, a subject emitted a pattern of three left- or right-key pecks. Over trials, all eight possible patterns appeared. A time interval separated the first phase from the second phase, which began with presentation of a randomly selected one of three cues. A reinforcer was delivered in the second phase if a subject pecked the side key that had appeared in the first phase in an ordinal position corresponding to the cue presented in the second phase. That is, the three cues probed a pigeon's memory for the side key it had pecked first, second, or third, in the first phase of a trial. The results show that a pigeon can remember for more than 4 sec the order in which it has just seen and pecked two lighted keys: a pigeon can remember the temporal organization or pattern of events in its recent environment. Consequently, the functional stimulus present when a reinforcer is delivered may include a subject's short-term memory for the temporal organization of recent events, such as the pattern of its own recent behavior. This possibility is consistent with a molecular analysis of operant behavior focusing on local patterns of behavior.

Key words: short-term memory, delayed stimulus control, relative recency, behavioral patterns, pigeons

Shimp and Moffitt (1974) developed a new "feature-probing method" (Tulving and Bower, 1974) to study short-term memory in the pigeon. An experimenter using this method presents a sequence of events and then, after a brief period, probes a subject's memory for some feature of this sequence, or pattern, of recent events by presenting a stimulus in the presence of which the pigeon is required to emit one of two responses, only one of which leads to food. The pigeon can choose the correct response only on the basis of its memory for the probed feature. Shimp and Moffitt (1974) demonstrated with this method that a pigeon can remember which of two responses was recently associated with which of three stimuli. The present experiment applied this feature-probing technique to the issue of what a subject can remember of the temporal structure, or organization, or pattern, of events in its recent past. This issue is central to the development of a general theory of human learning and memory (Estes, 1972; Tulving and Bower, 1974; Tulving and Madigan, 1970). Nothing is known, however, of the extent to which infrahumans are capable of remembering a pattern of recent events.

METHOD

Subjects

Three White Carneaux pigeons, maintained at approximately 80% of their free-feeding weights, had previously served in a short-term memory experiment (Shimp and Moffitt, 1974). Their previous extensive training on a similar schedule may limit the generality of the present results to subjects with similar experience; *i.e.*, the present results cannot necessarily be obtained from pigeons not having had similar histories (see Pretraining below). The purpose of using the same pigeons was to shorten the lengthy pretraining period (Shimp and Moffitt, 1974). This purpose does not conflict with the objective of the present experiment, that is, to demonstrate that a pigeon *can* remember aspects of the temporal organization of events in its recent environment.

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Table 1
Experimental Conditions

Condition	Presentation Time of First Item (sec)	Retention Interval (sec)	Average Number of Trials Per Day Over Last Five Days			Number of Days
			Bird 1	Bird 2	Bird 3	
1	0.5	0.1	435	351	400	21
2	0.5	1.0	302	224	307	11
3	0.5	4.0	125	123	96	13
4	4.0	4.0	108	116	92	25
5	10.0	4.0	82	66	56	16
6	4.0	0.1	271	234	205	18

Apparatus

Three standard three-key Lehigh Valley Electronics pigeon chambers were interfaced to a Digital Equipment Corporation PDP-12 computer that arranged all experimental contingencies and recorded the data.

Procedure

Each session consisted of a number of discrete trials and each trial consisted of two phases.

First phase. The first phase consisted of the presentation of a list of items. At the beginning of a trial, a dim white "X" appeared on a randomly selected side key. The first response on that key after a presentation time elapsed (varied over conditions as shown in Table 1) turned the "X" off and began a 0.1-sec interstimulus interval (ISI). This sequence of events constituted the first item in the list. During the ISI, all three keys were dark but a houselight remained on. When the ISI timed out, the "X" appeared again on a randomly selected side key and the first response on that key after 0.5 sec turned off the "X". These events constituted the second item in the list. The response element of the second item began a second ISI, also 0.1 sec in duration. When the ISI timed out, the "X" appeared for a third time on a randomly selected side key. The first response on the lighted key, after 0.5 sec elapsed from the onset of the "X", turned the keylight off and initiated a retention interval (varied over conditions as shown in Table 1), during which the experimental chamber was darkened. Responses on any of the three keys during the retention interval or the ISI had no scheduled consequences.

