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EFFECTS OF DELAYED REINFORCEMENT IN A CONCURRENT SITUATION[1]

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Pigeons were trained to peck either of two response keys for food reinforcement on equated aperiodic schedules. Delays of reinforcement for pecks at one key reduced the relative frequency of pecking exponentially as a function of the delay interval. Similar functions were obtained when other dependent variables were plotted against the delay interval.

Although evidence suggests that a short delay of reinforcement retards learning and discrimination, the effects of delayed reinforcement on performance of previously acquired responses have not been systematically explored. Skinner (1938) found that a brief reinforcement delay markedly depressed the rate of bar pressing by rats in a procedure that resembles the "differential reinforcement of low rates" (DRL schedule). The animal was permitted to respond during the interval between the effective response and reinforcement, but any such response reset the delay interval. The depression of response Skinner observed may have been due not to delay as such, but to the contingency of reinforcement specified by the procedure. A similar study was reported by Dews (1960). Using a more conventional delay procedure, Ferster (1953) found that pigeons maintained normal response rates for delays of up to 1 min if the delay duration was gradually increased for each pigeon.

In the present experiment, pigeons were initially trained to peck either of two response keys for food reinforcement on equated aperiodic schedules. Then, reinforcements on one key were delayed for various durations, and the resultant effects on behavior were parametrically investigated.

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METHOD

Subjects

Three male White Carneaux pigeons, experienced in a wide variety of experimental procedures, were maintained at approximately 80% of free-feeding body weight.

Apparatus

A standard experimental chamber for pigeons contained two response keys, spaced 9 cm apart, and a feeder that gave 3-sec access to food for reinforced responses. Pecks of at least 10-g force operated a relay to provide auditory feedback to the pigeon. A continuous white masking noise was delivered during sessions. The chamber was illuminated by a white bulb, and, except when the magazine was operated, each of the response keys was transilluminated by a 7-w red bulb.

Procedure

At first, pecks on either of the two response keys were reinforced on VI schedules with an average interval of 1 min. Two independent programmers arranged reinforcements on the two response keys, with the restriction that a switch from one response-key to the other prevented reinforcement for 1 sec (COD 1"). In other words, after a switch from one key to the other, responses emitted for 1 sec from the first peck did not produce a food reinforcement even if the programmer for reinforcement on that key had been primed. After three weeks of training, the number of responses on the two keys became approximately equal. Next, reinforcements on the left key were preceded by a period of 8 sec blackout in the chamber (delay-key). Pecks on either of the response keys during blackout were ineffective and provided no auditory feedback. Virtually no responses were emitted during the blackout. So that, except for the delay, pecking both keys would produce similar consequences, blackouts of the same duration were given for pecks on the right key on a 1-min VI schedule. Pecks on the right key therefore produced either immediate reinforcement or an 8-sec blackout, the frequencies of the two being closely matched. When both the reinforcement and the blackout programmers on the right key were primed, the first peck produced reinforcement, the second blackout. The reinforcement programmers for both keys and the blackout programmer for the right key were inactive during blackout and reinforcement. After 10 sessions with the 8-sec delay, a variety of delay intervals was imposed. The delays explored, in an irregular order, were: 0, 1, 4, 6, 8, 12, 16, 20, 24, and 28 sec. The duration of the intermittent blackouts on the non-delay key was identical to the delay interval of the delay key. Between 9 and 30 sessions were given at each value, depending on the speed with which stable performance was attained. To counter-balance position preferences, each delay interval was explored once on each key.

RESULTS

The relative number of responses on the delay key decreased steadily as the delay interval increased. In Fig. 1 the relative frequency of responding on the delay key is plotted against the duration of the delay. Points for each subject in Fig. 1, and the subsequent figures, were obtained by averaging the performances of the final three sessions at each duration. Figure 1 shows that a delay of 1 sec caused a small, but consistent, increase in the frequency of responding on the delay key. This may be attributed to the fact that a short delay could serve as a signal for the subject to move toward the feeder. It would permit it to be ready when the food magazine became available, and, thus, to obtain more food. Increases in delay interval beyond 1 sec caused a steady decline of the relative frequency of responding and reached the minimum asymptotically.

