COLLATERAL RESPONDING DURING DIFFERENTIAL REINFORCEMENT OF LOW RATES[1]

G. E. ZURIFF

WHEATON COLLEGE

Two pigeons were trained to peck either of two response keys for food, under two different variable-interval schedules. When responding stabilized, the schedule on the left key (reinforcement-key) was changed to a differential-reinforcement-of-low-rates schedule, and responses on the right key (extinction-key) were no longer reinforced. The mean interresponse time of responses on the reinforcement-key approximated the temporal requirement of the reinforcement schedule on that key. Collateral responding on the extinction-key was maintained by one of the birds. A "run" of these collateral responses was defined as a sequence of responses on the extinction-key occurring between two responses on the reinforcement-key. For this one bird, collateral behavior, measured by mean time per run and mean number of responses per run, was an increasing function of the temporal requirements of the reinforcement schedule on the reinforcement key, and it was strongly positively correlated with the mean interresponse time of responses on the reinforcement-key. However, from an analysis of the results, the collateral behavior did not appear to have mediated the temporal spacing of responses on the reinforcement-key.

An organism can be said to be "timing" when its responses are temporally spaced so as to correspond to the temporal requirements of a reinforcement contingency. This timing is conspicuous in behavior under the differential-reinforcement-of-low-rates (DRL) schedule of reinforcement. Under this schedule, a response is reinforced if and only if it occurs a specified time after a certain prior event, usually the previous response or reinforcement. Timing can be measured by the degree of correspondence between the interresponse time (IRT) and the interval required by the DRL schedule.

It is often reported (e.g., Wilson and Keller, 1953; Holz, Azrin, and Ulrich, 1963) that under a DRL schedule, a collateral chain of behavior that fortuitously precedes the reinforced response is maintained due to an adventitious temporal correlation with the reinforcer. Some authors have theorized that this collateral chain of behavior mediates timing

behavior and is instrumental in its maintenance. It is suggested either that the collateral chain fills up the necessary temporal delay between responses (Bruner and Revusky, 1961), or that the collateral behavior is used by the organism as a stimulus controlling subsequent behavior (Ferster and Skinner, 1957, p. 729). On the other hand, in many experiments in which subjects timed accurately, no overt chains of collateral behavior were observed (Anger, 1956; Kelleher, Fry, and Cook, 1959).

In order to assess the role played by this collateral behavior many studies have attempted to measure and control collateral responses under a DRL schedule. Using human subjects under a DRL schedule, Kapostins (1963) established a collateral chain of verbal responses which he was able to record and measure. Other experiments with DRL schedules have shown that the collateral responding can be brought under the same stimulus control as the timing response and that experimental manipulations affect both collateral behavior and DRL responding in related ways (Hodos, Ross, and Brady, 1962; Laties, Weiss, Clark, and Reynolds, 1965; Laties, Weiss, and Weiss, 1969).

The fact that collateral behavior often occurs under DRL schedules and may possibly mediate timing behavior has been used as an

explanatory concept in dealing with other phenomena related to DRL schedules. Hearst, Koresko, and Poppen (1964) suggested that features of the post-DRL-reinforcement generalization gradient may be attributed to collateral behavior during the DRL schedule. Similarly, Weiss, Laties, Siegel, and Goldstein (1966) tentatively appealed to a mediating chain of collateral behavior to explain certain features of interresponse time sequences under a DRL schedule. Schedule-induced polydipsia has been explained in terms of collateral chains (Clark, 1962; but see Falk, 1966). In addition, local interactions in concurrent schedules (conc), in which two or more responses are reinforced according to independent schedules, have been attributed in some cases to collateral chains (Catania and Cutts, 1963; Catania, 1966, p. 229).