Second phase. When the retention interval timed out, the houselight was turned on and a cue was presented on the center key. There were three, equally likely cues, a red, blue, or white light. The first peck on the lighted center key turned off the center key and presented lights of the same color on both side keys. That is, if the center key had been red, both side keys were red, and so on. This center-key contingency was designed to position the subject approximately midway between the side keys, one of which was now "correct". That is, a peck on the correct key produced a reinforcer. Red side keys cued a trial on which a peck on a side key was reinforced if it was to whatever key had appeared first in the list in the first phase of the trial. Blue side keys cued a trial on which a subject was required to peck the key that had appeared second in the list. Finally, if white keys appeared, a subject was required to peck whatever key had appeared third, or last, in the list. The houselight remained on throughout the second phase.

If a subject chose the correct side key, a reinforcer was delivered, the trial ended, and a 1-sec intertrial interval began. All lights in the chamber were off during the intertrial interval.

Correction procedure. A choice of the incorrect key was followed by a 2-sec "correction interval", during which the keylights were off but the houselight was on. After 2 sec elapsed, the same list of three items and the same cue were presented again. This correction procedure continued to recycle until a correct response ended the trial.

The correction procedure, coupled to the eight equally likely lists and three equally likely cues, ensured that responses on the two side keys were equally reinforced. This arrangement reduced the likelihood of a position bias developing.

Other arrangements. Reinforcement consisted of a 2-sec or a 0.25-sec presentation of mixed grain. The shorter presentation occurred on a random 60% of the trials and was too short for a subject to eat. Its purpose was to allow more trials per session with a reduced possibility of satiation effects. Sessions lasted 35 min, during which an average number of trials shown in Table 1 was presented. The experiment was conducted six days per week.

Pretraining. The subjects were placed in Condition 1 of the present experiment immediately after the end of the experiment reported by Shimp and Moffitt (1974). The present Condition 1 was designed to facilitate transfer of previous training, as it was the "easiest" of the conditions used here. The procedure used here differed from that of the previous experiment in only one way. In the previous experiment, the first, second, and third side key lighted in the first phase appeared red, blue, and white, respectively. Thus, color and ordinal position of an item in the first phase were confounded. The procedure therefore did not require a subject to remember the temporal order of an item. Here, all first-phase items were signalled by the same stimulus, a dim, white "X". The present procedure therefore required the subject to remember the temporal order of an item.

RESULTS

Consider the probability of a peck on the correct side key in the second phase as a function of the serial position of the tested item in the first-phase list. The probability of a peck on the correct side key was calculated by dividing the number of trials on which a subject's choice was reinforced by the total number of trials. All correction responses were excluded from the analysis. Also, results from the first two trials of a session were excluded in an attempt to avoid the inclusion of "warm-up" effects. Data reported here are averages over the last five days of a condition.

Figure 1 shows the data from Conditions 1, 2, and 3, across which only the retention interval varied while the scheduled presentation times of the lighted keys were all equal to 0.5 sec. Figure 1 shows a strong recency effect: more recent items were remembered better. But even the oldest, most difficult item was still remembered by two of the three subjects at a better-than-chance level, *i.e.*, better than

