PROPERTIES OF BEHAVIOR UNDER RANDOM INTERVAL REINFORCEMENT SCHEDULES¹

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In a temporally defined system of reinforcement schedules, the fixed interval case is defined when reinforcement probability, P , is equal to unity for the first response in any cycle length, T ; when P is less than 1.0, random interval schedules emerge wherein T/P specifies the expected interval between reinforcements. Key-pecking rates were found to be: (a) inversely related to T/P ; (b) higher at $T = 1.0$ second than at other T parameter values; (c) low and linear at several T and T/P values. The mean post-reinforcement pause, if initially small, increased, and if initially large, decreased, as T/P increased.

In 1956, Schoenfeld, Cumming and Hearst proposed a method for defining reinforcement schedules that was based on the independent variable of time and that early demonstrated a certain subsumptive power by generating behavioral patterns hitherto associated with ratio schedules. Two basic variables used to define this temporal system of reinforcement schedules were, t^D , a time period during which reinforcement is available, and t^A , a time period during which it is not. Symbols used to express combinations of these two variables are: $\bar{T}$ (cycle length), which is equal to $t^D + t^A$, and $\bar{T}$, which is equal to $t^D/t^D + t^A$. Three of the parameters of the system were restricted to fixed values in the early papers (Brandauer, 1958; Clark, 1959; Hearst, 1958; Schoenfeld and Cumming, 1957) to establish fundamental cases and to enable comparison with certain classical reinforcement schedules. These restrictions were: (a) that t^D and t^A alternate, (b) that they be held constant in length at any experimental point, and (c) that only the first response in t^D be reinforced.

Another parameter of this system, which is the focus of the present study, is called P , and is the probability of reinforcement for the first response in any cycle length, T . With P at unity, and $\bar{T}$ at unity, and the three stated restrictions, schedules are produced which are equivalent to fixed-interval schedules (when the fixed interval is timed from the end of the preceding interval rather than from the reinforcement) if T is greater than reinforcement time. The fixed-time interval between reinforcement availabilities is stated by the value of T or cycle length. When P is reduced to values less than unity, however, T comes to specify a minimum, rather than a fixed, time interval separating reinforcement availabilities, since it is now possible that more than one cycle length will separate reinforcements. Given (a) equal probabilities of reinforcement in each cycle length, T , and (b) an organism responding at a rate equal to or greater than $1/T$, the actual number of these lengths which will separate reinforcements can be predicted by the equation $P(N) = (1 - P)^{N-1} P$ where P equals the probability of reinforcement for the first response in any cycle length T , N equals the number of cycle lengths between reinforcements, and $P(N)$ is the probability of that number. According to this equation, the most probable number of cycle lengths between reinforcement availabilities as well as the smallest number possible, is one; a larger number will occur with an exponentially smaller probability. The mean interval between reinforcement availabilities is expressed by the ratio T/P . Since reinforcement

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for the first response is equally probable in any interval T , schedules that are generated when P is reduced from unity may be termed "random interval" schedules.

This study examines some behavioral effects of varying P at several fixed cycle length values.

METHOD

Subjects

Twelve experimentally naive, White Carneaux hen pigeons, 5 to 8 yr old, were obtained from the Palmetto Pigeon Plant, Sumter, S. C.

Apparatus

The experimental chamber in which all subjects (S s) were run has been described by Ferster and Skinner (1957). The response was key-pecking and the reinforcement was 3-sec access to mixed grain. A response and reinforcement contingency translator, described in detail elsewhere (Schoenfeld, Cumming, Hearst, Waine, Snapper, and Haas, 1960, I), shaped the pulses generated by response key closures, delivered them to external recorders, and provided the 3-sec reinforcements. The other components consisted of a random ratio programmer (Schoenfeld, *et al.*, 1960, II), which determined reinforcement probabilities for the first response in any cycle length, and cam timers which determined cycle lengths. The response and reinforcement pulses from each translator were recorded on separate Sodeco counters and cumulative recorders. In addition, for each translator, running time meters accumulated time from offset of the 3-sec reinforcement pulse to the occurrence of the next response pulse. Finally, transistorized switching circuitry and a bank of 40 Sodeco counters, available to one response and reinforcement contingency translator at a time, recorded inter-response times (IRT) at 0.05-sec steps or greater, as necessary.