The concurrent schedule has also been used in several experiments to study collateral behavior under a DRL schedule. Because the concurrent schedule provides additional manipulanda on which collateral responses may occur, these collateral responses, often merely casually observed and reported, can be objectively measured and recorded. Bruner and Revusky (1961) reinforced responses on only one of four response keys under a DRL schedule. Collateral responses occurring on the other keys were never reinforced, yet these collateral responses were maintained by the subject and could, therefore, be measured and studied. In another series of experiments (Segal-Rechtschaffen, 1963), it was found possible to examine how DRL behavior and collateral, possibly mediating, behavior interact by concurrently reinforcing responses collateral to responses under a DRL schedule.

The purpose of the present experiment was to establish, control, and study collateral behavior on a DRL schedule in which reinforcement is not contingent on the collateral response. To examine the relationship between timing and collateral behavior, the contingency controlling the timing response was manipulated, and the resulting change in the collateral behavior was measured.

METHOD

Subjects

Two adult male White Carneaux pigeons, 274 and 342, with previous experience in a variety of experiments, were maintained at about 80% of their free-feeding body weights throughout the experiment.

Apparatus

A standard experimental chamber for the pigeon contained two translucent response keys. The left one was transilluminated by a white light, and the right one by a red light. During reinforcement (4-sec access to mixed grain) both key lights were extinguished, and the feeder illuminated. For both keys, a peck of at least 10-g force was recorded and produced a feedback click. The chamber was illuminated by a white overhead light, and white masking noise was continuously present.

Procedure

Preliminary training. Pecks on the right key were reinforced according to a variable-interval schedule with a mean interval of 15 sec (VI 15-sec), and pecks on the left key were concurrently reinforced according to a VI 45-sec schedule. This preliminary training, *conc* VI 15-sec VI 45-sec, was maintained for 15 sessions at the end of which responding on both keys had reached a fairly high and steady rate.

Conc DRL EXT. The reinforcement schedule for pecks on the left key was changed to DRL 3-sec: a response on the left key (DRL-key) was reinforced if and only if it followed by 3 sec or more: (a) the previous response on the DRL-key, (b) the end of the previous reinforcement, or (c) the start of the session, whichever was most recent. Responses on the right key were now never reinforced (EXT). The DRL 3-sec was maintained for 30 sessions, at which point behavior showed no systematic changes. Thereafter, every six sessions the DRL requirement on the DRL-key was increased. One day with no session separated each six-session group. The DRL requirements used in the order presented were (in sec): 3.0, 3.5, 4.0, 4.5, 5.5, 6.0, 6.5, 7.0, 8.0, 8.5, 9.0, 9.5, and 10.0. Sessions terminated when 40 reinforcements had occurred.

RESULTS

Behavior on the DRL-key is presented in Fig. 1 for Subject 274 and in Fig. 2 by the filled circles for Subject 342. These functions show the mean interresponse time (IRT) on the DRL-key as a function of the DRL re-

quirement. The data represent the medians of the means for each of the last three sessions at each DRL value. The solid lines fitted to the obtained points are the regression lines. The equation for the line fitted to the points in Fig. 1 is $Y' = 0.686 X + 1.61$ with a standard error of estimate $S_{Y\cdot X} = 0.620$. The equation for the line fitted to the filled circles in Fig. 2 is $Y' = 0.784 X + 1.08$ and $S_{Y\cdot X} = 0.238$.

other hand, continued to respond on the EXT-key although reinforcement was not contingent on responses on that key. Moreover, this collateral behavior continued, even though on occasion no responses on the EXT-key intervened between reinforcements. All the data on collateral behavior represent the medians of the means for each of the last three sessions at each DRL value for Subject 342.
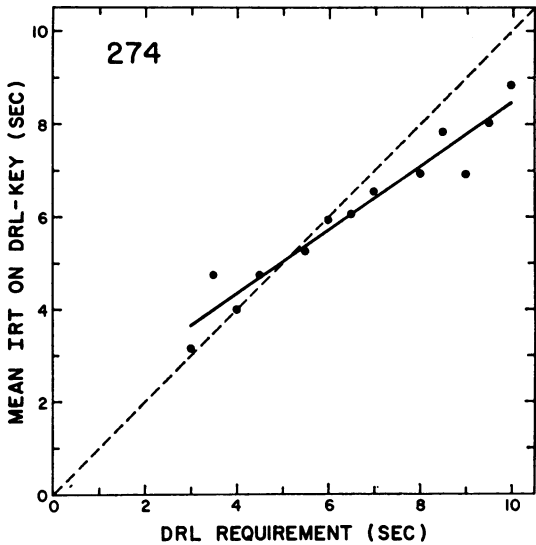

