CHARACTERISTICS OF RESPONDING UNDER A TEMPORALLY DEFINED REINFORCEMENT SCHEDULE OF LONG CYCLE LENGTH¹

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We examine here some properties of the pigeon's key-peck responding which emerge under a time-correlated reinforcement contingency reported earlier (Schoenfeld and Cumming, 1960). That reinforcement schedule employed a cycle length, $t^D + t^A$, of 1800 seconds (30 minutes), with only the first response in t^D reinforced. Values of t^D , in the order of presentation, were 1800, 120, 60, 30, 15, 7.5, 3.75, 1.88, 0.94, and 0.47 sec., corresponding to $\bar{T}$, or $t^D/(t^D + t^A)$, values of 1.00, 0.067, 0.033, 0.017, 0.0083, 0.0042, 0.0021, 0.0010, 0.0005, and 0.00025, respectively. The subjects were four white Carneaux hens, but detail data are reported here on only three of these as one died in mid-experiment. The subjects were exposed to the reinforcement schedule daily for sixteen consecutive hours, starting at approximately 5:00 P.M. and continuing until approximately 9:00 A.M. the next morning. Exposure to each schedule continued for thirty consecutive days (making a total of some 480 hours exposure to each schedule), and then was changed to the next value of $\bar{T}$. The apparatus and procedure, with few exceptions, were identical with those used routinely in this laboratory and described elsewhere (Schoenfeld, Cumming and Hearst, 1956; Schoenfeld and Cumming, 1957; Hearst, 1958; Cumming and Schoenfeld, 1958, 1960; Clark, 1959; Millenson, 1959).

RESULTS AND DISCUSSION

Figure 1 presents three aspects of responding as functions of $\bar{T}$ for the cycle length of 1800 sec. The upper two panels exhibit data from the last twelve days on each schedule as previously reported (Schoenfeld and Cumming, 1960, Table 1 and Figure 1), and are reproduced here for visual alignment against the data in the bottom panel. The latter relate $\bar{T}$ and the latency of the first post-reinforcement response ("post- S^R break"). The last 10 days of exposure to each schedule were taken as criterion days giving a fair estimate of stable performance on that schedule, and for each bird the post- S^R latency of first response was measured to the nearest tenth of a minute (6 sec.) at each reinforcement obtained on those 10 days. The raw values of these post- S^R "breaks" from the first to the last reinforcement on each of the 10 criterion days for each of the birds are given in Table A². Table 1 here gives the 10-day mean post- S^R pauses for each bird on each schedule, and indicates the number of reinforcements obtained by each bird during the 10 criterion days (where the number of these reinforcements was less than 50, the means were disregarded as being possibly unreliable, so that the function may be taken as ending at $\bar{T} = 0.0021$, with the lowest two values, including the rise at $\bar{T} = 0.0005$, similarly ignored as being based on data from only one of the animals). That the post- S^R "break" function has a genuine maximum is indicated by the fact that it appears with each bird (at $\bar{T} = 0.0042$ for birds 62 and 64, and at $\bar{T} = 0.0083$ for bird 68; if the function for bird 68 is arbitrarily shifted along the abscissa until its peak coincides with that of the other two birds, the resulting function

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²Table A, a 62-page table giving these data, has been deposited with the American Documentation Institute. Order Document No. 6536, remitting \$3.00 for 35-mm. microfilm, or \$8.75 for 6-by-8 inch photocopies. In this form, the raw data make possible a sequential analysis of the post-reinforcement pauses.

Figure 1. Three aspects of responding (averaged for the three birds) as functions of $\bar{T}$ for the cycle length ($t^D + t^A$) of 30 minutes: rate in responses per minute (corrected for food hopper presentation time); number of responses per reinforcement ($R's/S^R$); and, latency of the first post-reinforcement response (in minutes). Individual data for the function of the bottom panel are in Table 1; also, in the bottom panel, the values plotted at $\bar{T} = 0.0005$ and 0.0010 are based on a single bird's performance and may be unrepresentative. (Discussion in text).

does not differ much from that shown in the bottom panel of Fig. 1, save for some sharpening of the maximum and smoothing at the ends). It may be noted that the largest mean post-reinforcement pauses get beyond the value of the entire $t^D + t^A$ cycle of 30 min. (see also Fig. 5 below), and these long pauses perhaps help to explain the dip in the rate function of the upper panel.