Figure 2 shows the average function for the three subjects at the various delay intervals.

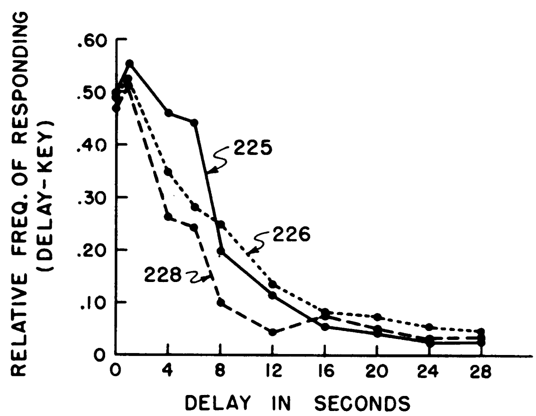

Fig. 1. The relative frequency of responding as a function of delay interval. Points are obtained by averaging the last three sessions' performances at each delay interval.

Points in Fig. 2 were found to be fitted reasonably well by an exponential function, $y = a \cdot e^{-bt} + c$. The parameters are estimated to minimize the sum of the squared deviations between the observed and the predicted values.

Although the programmed frequencies of reinforcement on the two keys were equated, the relative frequency of reinforcement actually delivered from each key varied as a function of delay interval, as shown in Fig. 3. The selected cumulative records displayed in Fig. 4 reveal the cause of the inequality in the frequency of reinforcement delivered from each key. As the delay interval increased, the

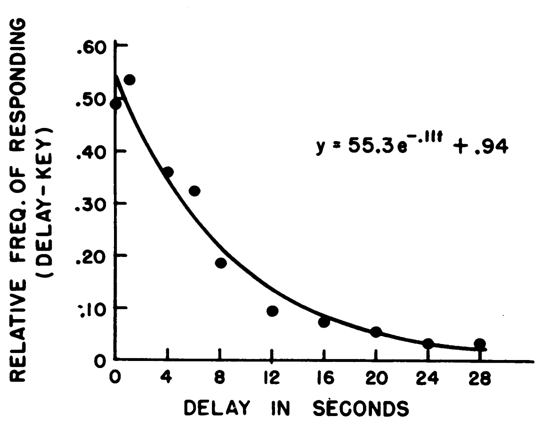

Fig. 2. The averaged relative frequency of responding as a function of delay interval. Points are obtained by averaging the three individual subjects' performances, plotted in Fig. 1. The parameters of the exponential function, $y = a \cdot e^{-bt} + c$, are estimated to minimize the sum of the squared deviations between the observed and predicted values.

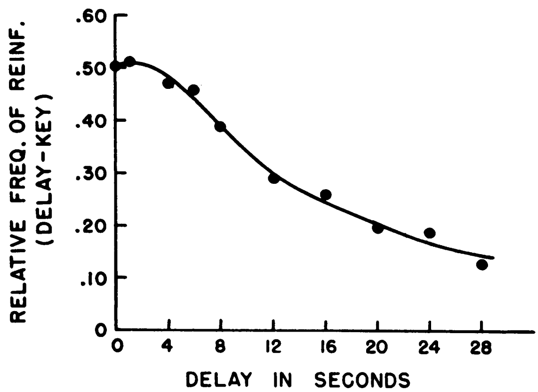

Fig. 3. The relative frequency of reinforcement actually delivered from the delay-key as a function of delay interval. Although the programmed rate of reinforcement on both keys was equated, the frequency of reinforcement actually delivered from the delay-key decreased as the delay-interval increased.

frequency of switching from one key to the other decreased. There was also an increasing tendency to postpone reinforcement on the delay key because of the 1″-COD requirement. That is, the subjects sometimes pecked the delay key within 1 sec of their first peck after the switch and then switched back to the nondelay key. In such cases, reinforcement, if primed on the delay key, was postponed.

