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MOLECULAR CONTINGENCIES: REINFORCEMENT PROBABILITY[1]

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Pigeons obtained food by responding in a discrete-trials two-choice probability-learning experiment involving temporal stimuli. A given response alternative, a left- or right-key peck, had 11 associated reinforcement probabilities within each session. Reinforcement probability for a choice was an increasing or a decreasing function of the time interval immediately preceding the choice. The 11 equiprobable temporal stimuli ranged from 1 to 11 sec in 1-sec classes. Preference tended to deviate from probability matching in the direction of maximizing; *i.e.,* the percentage of choices of the preferred response alternative tended to exceed the probability of reinforcement for that alternative. This result was qualitatively consistent with probability-learning experiments using visual stimuli. The result is consistent with a molecular analysis of operant behavior and poses a difficulty for molar theories holding that local variations in reinforcement probability may safely be disregarded in the analysis of behavior maintained by operant paradigms.

Key words: choice, local reinforcement probability, temporal stimuli, matching *versus* maximizing, pigeons

From its beginnings to the present, the experimental analysis of behavior has concentrated heavily on what has been called the "molar level of analysis" (Herrnstein, 1970; Skinner, 1938). The dependent variable in this analysis is an average rate of occurrence of a simple response such as a pigeon's key peck or rat's lever press. The computation of rate typically involves averaging over different local reinforcement contingencies. Thus, the experimental analysis of behavior typically ignores local reinforcement contingencies on the assumption that fundamental controlling relations are not to be found at the "molecular" level (Baum, 1973; Herrnstein, 1970; Honig, 1966). This theoretical assumption has only rarely been put to an empirical test in settings where the outcomes may be unambiguously interpreted as evidence for or against it. In the rare case when this assumption implicit in molar analyses is empirically tested, it uniformly fails. That is, when local reinforcement contingencies are experimentally controlled so that their effects may be unambiguously interpreted, one does not obtain the outcome required by the traditional molar analysis: one does not find that molar relationships are invariant over changes in molecular reinforcement contingencies. Indeed, the opposite result obtains: molar results are shown to be almost wholly dependent upon, and sometimes rather easily derivable from, molecular reinforcement contingencies (Hawkes and Shimp, 1975; Shimp, 1966, 1974, *in press;* Shimp and Hawkes, 1974).

Local reinforcement probability for a response in interval schedules is a function of the time since some previous event. In a variable-interval schedule, local reinforcement probability is a function of the time since the previous response. In a concurrent variable-interval variable-interval schedule, local reinforcement probability for a changeover from one schedule to the other is a function of the time since the last response in the other schedule. Both of these functions may be approximated by linear functions. Molar analyses assume that these local reinforcement contingencies do not control behavior. Molar analyses therefore ignore these contingencies and average over them (Baum, 1973; Catania, 1973; Herrnstein, 1970; Rachlin, 1973). Molecular

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analyses, on the other hand, view interval schedules the other way around. A molecular analysis attributes fundamental importance to the local contingencies and regards molar results as unimportant byproducts, *i.e.*, as cumulative effects of the control by molecular contingencies (Hawkes and Shimp, 1975; Shimp, 1966, 1969, 1974, *in press;* Shimp and Hawkes, 1974). It is not a trivial matter to determine the role that local contingencies play in interval schedules. In fact, it is impossible to determine this role by adopting the apparently straightforward method of examining behavior maintained by interval schedules (Anger, 1954; Menlove, 1975; Shimp, 1967, 1973, *in press*). Therefore, indirect methods must be used. One indirect method is the synthetic interval schedule. This method has not only failed to support a molar view, it has instead shown how behavior is sensitively controlled by quite delicate properties of local reinforcement contingencies (Shimp, 1973*b, c,* 1974, *in press*).

The present experiment used a second indirect method to investigate behavioral control produced by a local reinforcement contingency that resembled the local reinforcement contingency in interval schedules. Specifically, we asked how behavior was controlled by local reinforcement probability that was, as it is in interval schedules, a linear function of time since a previous event. The present method was designed to parallel a concurrent variable-interval variable-interval schedule in the additional sense that an organism, a pigeon, was engaged in pecking one key while local reinforcement probability for a peck on another key changed according to this linear rule.

METHOD

Subjects

Three White Carneaux pigeons (Birds 1, 2, and 3) served in all three experimental conditions. Due to an error in the recording of their free-feeding weights, these subjects were maintained at 92, 85, and 95% of their free-feeding weights in the first two experimental conditions. In condition 3, they were maintained at 80% of their free-feeding weights. Also in condition 3, two additional Homing pigeons (Birds 4 and 5) were maintained at 80% of their free-feeding weights. All subjects were deprived of food for 23 hr before each session.