Procedure

Birds were reduced to 80% of free-feeding weight which was maintained at ± 15 g throughout experimentation. Following shaping of the key-pecking responses, S s were placed in the experimental chambers for 20 successive days for 4-min daily sessions during which each response was reinforced. Following these 20 days of regular reinforcement, S s

were divided arbitrarily into five groups of two or three, with each assigned a different value of T , either 1.0, 5.0, 10.0, 30.0, or 60.0 sec. The three-bird groups were at $T = 1.0$ and 10.0 sec; the two-bird groups at $T = 5.0$, 30.0, and 60.0 sec. Each group was then exposed, at its fixed T value, to a series of decreasing values of the independent variable, P . Systematic decreases rather than random changes in the independent variable were used to maximize detection of any confounding of the primary effect of the independent variable with any sequential effects which may have been present (Schoenfeld and Cumming, 1957; Sidman, 1960). Table I gives the values of P , in their order of use (reading down each column) the resulting values of T/P and the corresponding session lengths that were used. Limitations in the random ratio programmer made it impossible to expose the group at $T = 1.0$ sec to a T/P ratio greater than 195 sec. Following exposure to all the points, an attempt was made to recover original behavior for three groups (representing T values of 5.0, 10.0, and 60.0 sec) at T/P equal to 240 sec, to provide some indication of the extent to which sequential effects were present. Birds were exposed to the first experimental point ($P = 0.5$ at $T = 1.0$ sec; $P = 1.0$ at $T = 5.0$ through 60.0 sec) for 60 days. Exposure time at all succeeding P values was 20 days.

All reported data calculations were based on criterion day performances. Of the first point's 60 days, the last 10 were taken as criterion days. For all other points, at which exposure time was reduced to 20 days, the last five days were criterion days. Session lengths varied from 5 min to 2 hr, depending on the expected number of reinforcements under a given schedule. All S s in a given group were run simultaneously. Cumulative records, total responses, total reinforcements, and total pause time between every reinforcement and the first response following reinforcement, were taken for each S . During one of the criterion-day sessions at several experimental points, an IRT record was taken on one S from each group.

RESULTS AND DISCUSSION

Post-reinforcement time was subtracted before determining the rates plotted in Fig. 1. Otherwise, rates would appear lower at the

Table 1

The fixed T parameter which distinguishes each of the five groups of birds is given at the head of each column. Listed underneath each T parameter and in the order in which they were used are the T/P ratios in seconds with corresponding P values in parenthesis. Session lengths in minutes were the same for all T/P ratios in a given row; these are given in the right hand column. The first T/P ratio in each column was in effect for 60 days; all other T/P ratios and regular reinforcement were in effect for 20 days. Three seconds have been added to the T/P ratios at T = 1.0 sec to correct for reinforcement time.

	1.0	5.0	T 10.0	30.0	60.0	Session Length (minutes)
			regular reinforcement			4
	5 (0.5)	5 (1.0)				5
	10 (0.143)	10 (0.5)	10 (1.0)			10
	20 (0.059)	20 (0.25)	20 (0.5)			20
T/P (P)	30 (0.037)	30 (0.167)	30 (0.333)	30 (1.0)		30
			40 (0.25)	40 (0.75)		40
	60 (0.0175)	60 (0.083)	60 (0.167)	60 (0.5)	60 (1.0)	90
				80 (0.375)	80 (0.75)	90
				100 (0.300)	100 (0.6)	120
	120 (0.0085)	120 (0.0417)	120 (0.0833)	120 (0.250)	120 (0.5)	120
	195 (0.0052)	240 (0.0208)	240 (0.0417)	240 (0.125)	240 (0.25)	120
		480 (0.0104)	480 (0.0208)	480 (0.0625)	480 (0.125)	120
		960 (0.0052)	960 (0.0104)	960 (0.0312)	960 (0.0625)	120

higher reinforcement frequencies (smaller T/P ratios) due to a greater proportion of time occupied by the pause following reinforcement, rather than to any decrease in rate while responding. Bird 5 at T = 5.0 sec stopped responding during the third criterion day session at T/P = 120 sec, probably due to the development of a faulty key-light in its experimental chamber. This S was withdrawn when it failed to resume responding for the last two consecutive criterion daily sessions following correction of the apparatus defect. Prior to this point, (T/P = 120 seconds) per-

formance was consistent with that of Bird 4 at T = 5.0 sec, as indicated in the individual functions in Fig. 1 at T = 5.0 sec. An inverse relation is indicated at T values of 1.0, 5.0, 10.0, and 30.0 sec as T/P increases. Most of the decreases in rate occurred prior to T/P = 120 sec. Average running response rates for the two birds at T = 60.0 sec rose slightly prior to this value (lower right-hand graph in Fig. 1). As with the latter portions of the functions at T values of 1.0 through 30.0 sec, the function at T = 60.0 sec also indicates small decrements in rate with increases in T/P

