SOME PROPERTIES OF SPACED RESPONDING IN PIGEONS¹

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Pigeons exposed to a schedule which reinforces interresponse times (IRTs) longer than a given value (DRL schedule) eventually reach a stable pattern of responding which is shown to be a function both of the DRL value and of previous experience with other DRL values. On any given DRL schedule, the stable performance of most pigeons which have been previously exposed to a variety of such schedules, shows an IRT distribution with median equal to the DRL value. For DRL values longer than about 30 sec, however, the median IRT falls short of the DRL value; this failure of adjustment to longer values appears to be a species characteristic of pigeons. The function relating reinforcement rate to 1/DRL value is also shown to be approximately linear over the same range, with variable slope (less than 45°) and a downturn in the vicinity of DRL 30.

Animals may be trained to space their responses in time by a technique which selectively reinforces interresponse times longer than a specified value (DRL schedules). Since Skinner's demonstration in 1938 that the time between successive responses is a conditionable dimension of behavior, the selective reinforcement of different interresponse times has been shown to be an important determinant of behavior on many reinforcement schedules, (Anger, 1956, 1963). This experiment is an attempt to ascribe quantitative properties to this process.

Wilson and Keller (1953) showed that the rate of responding on DRL schedules is directly related to the maximum reinforced rate (*i.e.*, 1/minimum reinforced IRT) specified by the schedule. Sidman (1956) described two characteristics of the distribution of interresponse times (IRTs) on DRL schedules: (a) the form of the distribution, often with a peak at the shortest recorded IRT interval due to "bursts" of very short IRTs, and usually with a second peak at or just before the minimum reinforced IRT; (b) the dependence of bursts (when they occur) upon the length of the preceding IRT—the probability of bursting is highest following IRTs near the

mode of the distribution. These properties have been widely confirmed by later works (*e.g.*, Conrad, Sidman, and Herrnstein, 1958; Kelleher, Fry, and Cook, 1959).

The present report describes the properties of responding generated by DRL schedules over the range DRL 5 to DRL 30 sec; an attempt is made to quantify the relation between the DRL requirement and the temporal pattern of responding resulting from that requirement. Some characteristics of DRL responding as a recoverable baseline are also described.

METHOD

Subjects

Three adult, male White Carneaux pigeons, without previous experimental experience, were kept at about 80% of their free-feeding weights.

Apparatus

A standard experimental chamber for pigeons (see Ferster and Skinner, 1957) contained a transilluminated response key which required a force of about 16 g to activate the controlling circuitry; an audible "feedback" click accompanied each effective response. During reinforcement (3-sec access to mixed grain) key and house lights were extinguished and the feeder illuminated. Programming and recording were controlled by a system of relays and timers.

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Procedure

After being trained to respond appropriately to the food magazine, Ss were shaped to peck the response key. Following at least one session in which 60 consecutive responses were reinforced (CRF) Ss were exposed to one session each of DRL 10, DRL 15, and DRL 20 sec before going on to the sequence of conditions shown in Table I. A new condition was

Table 1

Order and Duration of Experimental Conditions

No.	Condition	Number of Sessions
1	DRL 30(1) ^a	34
2	DRL 15(1)	26
3	DRL 20(1)	43
4	DRL 15(2)	45
5	DRL 5	26
6	DRL 10	23
7	DRL 20(2)	13
8	DRL 30(2)	45

Numbers in parentheses () refer to the first and second exposure to a given value and are so used in the text.

initiated after at least five days of stable responding (estimated visually) under the preceding condition.

On a DRL t schedule, responses were reinforced if they followed (a) a response, (b) a reinforcement, or (c) the start of the session (whichever was the shortest) by t seconds or more. Experimental sessions lasted approximately $2\frac{1}{2}$ hr or 60 reinforcements, whichever occurred first.

Subjects were run five days a week throughout the experiment as the time out from responding over weekends seemed to have little effect.

Interresponse times were recorded in 16 class intervals (cells) with a cell-width of $0.1t$, where t is the DRL value; responses falling in cells 11 through 16 were reinforced and all IRTs longer than $15t$ registered in cell 16.