The distributions of post-reinforcement pauses (which can be constructed from Table A) yield some interesting information, and a sample of these are presented in cumulated percent form in Fig. 2. For each bird, two distributions are shown, one for $t^D = 60$ sec. ($\bar{T} = 0.033$), and the other for that t^D value at which the bird gave the longest "breaks" after reinforcement. The 60 sec. distribution of birds 62 and 64 reveal that a large proportion of these "breaks" are (relatively) quite short (under four minutes), and the same general effect, though of smaller magnitude, may be seen in the $t^D = 7.5$ sec. distributions of these birds; bird 68 shows much less skewness in its 60 sec. distribution, but even for it the change in performance under $t^D = 15$ sec. is clear. At certain $\bar{T}$ values, the tendency to respond again (relatively) soon after reinforcement is much reduced, and, as the middle panel of Fig. 1 shows, this reduction is accompanied by a drop both in the over-all rate of responding and in the number of responses-per-reinforcement.

The frequency with which the first response after reinforcement occurs (relatively) early,

TABLE 1

Mean Latencies (in Minutes) of the First Response after Reinforcement for Each of the Birds
Computed for All the Reinforcements Obtained During the Last 10 (Criterion) Days
of the 30-Day Total Exposure to Each Schedule

$\bar{T} =$ t^D (sec) =	0.0005 0.94	0.0010 1.88	0.0021 3.75	0.0042 7.5	0.0083 15	0.017 30	0.033 60	0.067 120	1.00 1800
Bird 62	M = 25.7 N = 51	13.2 141	10.3 219	38.5 135	8.0 72	1.6 150	2.8 79	4.3 238	6.0 317
Bird 64	M = — N = —	— —	5.2 97	44.1 52	34.8 82	17.7 161	6.0 155	16.6 103	6.1 318
Bird 68	M = — N = —	— —	27.0 126	23.0 177	28.8 145	15.4 256	8.9 233	9.5 304	3.3 315
Grand Mean	25.7	13.2	14.2	35.2	23.9	11.6	5.9	10.1	5.1

N's are the number of post-reinforcement "break" measurements entering into the means; no means are given for N's below 50. The last row of latency grand means is plotted in the bottom panel of Fig. 1; the values at $\bar{T} = 0.0005$ and 0.0010 are based on only one bird (see also legend for Fig. 1). On the schedule $\bar{T} = 0.00025$ ($t^D = 0.47$ sec.), bird 62 did not receive 50 reinforcements during the last 10 criterion days, and no entries are included in this table.

Figure 2. Sample cumulated percent distributions of the latency of the first response following reinforcement ("post-S^R break") for the last 10 (criterion) days on each schedule. "Breaks" 50 minutes or greater in length have not been plotted. The indicated parameters are t^D values chosen to illustrate the presence, and the elimination, of the relatively early post-reinforcement response tendency. (Discussion in text).

Figure 3. Sample cumulative response record segments (each beginning at a reinforcement) showing the relatively early post-reinforcement response "burst" taken from the last 10 (criterion) days on each schedule. Numbers in parentheses accompanying the $\bar{T}$ values are corresponding t^D values. In only a few cases has the terminal rate been reached within the short post- S^R records shown. (Discussion in text).

led to a closer examination of the characteristics of such responding. From the last 10 criterion days on each $\bar{T}$ schedule, Fig. 3 gives for each bird a sample of cumulative response record segments, each beginning at a reinforcement and covering the first 15 minutes thereafter (except for bird 62 at $\bar{T} = 0.0021$ and 0.00025 , where shorter segments are necessitated by space requirements). Early response "bursts" of the sort pictured in these records were characteristic of over half of all post-reinforcement records for all three birds except at the mid-range $\bar{T}$ values. These "bursts" do not initiate "scallop" or "runs" leading to the next reinforcement, nor are they explicable on the basis of reinforcement history in this temporal position. Except for the regular reinforcement provided during the preliminary training period, reinforcements in this experiment were always separated by at least 30 minutes. It is this early response tendency (we have sometimes called them "probes") which becomes infrequent at the $\bar{T}$ values of 0.0042 and 0.0083 , to the point where only two examples could be found for bird 68 at $\bar{T} = 0.0083$ (the second example is in the left-most record of Fig. 4).