Fig. 1. Mean interresponse time of responses on the DRL-key as a function of the DRL requirement of a *conc* DRL EXT schedule for Subject 274. The equation for the regression line fitted to the obtained points is given in the text. The broken line represents the function that would be obtained if timing were perfect so that the mean interresponse time of responses on the DRL-key equaled the DRL requirement.
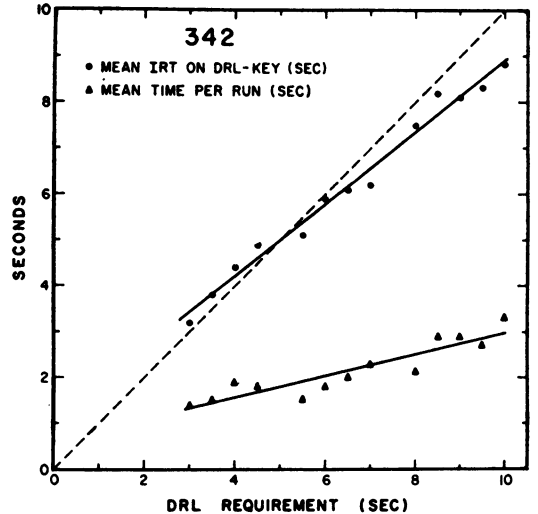

Fig. 2. The filled circles represent the mean interresponse time of responses on the DRL-key as a function of the DRL requirement of a *conc* DRL EXT schedule for Subject 342. The triangles represent the mean time per run on the EXT-key as a function of the DRL requirement. The equations for the regression lines fitted to the obtained points are given in the text. The broken line represents the function that would be obtained if timing were perfect so that the mean interresponse time of responses on the DRL-key equaled the DRL requirement.

The broken line represents the function that would be obtained if the mean IRT were equal to the DRL requirement in either figure. As is often found with DRL schedules (*e.g.*, Staddon, 1965), the obtained function approximates the 45° line although it falls increasingly short of the 45° line as the DRL requirement increases. "Timing" on the part of the organism will be defined as this correspondence between the mean IRT and the DRL requirement.

Both subjects at first continued to respond on the right key (EXT-key) when responses on that key were no longer reinforced. However, over the next few sessions under DRL 3-sec, the response rate on the EXT-key declined to near zero for Subject 274. Subject 342, on the

Following Nevin and Berryman (1963), collateral behavior will be analyzed in terms of "runs" where a "run" will be defined as a sequence of responses starting with the first response on the EXT-key following either a reinforcement or a response on the DRL-key, and terminating with the next response on the DRL-key. The mean interval of time per run for Subject 342 as a function of the DRL requirement is described by the lower function in Fig. 2 (triangles). The equation of the regression line fitted to the obtained points is $Y' = 0.237 X + 0.62$, and $S_{Y\cdot X} = 0.254$. Thus, as Fig. 2 shows, both the mean time per run and the mean IRT on the DRL-key are increasing functions of the DRL requirement,

and the correlation coefficient between mean time per run on the EXT-key and mean IRT on the DRL-key is 0.913.

For those IRTs on the DRL-key during which a run occurred, the IRT between response *A* and response *B* on the DRL-key equals the time per run plus the pause between response *A* and the next response to the EXT-key (pre-run pause). Since runs occurred during almost all IRTs on the DRL-key, the mean time per pre-run pause is closely approximated by the difference between the two functions in Fig. 2. The fact that the difference between the functions increases as the DRL requirement increases indicates that the pre-run pause increased with increases in the DRL requirement and thus was also controlled by the DRL contingency.