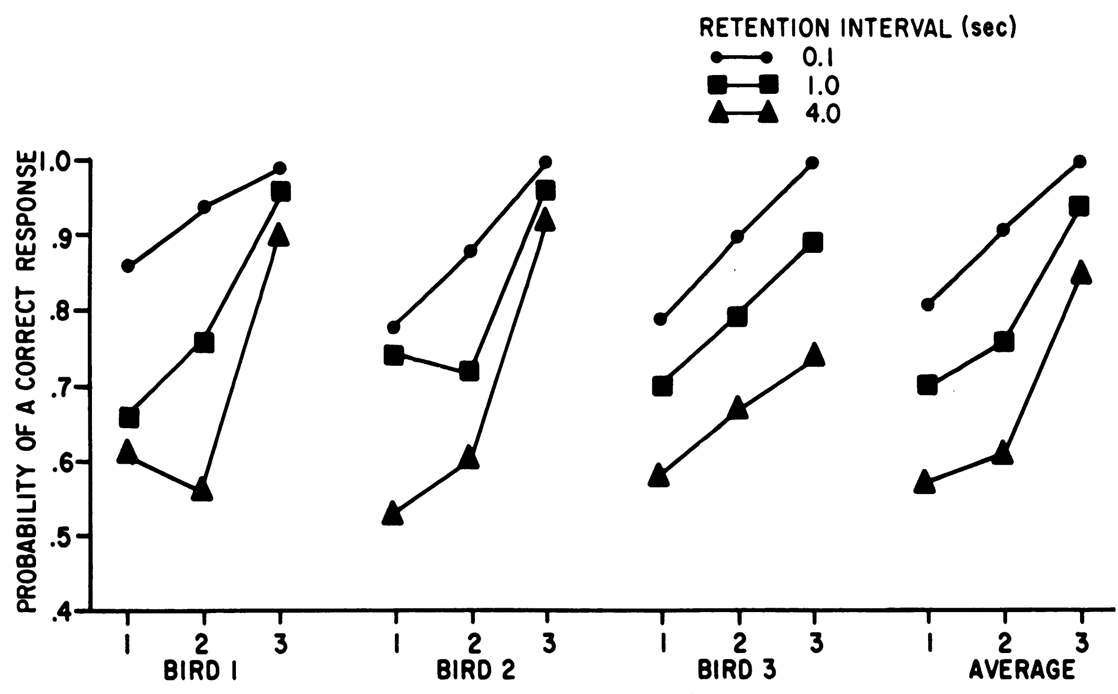

Fig. 1. The probability of a peck on the correct side key in the second phase of a trial as a function of the serial position of the tested item in the first phase of that trial.

0.50, for a retention interval of 4 sec. These data establish that a pigeon can to some extent remember the temporal organization of events in its recent environment.

Figure 2 shows the data from Conditions 1 and 6 (top row) and Conditions 3, 4, and 5 (bottom row). These data show how the serial-position curve can be affected by varying the presentation time of the first item. Figure 2 shows that increasing the presentation time of the first item tended to improve recall of that item. In fact, it could do so to an extent sufficient to overcome the recency effect so pronounced in Figure 1, that is, sufficient to make recall of the first item better than that of the second. Thus, a "primacy" effect sufficient to produce a U-shaped serial-position curve could be achieved by lengthening the presentation time of the first item. The oldest item in the list was clearly remembered by all subjects at an above-chance level with a retention interval of 4 sec, provided its presentation time was 10 sec.

The data in Figures 1 and 2 are averages over all eight first-phase lists. Recall of a given serial position was, of course, different for different lists. Table 2 shows how the probability of a correct response for a given serial