A decrement in frequency of responding on the delay-key caused a decrement in frequency of reinforcement delivered from that key, and *vice versa* until an equilibrium state was established. However, the decrement in the relative frequency of reinforcement does not sufficiently account for the decrement in frequency of responding. It has been shown repeatedly that these two variables closely match in an ordinary two-key situation (*e.g.*, Herrnstein, 1961). Figure 5 shows the relative frequency of responding as a function of relative frequency of reinforcement on the delay-key. The numbers by the points denote the delay interval. The points deviate from the predicted function, and the magnitude of the deviations is a function of the delay interval.

The absolute rate of responding as a function of the delay is shown in Fig. 6. The total rate of responding, obtained by dividing the total number of responses on both keys by the total session time excluding the blackout and reinforcement times, was approximately constant throughout the experiment. The rate of responding on the delay key, obtained by dividing the number of responses emitted on the delay key by the total session time excluding the blackout and reinforcement times, decreased exponentially as the delay interval increased.

In Fig. 7, the number of responses emitted per reinforcement (*i.e.*, the inverse of the probability of reinforcement) is plotted against the delay interval. The function is similar to those in Fig. 2 and 6. The number of responses emitted for a delayed reinforcement decreased exponentially as the delay interval increased, whereas the number of responses emitted for immediate reinforcement on the other key increased as the duration of the delay increased. The rationale for utilizing responses-per-reinforcement is somewhat anthropomorphic. When one considers responses as "work" in exchange for reinforcement, then Fig. 7 shows the "values" for immediate and delayed reinforcement.

DISCUSSION

The exponential relationship between the intervening variable and delay of reinforcement has been postulated by others. Hull (1943), for instance, deduced that the limit of habit growth (m′) is an exponential function of delay of reinforcement. By the least-square criterion, the exponential function was found to fit the present data better than a power or logarithmic function. However, the difference between the parameters of the present study and those predicted by Hull, and the unspecified relation between habit strength and the dependent variables examined here, make it difficult to assert that the present findings confirm Hull's prediction.

The functions obtained by utilizing three different dependent variables were shown to resemble each other closely (*cf*. Fig. 2, 6, and 7). Since the total rate of responding was shown to be approximately constant throughout all delays (see Fig. 6), the resemblance between the functions obtained by utilizing relative frequency of responding and rate of responding is expected. Likewise, given the fact that relative rate of reinforcement delivered from the delay key varies as a function of delays, as shown in Fig. 3, responses-per-reinforcement plotted against the delay interval can easily be deduced from the relative frequency of responding. It is noteworthy, however, that the total rate of responding re-