^aFor the sake of brevity nominal DRL values are given, the actual values (in seconds) are as follows:

nominal	actual
5	5.68
10	10.80
15	15.85
20	21.10
30	31.50

RESULTS

Point Measures

The left panel of Fig. 1 shows response rate as a function of DRL rate (*i.e.*, 1/minimum reinforced IRT; for a DRL 15 sec schedule, for example, the DRL rate is simply 4 per min or 60/the DRL value in seconds) for the eight experimental conditions; the right panel shows the corresponding relation between DRL value and the median interresponse time. Arrows indicate the order of the determinations. The stable (recoverable) form of the function relating response rate and DRL rate, as indicated by the later conditions of the experiment, appears to be approximately linear with 45° slope for all three pigeons. Similarly, the stable function relating median IRT and DRL value is linear with 45° slope and zero intercept (*i.e.*, perfect matching) for two Ss, although the third S shows a curvilinear relation—this bird is also the only one whose response rate *vs.* DRL rate function has a significantly non-zero intercept on the ordinate. All Ss show a more or less severe departure from the simple linear relation at the longest DRL value (DRL 30), the response rate being higher (and the median IRT shorter) than that predicted by the simple function.

These properties may be summarized as follows: (a) the relation between median IRT (or response rate) and DRL value (or DRL rate) obtaining during the later conditions of the experiment is simpler and more predictable than during the early conditions (when the response rate is usually too high), *i.e.*, the median IRT "homes in" on the DRL value as the experiment progresses; (b) for two out of the three Ss the stable relation between median IRT and DRL value is one of perfect matching for DRL values of 22 sec or less; (c) somewhere between values of 22 and 30 sec this simple relation breaks down: under DRL 30 the median IRT falls more or less short of the DRL value. This is reflected in the increase in response rate under DRL 30 (2) (the second determination of DRL 30) over the preceding DRL 20 (2) shown by two Ss.

The properties of the median IRT *vs.* DRL value function emerge more clearly in Fig. 2 which shows median and modal IRTs *vs.* DRL value for the latter part of the experi-

Fig. 1. Left panel shows response rate as a function of the minimum reinforced rate prescribed by the schedule (DRL rate); right panel shows median IRT as a function of DRL value. The arrowed lines joining the points indicate the order in which Ss experienced the five schedule values; each point represents the last five sessions under each condition. The 45° diagonals are the loci of perfect matching between prescribed and found values.

ment (conditions 4-8). Birds 420 and 422 show highly similar functions close to the matching line, while pigeon 421 shows a deviant non-linear relation. Both 420 and 421 depart widely from the matching function at the longest DRL interval. Both median and mode show the matching relation to DRL value, the mode showing the relation rather better in this case. A plot of mean IRT (1/mean rate) *vs.* DRL value for conditions 4-8 also shows a

linear relation (for all Ss in this case) but it is less orderly than the mode and median plots and is not reproduced here.

Figure 3 shows reinforcement rate as a function of DRL rate for the latter part of the experiment. Once again the form of the relation appears to be essentially linear, with the exception of the DRL 30 value which is close to zero for all Ss and in the vicinity of which the function shows some curvature.

Birds 420 and 422 appear to follow essentially the same relationship (within the limits of the greater variability of reinforcement rate as a datum), while 421 shows a lower slope; the general form of the function is the same for all Ss however.

IRT Distributions

Figure 4 shows IRT distributions and IRTs/Op functions for both occurrences of the DRL 15, 20, and 30 conditions (distributions for the DRL 5 and 10 conditions are not shown since they closely resembled the DRL 15 (2) condition). The IRTs/Op (IRTs per opportunity) function, which is a measure of

the conditional probability of responding as a function of time, was selected by Anger (1956, 1963) as a convenient statistic for the detection of temporal discrimination. When responding is random with respect to time the IRTs/Op function is constant for all IRTs; any deviation from the form of a horizontal straight line therefore indicates some form of temporal discrimination. Typically on DRL and Sidman avoidance procedures the IRTs/Op function rises for longer IRTs. Instead of the usual ordinate showing "per cent total responses" the ordinate for the IRT distributions is IRTs/100 min. Including time in the response measure has the advantage that the

Fig. 2. Median and modal IRT vs. DRL value for conditions 4-8 for the three Ss. Diagonal indicates matching function. The linear function is fitted by eye to the medians for bird 420.

absolute values on the curves for different animals may be directly compared, and—perhaps the most important advantage—the frequency of long IRTs is not distorted by high frequencies in the first cell (a spurious effect of the large number of opportunities in that cell).