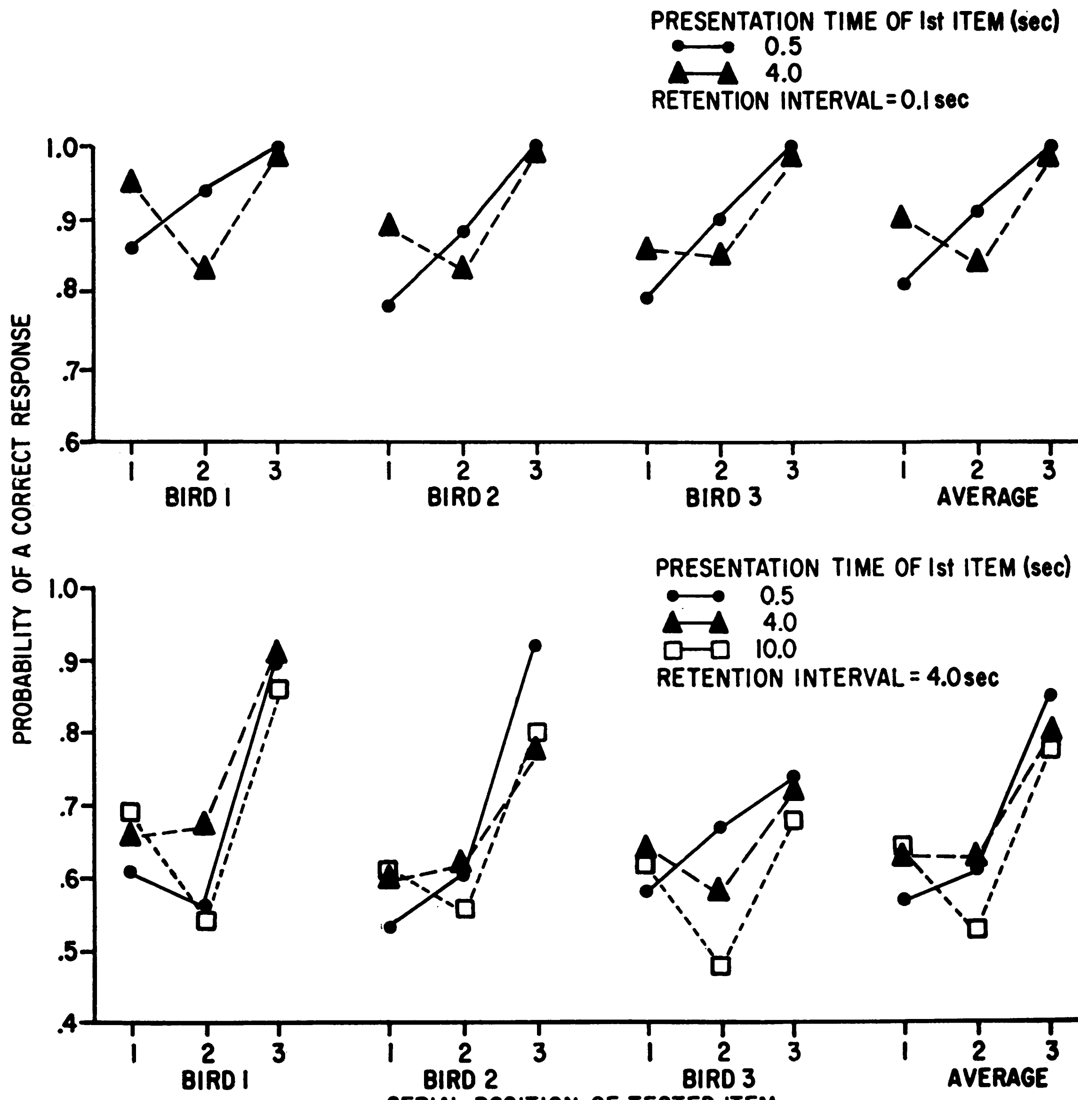

Fig. 2. The probability of a peck on the correct side key in the second phase of a trial as a function of the serial position of the tested item in the first phase of that trial.

Table 2

Probability of a correct response in the second phase of a trial for each combination of first-phase list and probe cue, in selected conditions.