On occasion, an early post-reinforcement "burst" of the type pictured in Fig. 3 is quite large before ending in another "break"; at other times, the "end" of the early "burst" is only a change in response rate, or a brief irregularity or "flutter" in the curve. Examples of these are shown in the 15-minute record segments of Fig. 4 taken from the last 10 criterion days of birds 68 and 64 on the schedules indicated; each segment begins at a reinforcement, with each circled number being the ordinal reinforcement number on the criterion day in which the example was found.

The dropping out, at such $\bar{T}$ values as 0.0042 and 0.0083 , of the early post- S^R "burst," gives way to the emergence of occasional (approximately one per daily experimental session) very long post- S^R pauses. Fig. 5 shows two examples for each bird, each record segment beginning at a reinforcement (circled R) and ending with not less than one complete excursion of the recorder pen following reinforcement (for the bottom record, a sample of the response curve immediately preceding the reinforcement is included as well as post-"break" responding up to the procurement of the next reinforcement); the segments shown are each

Figure 4. Variants (selected from the criterion last 10 days on each schedule) of the relatively early post- S^R "burst" following the indicated ordinal reinforcement number (circled numbers) within the session, on the indicated schedules. The "burst" may be quite long and may not be ended by a complete halt in responding but rather by a rate differential. (Discussion in text).

Figure 5. Cumulative response record segments (selected from the criterion last 10 days on each schedule) showing long post-reinforcement "breaks" (given to the nearest whole minute) for the indicated birds and schedules. Circled R's indicate reinforcement. (Discussion in text).

from one of the last 10 criterion days of the indicated bird on the indicated schedule. The duration of the pause between reinforcement and the first subsequent response is shown with each record; these pauses were not selected as the longest of those measured for any bird, but only as more or less typical of the way responding recommenced after the pause. (On occasion, also, the last S^R obtained on any day was not followed by a response before the session ended, and the pause following that last S^R might already have been, at session's end, longer than any preceding post- S^R pause in that session—these terminal pauses, because they were not measurable or specifiable, were not included in the present data or in Table A). It may be noted that, while a post- S^R "break" may exceed 8 hours (e.g., bird 62's pause of 495 minutes in the first example under $t^D = 7.5$ sec.), the resumption of responding may be abrupt and at essentially the terminal rate. The comparison of pre- S^R responding and that resuming after a pause of 460 minutes in the bottom record segment of bird 62, shows that the two rates are quite similar especially after a short acceleration period in the post-"break" responding.

Figure 6. Complete cumulative response curve of the twelfth 16-hour session of bird 70 on the indicated schedule. Circled numbers are the ordinal reinforcement number within the session. The total of 99,270 responses was the largest obtained from any bird in any session of this experiment. (The slight curvature near the top of each pen excursion is an artifact arising from a defect in the recorder). (Discussion in text).

The schedules employed in this study are capable of generating a very large behavior output for each reinforcement (*vide*, middle panel of Fig. 1). An example of this is shown in Fig. 6, which gives for bird 70 the cumulative response record for an entire 16-hour session on the schedule $t^D = 60$ sec., $\bar{T} = 0.033$ (since this bird died in mid-experiment 21 days after the record shown here, no data from it have been included in the functions discussed in this paper). For the session shown, 32 reinforcements (none "missed" that session) were procured by 99,270 responses, or about 3100 responses-per-reinforcement. Some features of responding under these conditions and schedule are: (a) periods of uninterrupted rapid responding are interspersed with "breaks" or periods of rate irregularity; (b) rates during periods of uninterrupted rapid responding are of several values, rather than one, and it is not certain that any relation, sequential or otherwise, exists among those rates; (c) transitions from one rate to another may occur at a reinforcement (e.g., reinforcement #3, #23), or between reinforcements (e.g., between #6-7, #10-11, #14-15, #18-19); (d) reinforcement need not produce a rate shift, and responding can show a "run through" (e.g., reinforcement #22, #27, and #17 and #18 after brief interruptions); (e) pauses, short "bursts," and rate irregularities in general, may occur both immediately following reinforcement (e.g., following reinforcement #4, #8, #24), or between reinforcements after some time of fairly steady response rate (e.g., between reinforcements #11-12, #15-16, #17-18, #23-24).

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