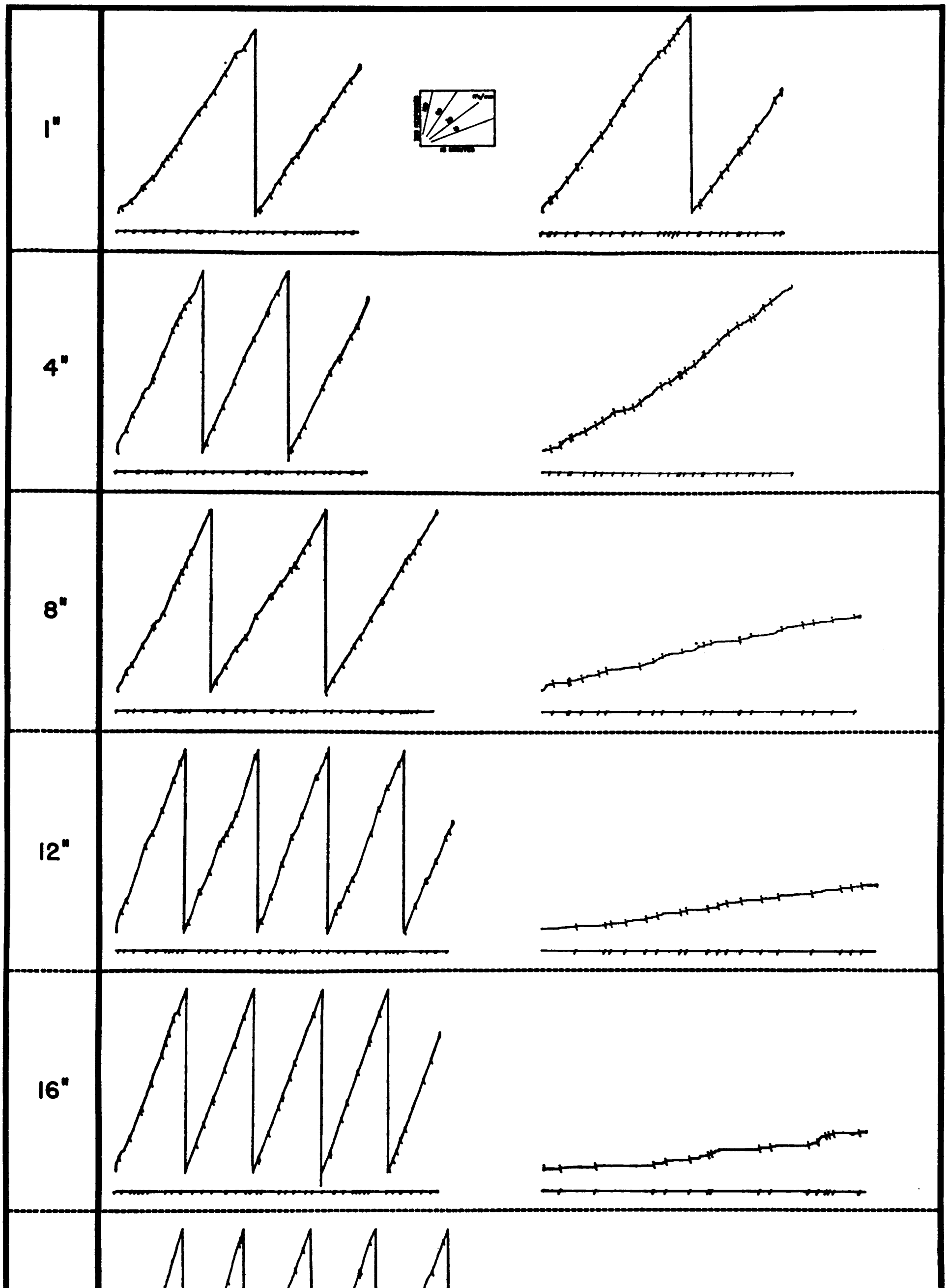

Fig. 4. Selected cumulative records for S-228. The records displayed at left are obtained from the non-delay key and those at right from the delay-key. Blackouts are indicated by the small downward mark on the baseline. The numbers accompanying the records denote the delay interval.

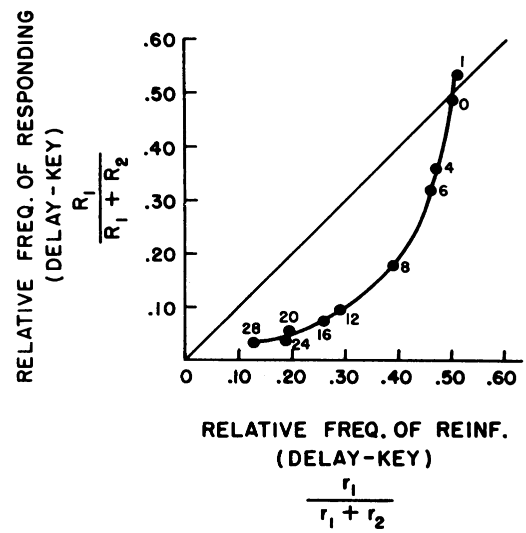

Fig. 5. The relative frequency of responding on the delay-key as a function of relative frequency of reinforcement delivered from that key. The function indicates that the decrement in the frequency of reinforcement delivered from the delay-key does not sufficiently account for the decrement in frequency of responding on that key.