Figure 3 shows the mean number of responses per run (not including the response on the DRL-key which terminates the run) for Subject 342 as a function of the DRL requirement. The regression line fitted to the obtained points has the equation $Y' = 0.432\ X + 1.78$, and $S_{Y \cdot X} = 0.487$. The mean number of responses per run is also an increasing function of the DRL requirement, and the correlation coefficient between mean number of responses per run and the mean IRT on the DRL-key is 0.901.

Although both measures of collateral behavior, responses per run and time per run,

are increasing functions of the DRL requirement, they are not monotonically increasing functions. For both functions there is an inversion in each case in which the DRL requirement was increased by a full second rather than the more usual 0.5 sec. On the other hand, the increases of 1 sec did not have the same disruptive effect on the DRL response rate.

Response rate during a run did not vary systematically with the DRL requirement. With DRL requirements between 4.5 and 6.5 sec, the response rate was stable between 140 and 160 responses per minute. At longer and shorter DRL requirements, response rate during a run was between 110 and 120 responses per minute.
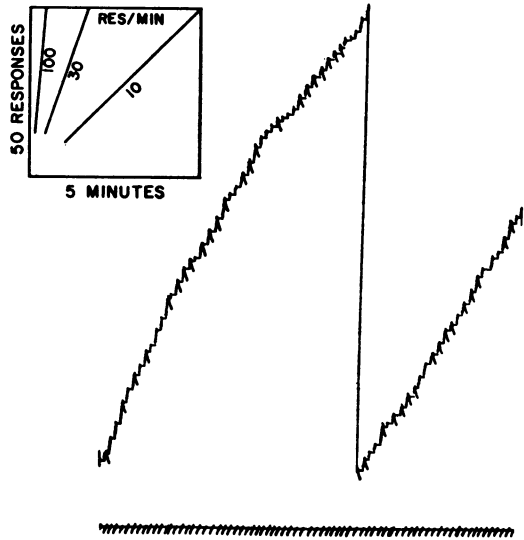

Fig. 4. A cumulative record of responses on the EXT-key under a *conc* DRL EXT schedule for Subject 342. The record represents the entire final session (about 12.3 min) when the DRL requirement was 10 sec. The diagonal pips represent reinforcement after a response on the DRL-key, and the event markers at the bottom of the record responses on the DRL-key. The recorder stopped only during reinforcement.

The pattern of responding on the EXT-key is shown in Fig. 4, which is a cumulative record of all responses on the EXT-key during an entire session when the DRL requirement was 10 sec. Typically, after a response on the DRL-key or a reinforcement, there is a short pause in all responding. After the pause (the pre-run pause), there is a rapid burst of responding on the EXT-key, followed immedi-
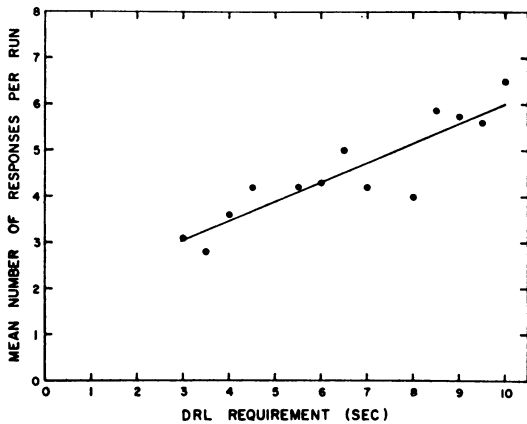

Fig. 3. The mean number of responses per run on the EXT-key under a *conc* DRL EXT schedule as a function of the DRL requirement for Subject 342. The response on the DRL-key which terminated the run was not included in calculating the number of responses per run. The equation of the regression line fitted to the obtained points is given in the text.

ately by a response on the DRL-key. Then the pattern repeats. This "pause-run" pattern was also found by Segal-Rechtschaffen (1963) for collateral behavior on a DRL schedule.