Two properties of the distributions in Fig. 4 stand out: (a) the similarity in form of the distributions under DRL values of 20 sec or less (especially the (2) conditions) by contrast with the much poorer temporal discriminations developed under DRL 30; (b) the tendency of the modal IRT to shift towards a point at or just before the minimum reinforced IRT on the second exposure to a given DRL value. This generalization does not apply to the DRL 30 conditions; in this case little improvement is noticeable in the performance of bird 420, a decrement may be noticed in bird 421, and only 422 shows a shift resembling that observed at the other DRL values. The IRTs/Op function does not differentiate as clearly between DRL 20 and

DRL 30—the function shows a more or less sharp (depending on the animal) rise in both cases. A clear quantitative difference—higher IRTs/Op in the early class-intervals under DRL 30—is apparent.

"Bursts"

Examination of individual data reveals little correlation between the frequency of IRTs in the first cell ("bursts") and schedule value. Figure 5 does show a relation between this frequency and time in the experiment. For both birds 420 and 422 the frequency of these short IRTs decreases almost monotonically with continued exposure to the timing situation. In the case of bird 421, the frequency at first increases monotonically and then drops steeply during the DRL 5 condition only to return to a high value which decreases slowly thereafter. This curious pattern is presumably related to this S's deviant behavior in other respects (Fig. 2 and 3). These results suggest that future work on bursts should pay some

Fig. 3. Reinforcement rate vs. DRL rate for conditions 4-8 for all Ss. Diagonal shows perfect responding. The line through the Wilson and Keller data is fitted by eye.

Fig. 4. Interresponse time distributions and IRTs/Op functions for all Ss for both exposures to the DRL 15, 20 and 30 conditions. The size of the class-interval in each case is 1/10 the DRL value. Each point is the arithmetic mean of the last five sessions under each condition. IRTs in cells 11 through 16 were reinforced. IRTs/Op are not plotted where fewer than 50 opportunities occurred in five sessions.

Fig. 5. Frequency of IRTs in the first cell *vs.* position in the experiment for all Ss. Each point is the average of the last five days under each condition. Although the duration of the first cell depends upon schedule value, the great majority of responses in that cell terminate IRTs less than $\frac{1}{2}$ sec in length, no matter what the schedule. The measure is therefore less distorted than it appears.

attention to familiarity with the timing situation (or some correlated factor) as a possible determining variable.

DISCUSSION

The results of the present experiment may be compared with the earlier data of Wilson and Keller (1953). Figure 2 shows that their median IRT function differs in two respects from the ones obtained here: (a) the slope of the earlier function is much less than 45° . This is presumably attributable both to the small number of sessions (six or seven) and the ascending order of presentation (DRL 10

to DRL 30) in the earlier study; moreover each animal was exposed to each condition only once. (b) Wilson and Keller found no downturn at the 30-sec value. There is some reason to attribute this to a species difference between rats, which they used, and the pigeons in this experiment, the pigeons performing less adequately at the longer value (see, for example, the rats of Farmer and Schoenfeld, 1964 or of Anger, 1956 on DRL 40 showing good performances).

In another experiment (Staddon, 1963) pigeons were required to space their responses between t and $t+t/10$ sec apart (DRL t LH $.t$) on a schedule in which the value of t changed

every 5 min in a cyclic fashion. Under conditions which enabled the pigeons to adjust their responding to the value of t as it varied, the function relating mean response rate to DRL rate approached the linear form with unit slope (although with non-zero intercept because of the other schedule parameters). Thus the present linear function receives some confirmation.