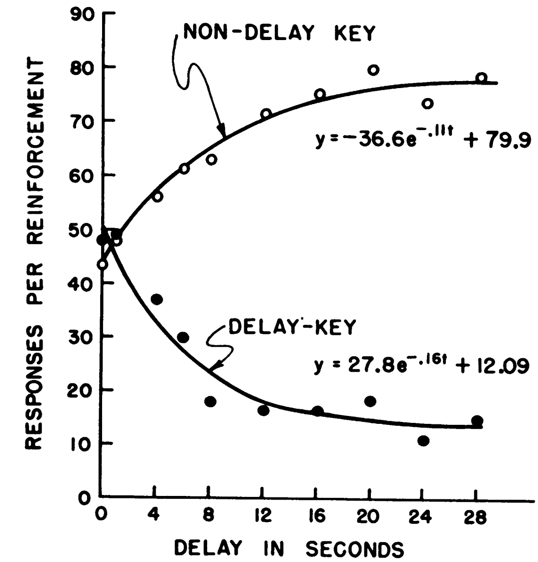

Fig. 7. The responses-per-reinforcement (*i.e.*, the inverse of the probability of reinforcement) as a function of delay interval. The number of responses emitted for a delayed reinforcement decreased exponentially as the delay interval increased, whereas the number of responses emitted for an immediate reinforcement increased exponentially.

mained approximately constant throughout all delays, despite the fact that the rate of reinforcement, when the blackout time is included, varied from 1 to 2 per min. This observation confirms Dews' (1962) findings that fixed-inter-

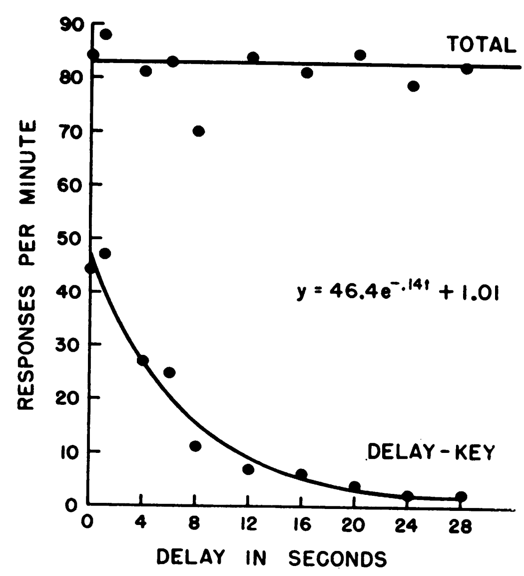

Fig. 6. The total response rate and response rate on the delay-key as a function of delay interval. The total response rate remained approximately constant for all delays, whereas the response rate on the delay-key decreased exponentially as a function of delay interval.

val performance in the pigeon was unaffected by interpolated blackouts. Also noteworthy is the fact that the responses-per-reinforcement for the delay and non-delay keys varied exponentially as a function of the delay interval. Revusky (1962) deduced from Herrnstein's (1961) findings that responses-per-reinforcement is constant for all schedules where the relative response and reinforcement frequencies match. That the matching did not occur (and consequently, responses-per-reinforcement did not remain constant) indicates that the known relations between the variables can be distorted systematically by introducing an additional variable, namely, delay of reinforcement. Similar effects were observed when the effort requirement for responding was introduced for each of the two response keys (Chung, 1965).

A general inference to be drawn from the present findings is that delays of reinforcement depress previously acquired responses and retard learning and discrimination. Choice in a two-key situation is known to be governed by such factors as frequency of reinforcement (*e.g.*, Herrnstein, 1961), effortfulness of responding on each of the two keys (Chung, 1965), and amount of reinforcement (Catania, 1963). In light of the present findings, immediacy of reinforcement must be added to the above list of factors that have potent effects on performance in a concurrent situation.

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