DISCUSSION

There are at least three possible reasons why responses on the EXT-key were maintained under the *conc* DRL EXT schedule even though they were no longer reinforced: (1) response induction from responses on the DRL-key; (2) previous strengthening during the *conc* VI VI schedule; and (3) strengthening due to adventitious temporal correlations with reinforcements following responses on the DRL-key. The fact that responding on the EXT-key was maintained throughout the experiment by only one of the subjects suggests, however, that accidental circumstances controlled the collateral responding, thus supporting the third of the putative explanations.

Both response measures of collateral behavior on the EXT-key—time per run and responses per run—were functionally related to the DRL contingency, indicating that the collateral behavior came under the control of the same contingency which controlled responding on the DRL-key. Moreover, the response measure of the DRL-key, *i.e.*, mean IRT, was strongly positively correlated with the two measures of collateral behavior. Beyond the mere correlation of the DRL behavior and the collateral behavior, can it be said that the collateral chain *mediated* timing under the DRL schedule?

Clearly, collateral responding to the EXT-key was not necessary for timing on the DRL-key, since Subject 274 timed but did not respond on the EXT-key at any appreciable rate. Furthermore, the fact that at all values of the DRL requirement, the mean time per run was less than the mean IRT on the DRL-key (see Fig. 2) indicates that the responses on the EXT-key alone were not even sufficient to mediate the entire interval between temporally spaced responses on the DRL-key. As noted in the Results section, the pre-run pause also increased with increases in the DRL requirement and thus was under the control of the DRL contingency. If timing was mediated, the mediating behavior consisted not only of responses on the EXT-key, but in addition, included unrecorded behavior during the pre-run pause.

If then, responding on the EXT-key were mediating the timing behavior at least in part, it would be expected that the collateral behavior would be no more variable and at least as accurate as the timing behavior, just as would a clock in comparison with the behavior of the person using it. However, in Fig. 2, the standard error of estimate of the equation fitted to the collateral behavior is slightly greater than the standard error of estimate of the equation fitted to the timing behavior. Furthermore, the coefficient of determination, *i.e.*, the proportional reduction in the variance of the dependent values in Fig. 2, given the DRL requirement and the linear equations fitted to the points, is greater for the timing behavior (0.982) than for the collateral behavior (0.892). Therefore, the timing behavior shows a stronger linear functional relationship with the DRL contingency than does the collateral behavior, which is supposed to mediate the control exerted by the DRL contingency. Thus, the collateral behavior on the EXT-key appears to be more variable and less strongly related to the DRL requirement than the timing behavior, and therefore, hardly seems qualified to serve as a clock.

Considerations that cast doubt on the hypothesis that the collateral behavior mediated the timing also tend to raise the question as to why it is necessary to assume that timing behavior is mediated. Under the proper set of reinforcement contingencies, subtle properties of a response, such as its force, location, and duration can be selected and shaped. The IRT of a response can also be considered a differentiable property of a response (Morse, 1966, p. 67), and timing can be construed as the successful shaping of selected IRTs.

Alternately, timing behavior can be interpreted as temporal discrimination. Under the proper set of contingencies, the behavior of an organism can be brought under the control of subtle features of a stimulus such as the orientation of a line, the intensity of a light or the frequency of a tone. Duration, too, is a discriminable feature of a stimulus (Stubbs, 1968), and timing can be viewed as the successful discrimination of stimulus duration. Since the complex stimulus from which duration is abstracted by a timing organism under a DRL

schedule is ordinarily unidentified, there is no good reason to assume, *a priori*, that the stimulus whose duration is the discriminative stimulus for timing behavior must be either an internal stimulus, as Anger (1956) suggests that it might be, or is a chain of responses, as proponents of the mediation hypothesis maintain. Any stimulus, external, internal, or generated by behavior might possibly serve as the stimulus from which duration could be abstracted.

When viewed as response differentiation or stimulus discrimination, timing loses much of the uniqueness that makes the mediation hypothesis an appealing theory.

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