Apparatus

Each of three standard Lehigh Valley Electronics pigeon chambers was equipped with a houselight and three keys, each of which could be transilluminated by blue light. A minimum of 1.5 to 2 N was required to operate the keys. A food hopper in each chamber could provide a subject with access to mixed grain equivalent to that available from Ralston Purina Co. These chambers were interfaced to a Digital Equipment Corporation PDP-12 laboratory computer that controlled the presentation of stimuli and reinforcers, and recorded data on magnetic tape.

Procedure

Birds 1, 2, and 3 were first trained on a two-key concurrent variable-interval variable-interval schedule of reinforcement with equal components. These birds were then trained in conditions like those described below, except that a 0.25-sec operation of the food hopper substituted for food presentation on a random 75% of the trials. Birds 4 and 5 were exposed to a variety of procedures, including an immediately preceding condition in which choice behavior was probabilistically reinforced.

Each trial began with one of 11 randomly selected temporal intervals during which the center key was illuminated with a blue light and the houselight was turned on. These 11 intervals extended from 1.0 sec to 11.0 sec and the class interval width was 1.0 sec. The first response on the center key occurring less than 0.75 sec after the previous response and after the interval elapsed turned off the center key and the houselight and transilluminated the two side keys with blue light. A response on the side key to which reinforcement had been assigned darkened all keylights and produced 2.25-sec access to food. The end of reinforcement began a 2.25-sec intertrial interval during which all lights in the chamber were off. A response on the side key to which reinforcement had not been assigned initiated a 2.25-sec blackout, the correction interval. When the blackout ended, the center key and the houselight were once again illuminated. The same center-key interval was arranged again, and the same assignment of reinforcement to the left or right key remained in effect until reinforcement was collected. Any number of repetitive errors was possible. A peck on any key during the intertrial interval, or during the correction interval, restarted the interval from the beginning. Less than 10% of these intervals were restarted.

The probability of reinforcement for a response on the left key was a linear function of the center-key interval. The probability of reinforcement on the left was complementary to that on the right for a given center-key interval: reinforcement was always arranged on either the left or right key. In condition 1, which lasted 61 sessions, the computer arranged reinforcements for left-key pecks with probability 0.0, 0.1, 0.2, . . . , 0.8, 0.9, 1.0, for center-intervals of 1, 2, 3, . . . , 9, 10, 11 sec, respecrespectively. Thus, reinforcement probability for a left-key peck was a linearly increasing function of the center-key interval. Sessions lasted 50 min and subjects received an average of 140 trials per session. In condition 2, which lasted 49 sessions, the computer arranged reinforcements for left-key pecks with probability 1.0, 0.9, 0.9, . . . , 0.2, 0.1, 0.0, for center-key intervals of 1, 2, 3, . . . , 9, 10, 11 sec, respectively. Thus, reinforcement probability for a left-key peck was a linearly decreasing function of the center-key interval. Sessions again lasted 50 min and subjects received an average of 165 trials per session. In condition 3, which lasted 230 sessions, the reinforcement contingency was as in condition 2, but the session duration was halved to 25 min and the subjects received an average of 75 trials per session. In all conditions, the computer randomly selected center-key intervals, so that all 11 intervals were equiprobable, and the probability of reinforcement for a left-key peck, averaged over all 11 center-key intervals, was 0.5.

RESULTS

The question we wish to answer is this: how did local choice probability depend on local reinforcement probability that was itself a function of time since some event? We focused on steady-state behavior for two reasons. First, we wished to relate the present data to steady-state data from operant schedules. Second, acquisition presumably depended on previous training. The dependent and independent variables were therefore calculated as follows. The dependent variable, steady-state local choice probability, was calculated for each of the 11 different local reinforcement contingencies, *i.e.*, for each of the 11 different center-key durations. For a given duration, choice probability was estimated by the relative frequency of trials on which a subject chose the left key. The local reinforcement contingency for the choice on a trial, the first response on a trial, was different from the local reinforcement contingency for any subsequent responses, the reinforcement probability for which was cued solely by the unreinforced choice, rather than by the center-key interval. The calculation of the dependent variable involved only those responses the local reinforcement contingency for which was cued by the center-key interval. This calculation specifically eliminated all repetitive errors within a trial, the mean number of which following an unreinforced choice was 0.46, 0.73, 0.35, 0.81, and 0.29 for Birds 1, 2, 3, 4, and 5, respectively, in condition 3. Equivalent means are not available for other conditions because of a slight change in the computer program. Had responding after an error been controlled perfectly by the correction procedure, this mean would have equalled zero. Variability in the dependent variable was estimated by the standard deviation of the distribution of choice probabilities over terminal blocks of trials in a condition. The distribution was based on terminal blocks having roughly the same number of trials in different conditions, and therefore different numbers of sessions per block. Thus, for condition 1, choice probability was calculated separately for each of the last five blocks of two days each, but for condition 3, choice probability was calculated separately for each of the last five blocks of four days each to compensate for the smaller number of trials per session. No estimate of reliability for the dependent variable is available for condition 2 because of an accidental erasure of data.