First-Phase List (1st, 2nd, 3rd item)	*Ordinal Number of Response in First Phase Probed In Second Phase*	*Condition 1*			*Condition 2*			*Condition 3*		
		Bird 1	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*	*Bird 1*	*Bird 2*	*Bird 3*
Left, Left, Left	First	0.947	0.901	0.742	0.983	0.976	0.930	0.866	0.521	0.478
	Second	0.980	1.000	1.000	0.936	0.949	1.000	0.618	0.727	0.727
	Third	1.000	1.000	1.000	1.000	1.000	0.965	0.971	0.967	0.471
Left, Left, Right	First	1.000	0.921	0.794	0.842	0.857	0.682	0.509	0.354	0.333
	Second	1.000	0.925	0.963	0.863	0.504	0.647	0.644	0.354	0.342
	Third	0.965	1.000	0.990	0.883	0.816	0.877	1.000	0.931	0.530
Left, Right, Left	First	0.875	0.505	0.772	0.505	0.445	0.552	0.570	0.299	0.390
	Second	0.903	0.880	0.844	0.617	0.674	0.705	0.415	0.660	0.620
	Third	1.000	0.982	1.000	0.939	0.967	0.751	0.835	0.835	0.653
Left, Right, Right	First	0.795	0.648	0.918	0.523	0.529	0.507	0.500	0.210	0.290
	Second	0.882	0.711	0.921	0.716	0.704	0.901	0.642	0.850	0.670
	Third	0.989	1.000	1.000	1.000	1.000	0.971	1.000	0.933	0.800
Right, Left, Left	First	0.660	0.728	0.806	0.491	0.504	0.434	0.607	0.507	0.383
	Second	0.941	0.922	0.749	0.764	0.895	0.827	0.664	0.658	0.790
	Third	1.000	1.000	1.000	0.987	1.000	0.872	0.797	0.893	0.833
Right, Left, Right	First	0.639	0.575	0.692	0.439	0.693	0.695	0.558	0.779	0.800
	Second	0.932	0.629	0.922	0.696	0.455	0.475	0.464	0.267	0.486
	Third	1.000	1.000	1.000	0.987	1.000	0.939	0.917	0.910	0.775
Right, Right, Left	First	0.886	0.949	0.947	0.729	0.940	0.877	0.667	0.722	0.813
	Second	0.718	0.918	0.966	0.739	0.668	0.762	0.359	0.508	0.742
	Third	1.000	1.000	1.000	0.942	0.922	0.740	0.770	0.883	0.430
Right, Right, Right	First	0.945	0.932	0.965	0.784	1.000	0.977	0.562	0.762	1.000
	Second	1.000	1.000	1.000	0.914	0.939	1.000	0.720	0.576	0.967
	Third	1.000	1.000	1.000	1.000	1.000	1.000	0.950	0.967	1.000

position was a function of the first-phase list. Conditions 1, 2, and 3 were selected for Table 2 because they conveniently include orderly and wide variations in the probability of a correct response. It is clear from Table 2 that the lists left, left, left and right, right, right, tended to be "easy", but otherwise, differences in recall of a given serial position did not appear to follow any recognizable patterns that were consistent over the three subjects and the various experimental conditions. A profitable analysis of data such as these may require the systematic variation of sequential properties of the first-phase lists.

DISCUSSION

The present experiment demonstrates that a pigeon can remember features of the temporal organization, *i.e.,* pattern of events in its recent past. That is, a pigeon's behavior, like a human's (Yntema and Trask, 1963), can be controlled by the "relative recency" of past events. The accuracy of this control in the pigeon depends on the retention interval and on the duration of the to-be-remembered event. The latter variable may be manipulated so that one may obtain the U-shaped serial position curve that is so familiar in the corresponding literature on human memory (Bower, 1971; Tulving and Madigan, 1970). The generality with which the relative recency of past events controls a pigeon's behavior remains largely unknown. It is not clear whether such control is widespread or atypical. It is an understatement to say that it would be worthwhile to discover the range of contexts where such control obtains. Control of this type poses interrelated difficulties for, and suggests alternatives to, several theoretical and methodological traditions in the experimental analysis of behavior.

1. *The Law of Effect.* Response-reinforcer temporal contiguity was long assumed to be essential for learning (Estes, 1959; Skinner, 1948). The traditional temporal-contiguity assumption in the experimental analysis of behavior is that a pigeon learns to peck a key when it is the key peck that is temporally contiguous with a reinforcer. This issue of what it is that a reinforcer strengthens resembles the old issue of "what is learned?" (*e.g.,* see Tolman, 1959). The present results and other recent results suggest that temporal contiguity is not essential (Hawkes and Shimp, 1975; Shimp, 1975; Shimp and Moffitt, 1974). An alternative view that is consistent with these new results holds that the repeated delivery of a reinforcer after a behavioral pattern a few seconds in duration may strengthen the entire pattern and establish it as a functional unit. In other words, a pigeon learns one or more patterns of key pecks, not just a key peck.