Fig. 1. Individual and averaged functions which relate rate of responding, at five T values, to the ratio T/P . These rates were corrected by subtracting total reinforcement time and total post-reinforcement pause time from the criterion session lengths over which they were determined. The lower right-hand graph represents average running response rates for two S s at $T = 30.0$ and 60.0 sec, three S s at $T = 1.0$ and 10.0 sec and an individual function (Bird 4) at $T = 5.0$ sec. Extra data points in the individual functions at $T = 5.0, 10.0$, and 60.0 sec at $T/P = 240$ sec, are redeterminations.

beyond 120 sec. Similar changes in response rate are found in several studies of variable-interval schedules where mean intervals between reinforcements ranged from 0.5 to 9 min (Herrnstein, 1955), 1 to 15 min (Cumming, 1954), and from 2 to 20 min (Findley, 1958). These studies and the present one, agree that rate changes are relatively gradual as the mean interval between reinforcements increases beyond 2 min.

Some of the early and rapid decline in rate noted in the rate functions at $T = 5.0$ through 30.0 sec may be due in part to the fact that,

for these functions, not only is the mean interval between reinforcements increasing, but also a transition is being made from a fixed, or periodic, to a random schedule of reinforcement. Periodicity in reinforcement delivery may itself be a factor in producing high rates, with the initially rapid decline in rate due in part to disruption of this periodicity. It may be noted that rates at the equivalent fixed-interval schedules (where $T = T/P$) tend to be higher than those of random-interval schedules (where $T < T/P$) for a given T/P value.

Average rates at $T = 1.0$ sec are, in general, higher than those at T values of from 5.0 to 60.0 sec, indicating that the minimum interval may be an important determinant of rate independently of a wide range of mean interval (T/P) values. In fact, if the minimum interval, T , were reduced further, to less than the minimum IRT of the responding organism, for example, random ratio schedules would be defined (with P specifying the constant reinforcement probability for all responses) and rates still higher than those at $T = 1.0$ sec would emerge (Brandauer, 1958). Over the latter portion of this function (at $T = 1.0$ sec and beginning at $T/P = 60$ sec), rates appear comparable to those produced by variable-interval schedules, provided that these latter schedules include minimum intervals of the order of 1.0 sec (Ferster and Skinner, 1957; Herrnstein, 1958). If variable-interval schedules contain minimum intervals greater than 5.0 sec, however, they appear to generate rates more like those of the present study at $T = 5.0$ through 60.0 sec (Findley, 1958).

Finally, it may be noted that three of the four S_s at shorter T parameter values (5.0 and 10.0 sec) in the present study extinguished at $T/P = 960$ sec, while all four S_s at T values of 30.0 and 60.0 sec continued to respond at a stable rate. This finding suggests that the positive relation between resistance to extinctions and fixed interval lengths up to 1 min found by both Sherman (1959) and Wilson (1954) may hold even with an intervening history of reinforcement at long mean intervals.

Mean post-reinforcement pause times for the equivalent fixed-interval schedules at the first point of each of the four functions in Fig. 2 where $T = T/P$ at T values of 5.0, through 60.0 sec, approach a linear function of cycle length. Sherman (1959) found a similar function for rats, with median pause times linearly related to fixed interval length up to 4 min. Post-reinforcement pauses of appreciable length continue to be prominent features of fixed-interval behavior with fixed-interval lengths up to 30 min (Cumming and Schoenfeld, 1958).

As a relative measure, mean pause may be judged "large" or "small" by comparing it with the reciprocal of running response rate, *i.e.*, the mean IRT of the responding organism. For this reason, the individual and group

functions relating the mean post-reinforcement pause/IRT ratio to T/P are plotted in Fig. 3. A comparison of Fig. 2 and 3 at $T = 1.0$ sec suggests that, as T/P increases above 60 sec, mean post-reinforcement pause for each S relative to the mean pause between responses (mean IRT) increases somewhat more sharply than do the absolute post-reinforcement pause lengths of these S_s . In contrast, at all other T values, the effect of dividing mean pause by the mean IRT is to make the overall slope less positive at $T = 5.0$ and 10.0 sec, and more negative at $T = 30.0$ and 60.0 sec. The outcome is an obvious convergence among these four functions at $T/P = 480$ sec (lower right-hand graph, Fig. 3).