The independent variable, local reinforcement probability, was calculated as follows. For a given center-key duration, the probability of reinforcement for a peck on the left key was estimated by the percentage of reinforcements delivered after that center-key duration that were for left-key pecks. Some of the reinforcements delivered after one center-key duration had been arranged by the computer to be delivered after some shorter center-key duration: if a subject did not satisfy the 0.75-sec pacing contingency within the intended interval, the actual interval exceeded the intended interval. For example, if the computer selected a 6-sec center-key interval but a bird failed to terminate it until 7.7 sec, the actual center-key interval was 7.7 sec. This difference between arranged and obtained intervals is important only because it occasionally changed the obtained local reinforcement probabilities from the arranged probabilities described in the Method section. Table 1 displays the actual numerical values of the local reinforcement probabilities. The values in Table 1 typically are only slightly different from the arranged probabilities because on most trials the intended and actual center-key intervals were the same. The percentage of trials on which a choice response was preceded by an interval different from the intended interval was 0.10, 0.16, 0.11, 0.21, and 0.09, for Birds 1, 2, 3, 4, and 5, respectively, averaged over the sessions for which data are presented here. There were occasional tendencies for these two durations to be unequal more often for some intended durations than for others. For Bird 1, they were somewhat more often unequal when the intended duration was short than when it was long, indicating that Bird 1 did not always begin to respond immediately at the beginning of the center-key interval. For Bird 3, they were unequal slightly more often for long than for short durations, indicating that Bird 3 paused longer than 0.75 sec more often toward the end of longer intervals. There was no systematic tendency for Birds 2, 4, or 5. In any event, Table 1 summarizes the consequences of these center-key behaviors for the obtained value of the local reinforcement probability for each center-key duration. Table 1 also shows, for the sake of completeness, the results from the less than 2% of the trials on which the center-key interval was longer than 11 sec.

With these preliminaries accomplished, we may now examine Figure 1, which shows local choice probability as a function of local reinforcement probability. The variability around each mean is indicated by a vertical line extending one standard deviation in each direction from the mean. Each standard deviation

Table 1

Local Reinforcement Probability (π) and Local Choice Probability (p)

Bird No.	*Condition No.*	*Variable*	*Center-key Interval (sec)*												*Average*
			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	
1	1	π	0.000	0.057	0.202	0.281	0.364	0.551	0.634	0.687	0.783	0.871	0.947	0.900	0.523
		p	0.073	0.088	0.095	0.227	0.293	0.343	0.502	0.636	0.836	0.874	0.894	0.793	0.470
	2	π	0.000	0.058	0.194	0.328	0.312	0.489	0.480	0.677	0.802	0.875	0.959	0.897	0.506
		p	0.018	0.011	0.056	0.118	0.340	0.580	0.577	0.742	0.867	0.806	0.837	0.833	0.482
	3	π	0.000	0.082	0.242	0.263	0.374	0.443	0.592	0.745	0.819	0.875	0.000	0.900	0.511
		p	0.008	0.094	0.057	0.143	0.212	0.452	0.668	0.861	0.910	0.959	1.000	1.000	0.530
2	1	π	0.000	0.056	0.186	0.270	0.379	0.507	0.531	0.747	0.820	0.905	0.962	0.633	0.500
		p	0.000	0.019	0.087	0.248	0.390	0.643	0.723	0.843	0.865	0.915	0.877	0.457	0.506
	2	π	0.000	0.086	0.121	0.288	0.286	0.485	0.581	0.716	0.767	0.875	0.983	0.533	0.477
		p	0.079	0.135	0.175	0.216	0.326	0.563	0.633	0.767	0.840	0.894	0.923	0.424	0.498
	3	π	0.000	0.054	0.204	0.217	0.424	0.421	0.577	0.727	0.743	0.925	0.867	0.867	0.502
		p	0.121	0.114	0.186	0.273	0.493	0.728	0.783	0.886	0.929	0.934	1.000	1.000	0.621
3	1	π	0.000	0.153	0.209	0.350	0.313	0.464	0.594	0.691	0.788	0.871	0.978	0.914	0.527
		p	0.006	0.026	0.063	0.107	0.204	0.438	0.571	0.725	0.874	0.895	0.939	0.931	0.482
	2	π	0.000	0.114	0.187	0.366	0.353	0.470	0.589	0.694	0.783	0.866	0.911	0.823	0.521
		p	0.044	0.046	0.094	0.279	0.397	0.642	0.859	0.876	0.839	0.897	0.900	0.889	0.564
	3	π	0.000	0.134	0.206	0.275	0.395	0.546	0.598	0.721	0.760	0.886	0.821	0.931	0.523
		p	0.000	0.064	0.138	0.246	0.557	0.697	0.851	0.835	0.821	0.845	0.931	0.707	0.558
4	3	π	0.000	0.063	0.150	0.266	0.333	0.504	0.469	0.687	0.720	0.868	0.903	0.917	0.490
		p	0.033	0.017	0.089	0.116	0.144	0.346	0.405	0.642	0.749	0.817	0.959	0.865	0.432
5	3	π	0.000	0.152	0.168	0.304	0.408	0.403	0.590	0.751	0.780	0.850	0.733	0.387	0.460
		p	0.010	0.020	0.037	0.162	0.414	0.590	0.782	0.869	0.886	0.910	0.900	0.775	0.530