While the matching form of the relation between median or mean IRT and DRL value is easily accepted because of its inherent plausibility, the obtained breakdown between 22 and 30 sec requires greater support. However, the present experiment was performed in part to confirm an earlier unpublished finding of a discontinuity on DRL 30 LH 3, as compared with DRL LH schedules from 8 to 15 sec. In that experiment, an increase in rate under DRL 30 LH 3 over DRL 15 LH 1.5 occurred in all three of the animals used. Evidence for a large increase in the "difficulty" of DRL schedules longer than about 22 sec (for pigeons) is therefore quite strong (this is not to say that DRL schedules less than 22 sec are all equally "difficult"). Moreover, published IRT distributions of responding by pigeons on DRL 30 typically show rather poor adjustment to the schedule (e.g., Holz, Azrin, and Ulrich, 1963). Naturally this does not imply that pigeons cannot, by means of appropriate training procedures, be made to adjust as well to DRL 30 as to shorter DRL values. In essence these results simply make a qualitative, actuarial statement concerning the probability of such adjustment in the absence of special training. On the basis of these and other results it can be said that few pigeons exposed to DRL 30 will adjust to it in a way comparable to their adjustment to shorter values.

The approximately linear part of the reinforcement function depicted in Fig. 3 receives some support from the data of Wilson and Keller (1953) replotted there. As with their response function, the lack of a downturn at the 30-sec value is probably attributable to a species difference. The low slope of their function, on the other hand, is presumably due to the short duration of each condition. In addition to the results of the present experiment, the downturn to near-zero reinforcement rate at DRL 30 depicted in Fig. 3 receives confirmation both from the unpub-

lished (DRL LH) experiment referred to above, and from most published results (e.g., Holz *et al.*, 1963); this downturn is the counterpart of the deviation shown by the response function at 30 sec.

These functional relations also shed light on the stability and recoverability properties of DRL responding. Figure 1 suggests two kinds of stability: the first might be termed *true stability* and is characterized by a pattern of responding which places the median IRT on the matching response function of Fig. 2. Its major property is that it presents a pattern which is recoverable following the interpolation of a different DRL value. The second kind is best termed *metastability* and is characterized by a stable pattern of responding which does not change with prolonged exposure to the same schedule value, but which is not recoverable following interpolation of different DRL values. A performance stable in this sense shows the median IRT more or less displaced from the matching function of Fig. 2. This characterization of stability is equivalent to defining the DRL response function as that function whose points are recoverable under the conditions of this experiment. The empirical datum on which these two types of stability are based is the observation that repeated exposure to different DRL values always displaces the response measure towards the matching line, and never in the reverse direction. This irreversible shift is the counterpart, in temporal discrimination, of the formation of a "learning set" in more familiar kinds of discrimination. Thus, in learning set experiments the animal's ability to solve a certain class of problems, as measured by trials to criterion on any instance of that class, increases as a function of the number of previous instances to which he has been exposed. Moreover, this change is not reversible; further exposure to problems of the same class never decreasing the animal's ability to solve still other problems. In the same way, pigeons' ability to solve a class of timing problems (DRL schedules), as measured by agreement between mean IRT and DRL value, seems to depend irreversibly upon their previous exposure to different instances of that class (different DRL values).

These results suggest that continued exposure to one DRL value, e.g., DRL 20, for a given (large) number of sessions would not be

as effective in producing adjustment to that schedule as a more varied procedure extending over the same period—especially if that procedure included exposure to some short values, *e.g.*, DRL 5.

The close relation between the behavior demanded of the animals and the behavior produced by them on DRL schedules (over the 0-22 sec range), together with the irreversible, "learning set" kind of adjustment to the timing procedure as such, suggest that the properties of temporal discrimination demonstrated here may be directly compared to those of discriminations on more familiar continua. This comparison has already been made in connection with a rather different kind of complex temporal discrimination (Staddon, 1963) and the results of the present study seem adequately described in the same way.

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