The pause after reinforcement that develops when some appreciable time interval intervenes between successive reinforcements has been considered as evidence that a "temporal discrimination from the preceding reinforcement" has been formed by the organism (Skinner, 1938, p. 271). Since a response is rarely reinforced immediately following a reinforcement, the latter acquires, in addition to its reinforcing function, a discriminative or S^A function that serves to weaken the operant. This latter effect diminishes following a lapse of time and the organism resumes responding. Another type of temporal discrimination which Skinner (1938, p. 274) calls a "temporal discrimination from the preceding response," may develop in random-interval schedules. That is, as with the occurrence of a reinforcement, the emission of a response may also acquire S^A properties which momentarily weaken the operant. Skinner maintains that this second type of temporal discrimination develops in interval schedules due to the fact that a response is more frequently reinforced when it terminates a long pause than when it terminates a short one. (In random-interval schedules the IRT which will most probably precede a reinforcement is determined by the parameter T . A response which terminates IRTs equal to or greater than this value is reinforced at a maximal probability which, in turn, is equal to P .) As has been seen (Fig. 3) as T/P increases, the mean post-reinforcement pause at T values of 5.0 through 60.0 sec tends to approach some small multiple of the mean IRT. This finding suggests that at long mean intervals between reinforcements, a temporal discrimination from the preceding

Fig. 2. Individual and averaged functions which relate mean post-reinforcement pause at five T values to the ratio T/P. The mean pause was determined at each point by dividing the total time, summated over all criterion sessions, which accumulated between the termination of reinforcement and occurrence of the first response following reinforcement, by the number of reinforcements delivered during these sessions. The lower right-hand graph includes average functions for two Ss at T = 30.0 and 60.0 sec, three Ss at T = 1.0 and 10.0 sec, and an individual function (Bird 4) at T = 5.0 sec. Extra data points in the individual functions at T = 5.0, 10.0, and 60.0 sec at T/P = 240 sec, are redeterminations.

response is an important controlling factor in that pause lengths appropriate to it, rather than to the preceding reinforcement, tend to occur after reinforcement. The same argument with supporting evidence has been made by Ferster and Skinner (1957) who found, following the introduction of a 5-min time-out (TO) after each reinforcement on a 16-min fixed-interval schedule, that the post-reinforcement pause, which had been minimal prior to its introduction, lengthened considerably. The

presumed effect of the TO during which S was not responding, was to eliminate effective stimulation from preceding behavior and to reinstate discriminative control of the preceding reinforcement.

The mean post-reinforcement pause at T = 1.0 sec, unlike those at T = 5.0 through 60.0 sec, cannot be attributed to the development of reinforcement as a cue for non-reinforcement, since obviously, at this cycle length (given a 3-sec reinforcement time) successive

Fig. 3. Individual and averaged functions which relate the mean post-reinforcement pause/IRT ratio, at five T values, to the ratio T/P. The lower right-hand graph includes average functions for two Ss at T = 30.0 and 60.0 sec, three Ss at T = 1.0 and 10.0 sec and an individual function (Bird 4) at T = 5.0 sec. Extra data points in the individual functions at T = 5.0, 10.0, and 60.0 sec at T/P = 240 sec are redeterminations.

reinforcements are probable (equal to P). Other factors, perhaps similar to those presumed present in ratio schedules, may account for the post-reinforcement pause at this T parameter value of 1.0 sec (Boren, 1961).

At T/P = 30 sec, in Fig. 4, the prior history of fixed-interval training is reflected in the cumulative record for Bird 7, by periods of no responding after reinforcement which are followed by an abrupt shift to a high rate. This high rate often again shifts rather abruptly, to a lower rate which is generally maintained until reinforcement. The sequence of post-reinforcement pause, followed by high

rate, then low rate, becomes less marked at T/P = 240 sec, while only the pause and low rate are clearly evident at T/P = 480 sec. Similar response patterns and similar changes in these patterns, are also noted in the cumulative records of Bird 12 at T = 60.0 sec (Fig. 5). A very low, highly stable rate of approximately 12 responses per min emerges for this S at T/P = 960 sec. A visual comparison of cumulative records for Bird 7 at T/P = 240 and 480 sec and for Bird 12 at T/P = 960 sec, with those shown by Ferster and Skinner (1957) suggests that a more linear performance might occur with random-interval than

Fig. 4. Sample cumulative records for Bird 7 at $T = 10.0$ sec and at several T/P ratios. Each sample record except at $T/P = 30$ sec was taken from the middle portion of a criterion day session. The record at $T/P = 30$ sec represents an entire criterion day session. Diagonal pip marks indicate reinforcements.