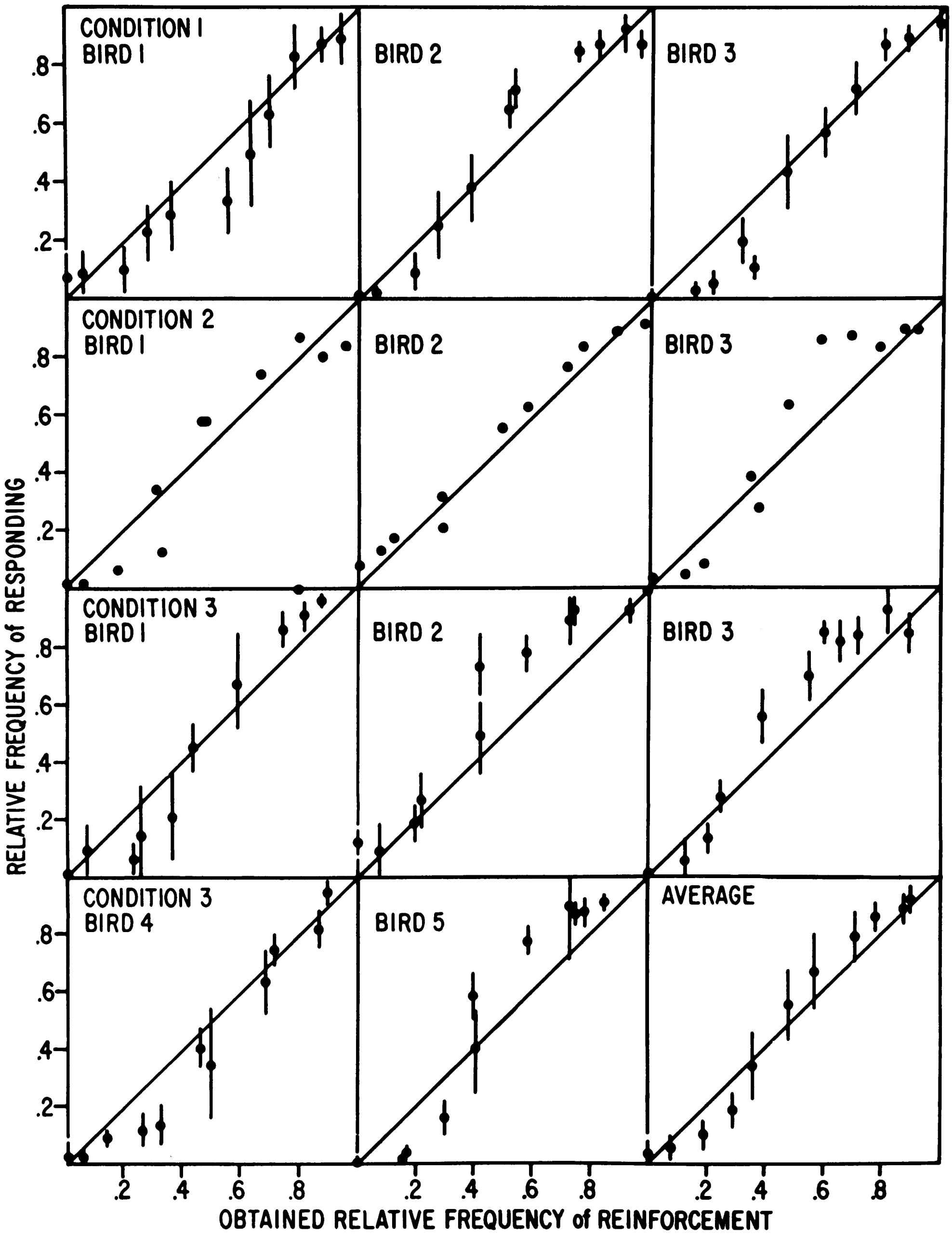

Fig. 1. Local choice probability as a function of local reinforcement probability. The vertical lines extend one standard deviation in either direction from the mean. The diagonal in each graph represents probability matching.

in the panel for the group average is the average of the corresponding standard deviations in the individual panels. In order to make the curves in Figure 1 comparable, those for conditions 2 and 3 are for the probability of choosing the right key and those for condition 1 are for the left key. Thus, low relative frequencies of reinforcement on the horizontal axis in Figure 1 are correlated with short center-key intervals and high relative frequencies of reinforcement are correlated with long center-key intervals.

Local choice probability clearly depended on local reinforcement probability. Indeed, the function relating local choice probability to local reinforcement probability was roughly S-shaped, indicating that local choice probability tended to fall between the probability-matching value (the diagonal in each graph) and the maximizing value (a relative frequency of responding of 0.0 or 1.0 for relative frequencies of reinforcement less than or greater than 0.5, respectively). Only the curve for Subject 2 in condition 2 failed to show any of the properties expected from an S-shaped curve lying between the curves corresponding to matching and maximizing. Of the points for reinforcement probabilities between 0.1 and 0.4, and between 0.6 and 0.9, *i.e.*, for the points that should most clearly discriminate between the matching and S-shaped curves, 57 of 71 points deviated from matching in the direction of maximizing. Such an outcome is very unlikely by chance if the true curve was a matching function.

Overall choice probability, averaged over the various local reinforcement contingencies, approximately equalled the overall reinforcement probability, 0.5.

DISCUSSION

The present experiment generated at a molar level of analysis about the simplest and most elegant relationship one could imagine: choice probability, averaged over all local reinforcement contingencies for choice behavior, closely matched the average reinforcement probability: both closely approximated 0.50. Such an elegant relation between responding and reinforcement induces us to accept the variables in terms of which it is stated as those that reveal fundamental behavioral laws (Herrnstein, 1970). Yet, the present experiment illustrates how incorrect it would be always to accept the molar level of analysis on the basis of elegant molar outcomes, without first closely