2. *The functional unit of analysis.* As we have just seen, the key peck is traditionally taken to be the unit of analysis by virtue of the role given to response-reinforcer temporal contiguity in the Law of Effect. The concept of a "free-operant" also seems to require that the functional unit be essentially instantaneous. But if a reinforcer interacts not simply with a key peck, but with a recent pattern of behavior as suggested above, there would be no reason to take the key peck by itself as the unit of analysis. The alternative possibility is clearly that one or more patterns of key pecks are functional units of analysis. Evidence from a variety of sources supports this possibility (Hawkes and Shimp, 1975; Shimp and Hawkes, 1974; Shimp 1974, 1975) over the traditional assumption that the behavioral unit is essentially instantaneous.

3. *The criterion of observability.* Radical Behaviorism encourages a theorist to interpret behavior strictly in terms of observables. If the functional unit is instantaneous, this is easy to do: at each moment, one can categorize observed behavior as an instance of, or as not an instance of, the functional unit. A difficulty arises for the observability criterion if in a situation there are two or more functional units that are patterns. If the patterns share one or more response topographies, one cannot tell which functional unit is occurring whenever one of these shared topographies occurs. For example, if two classes of interresponse times are different functional units, one cannot most of the time decide by observation which is occurring. In particular, one cannot observe at the beginning of either unit which it is that a subject has initiated, or chosen. Thus, a pattern analysis suggests a more liberal interpretation of the observability criterion than is traditionally encouraged by Radical Behaviorism.

4. *Linear chaining and integrated behavioral patterns.* The experimental analysis of behavior has at its disposal two traditional

ways in which to interpret delayed stimulus control: delayed reinforcement, and mediating behavioral chains. It has been explained elsewhere why a delay-of-reinforcement account fails to describe some behavior that is temporally patterned (Hawkes and Shimp, 1975). Consider the mediating chain notion. This interpretation maintains that a behavioral pattern at only the end of which is there an observable reinforcer actually consists of a linear chain of separate links. Each link in the chain is assumed to have properties more or less consistent with the temporal contiguity component of the Law of Effect. That is, each link is said to have discriminative properties that set the occasion for the relatively simple response in that component link and also to have conditioned reinforcing properties that strengthen the response in the previous link (Skinner, 1934). This interpretation works reasonably well for contexts such as Sidman avoidance schedules and differential-reinforcement-of-low-rate schedules, where only one chain typically needs to be hypothesized, and where observable behaviors having some of the desired properties sometimes can be located (Laties, Weiss, and Weiss, 1969). However, the linear chain idea is cumbersome in many other contexts (Lashley, 1951), specifically with complex interresponse-time schedules (for example, Shimp, 1974). It is certainly unappealing for the present experiment, for which something on the order of 48 different five-link chains would have to be assumed to exist.

The previous discussion suggests that the rationale for interpreting behavioral patterns as linear chains tends to weaken if one relaxes the observability criterion, abandons the assumption of response-reinforcer temporal contiguity, and increases the permissible complexity of the functional unit of behavioral analysis. Thus, we have a revised picture of what a chain might look like. If a chain were to exist, its links might be composed of behavioral patterns, and some shorter hypothetical chains might not be chains at all but patterns functioning as integrated units. The linear chaining idea by itself may not suffice to describe behavioral patterning. One may at times be compelled to accept a pattern as a unit.

The perspective on behavioral patterning presented above as an alternative to traditional views in the experimental analysis of behavior is most certainly not yet proven true. Nor is it likely to be in the near future. In this one regard, it is similar to traditional views.

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