Fig. 5. Sample cumulative records for Bird 12 at $T = 60.0$ sec and at several T/P ratios. Each sample record was taken from the middle portion of a criterion day session. Diagonal pip marks indicate reinforcements.

with variable-interval schedules with the latter at comparable or lower, mean interval values. A relatively high frequency of reinforcement after short intervals (common to geometric and Fibonacci variable interval schedules), and a constant difference between intervals (common to arithmetic variable interval schedules) are both found in random-interval schedules; together, these characteristics may be responsible for the observed linearity in performance. Another characteristic of random-interval schedules which may contribute to linear rates is the limit imposed by these schedules on the extent to which rate can affect reinforcement probability (*i.e.*, the ratio of reinforcements to responses). In these schedules, pause lengths greater than T cannot increase the probability of reinforcement to values greater than P . This property minimizes the number of instances of reinforcement after one, or a few, responses, instances to which Skinner (1938) has attributed a variety of rate fluctuation found in fixed-interval schedules of reinforcement. One obvious divergence from linearity, the pause after reinforcement that is appreciable at some T and T/P values

(*e.g.*, at $T = T/P = 60$ sec), has been noted as being attributable in many cases to the fact that the minimum interval between reinforcement availabilities is long (equal to T). These pauses may be minimized by the inclusion of a "zero" interval between reinforcements, accomplished in the present methodology at any cycle length value, by holding probability of reinforcement constant for the first two responses in any cycle length. One finding of the present study, however, has been that a relatively high frequency of zero intervals between reinforcements, as occurred at $T = 1.0$ sec, tend to produce high rates relative to those at other cycle length values, and that high rates are correlated with appreciable pause lengths after reinforcement especially at low reinforcement frequencies (see Fig. 2 and 3 at $T = 1.0$ sec). But high rates and their correlated post-reinforcement pauses may not appear if the zero interval is used concomitantly with relatively long T values, perhaps 30.0 or 60.0 sec.

The IRT distributions indicate that when rate of responding is relatively high, as with Bird 2 at T/P values of 5 through 30 sec

(Fig. 6), a single mode tends to predominate with 50% to 75% of all IRTs falling between 0.35 and 0.45 sec. Otherwise, typically (Fig. 7), more than one mode appears, and indeed, sometimes as many as four, and possibly five (Bird 12 at $T/P = 120$ sec), modes are suggested. The multi-modal nature of these distributions is obscured as the IRT category size is increased from 0.05 to 0.1 or 0.2 sec (Bird 12 at $T/P = 480$ and 960 sec respectively). No consistent or simple relation is obvious among the several peaks of a given distribution, either in terms of their height relative to each other, or in distance between them. Motion pictures of Bird 12, taken following collection of IRT data at $T/P = 60$ sec, showed that "misses" (forward thrusts of the beak which may hit the wall near the key but do not hit the key itself) occurred. A probable conclusion is that misses, and IRTs not

Fig. 6. IRT distributions for Bird 2 at $T = 1.0$ sec, and at several T/P ratios. The IRT distribution at $T/P = 5$ sec were taken over two criterion day sessions. All others represent a single criterion day performance. The IRTs are distributed in 50 msec categories and the final category includes IRTs equal to and greater than 2.0 sec. Distributions at $T = 5.0$ and 10.0 sec represent approximately 150 and 800 IRTs respectively. All other distributions represent from 1000 to 8000 IRTs.

Fig. 7. IRT distributions for Bird 12 at $T = 60.0$ sec and at several T/P ratios. The IRT distributions at $T/P = 60$ sec were taken over two criterion day sessions. All others represent a single criterion day performance. Except at $T/P = 480$ and 960 sec, the IRTs are distributed in 50 msec categories and the final category includes IRTs equal to and greater than 2.0 sec. At $T/P = 480$ sec, the IRT category is 100 msec; at $T/P = 960$ sec, it is 200 msec. All distributions represent from approximately 2000 to 8000 IRTs.

contaminated by misses, combine in some non-simple way, to produce the complex relation between the successive modes of these distributions.

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