scrutinizing the origins of those outcomes. Here, the elegant molar outcome plainly was a byproduct of behavioral relations involving local reinforcement contingencies. Thus, no one would wish to argue that the present elegant relation with molar variables reveals a fundamental relation between behavior and reinforcement. This writer previously has argued for similar reasons that molar results obtained with interval schedules are suspect, because no one has yet demonstrated that they are not byproducts of local reinforcement contingencies (Shimp, 1966, 1967, 1969, 1973*b*, 1974, *in press*). The present results are consistent with, and provide additional indirect support for, the view that molar relationships in interval schedules are indeed byproducts and may not safely be interpreted as fundamental controlling relations. The present results provide this support for a molecular analysis by virtue of a similarity between local reinforcement contingencies here and in interval schedules. In both situations, local reinforcement probability is a linear function of time since some preceding event. Present data agree with data from synthetic interval schedules; indeed, with all available indirect evidence on the issue of whether the controlling relations in interval schedules involve molar or molecular variables.

Yet another class of experiments methodologically similar to the present one supports a molecular analysis over a molar one. The present method may be viewed as a discrete-trials probability-learning method with an added correction procedure (Graf, Bullock, and Bitterman, 1964; Experiment I in Shimp, 1966; Experiment I in Shimp, 1973*a*). The present experiment simply replaced the typical visual cues correlated with reinforcement probability with temporal cues. The outcome of the present experiment with temporal cues agrees qualitatively with that of the earlier experiments with visual cues: the probability of choosing an alternative tends to deviate from the probability of reinforcement for that alternative in the direction of exclusive preference for the more-frequently reinforced alternative (Graf *et al.*, 1964; Shimp, 1966, 1973*a*). Thus, earlier probability-learning experiments, synthetic schedules, and the present experiment, all reveal a sensitivity of behavior to variations in local reinforcement contingencies. These experiments testify to the general applicability of a molecular analysis focusing on local reinforcement contingencies and on the temporal patterns of behavior to which they give rise (Hawkes and Shimp, 1975; Shimp, 1966; *in press*).

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