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SEPARATING THE EFFECTS OF INTERREINFORCEMENT TIME AND NUMBER OF INTERREINFORCEMENT RESPONSES[1]

ALLEN J. NEURINGER AND BRUCE A. SCHNEIDER

FOUNDATION FOR RESEARCH ON THE NERVOUS SYSTEM
AND COLUMBIA UNIVERSITY

The relative importance of interreinforcement time and interreinforcement responses was evaluated by varying each independently. To do this, a blackout was presented after each nonreinforced response under both fixed-ratio and fixed-interval schedules of reinforcement. Manipulating the blackout duration under the fixed-ratio schedule caused interreinforcement time to vary without affecting the number of interreinforcement responses. Pigeons' post-reinforcement and post-blackout response latencies were found to increase linearly with interreinforcement time. Under the fixed-interval schedule, the same blackout manipulations changed the number of interreinforcement responses without affecting interreinforcement time. Post-reinforcement and post-blackout response latencies under this condition were approximately constant. These results suggest that responding is controlled by interreinforcement time and is not influenced by the number of responses emitted between reinforcements.

An animal's behavior might be influenced by the time it spends between reinforcements, by the number of responses it emits during this time, or by both. The relative importance of these variables is not known, primarily because a change in the value of one is usually accompanied by a change in the value of the other. For example, when a fixed-ratio 5 schedule is increased to a fixed-ratio 100, the number of responses emitted between reinforcements increases and, because it usually takes longer to emit 100 responses than 5, the average time between reinforcements also increases. Thus, variations in responding with ratio requirements might be accounted for, at least in part, by correlated changes in interreinforcement time (Ferster and Skinner, 1957; Boren, 1961; Felton and Lyon, 1966). Similarly, when a fixed-interval 5-sec schedule is increased to 60 sec, the average number of interreinforcement responses typically increases. The effects produced by increasing the time between reinforcements might thus be due to changes in the number of responses emitted per reinforcement (Wilson, 1954; Clark, 1958; Hanson, Campbell, and Witoslawski, 1962; Dews, 1965). As long as interreinforcement responses and interreinforcement time remain correlated, it is impossible to determine unequivocally the extent to which each variable controls responding. The present experiment attempted to overcome the difficulties posed by these correlations by manipulating each variable independently.

METHOD

Subjects

Eight male White Carneaux pigeons, with previous experience in a variety of experiments, were maintained at approximately 80% of their free-feeding body weights throughout the experiment.

Apparatus

A standard experimental chamber contained a translucent Gerbrands response key and a feeder which gave 2.9-sec access to mixed grain. The key was transilluminated by a 7-w blue bulb except during reinforcement, when the feeder was lighted by two 7-w white bulbs, and during periods of blackout, when the chamber was completely dark. No houselight was present. Pecks of at least 20-g force were recorded and, whenever the key was lighted,

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produced feedback clicks from a dc relay mounted behind the panel. White masking noise was continuously present. All sessions were terminated after 55 reinforcements.

Procedure

The eight pigeons were arbitrarily divided into two equal groups, a fixed-ratio (FR) and a fixed-interval (FI) group. Throughout the experiment, every fifteenth response was reinforced (FR 15) for each FR bird, while the first response to occur at least 30 sec after the previous reinforcement was reinforced (FI 30-sec) for each FI bird. On both schedules, every response except the reinforced response was followed by a brief blackout during which the key was inoperative and the chamber totally dark. Thus, on the FR schedule, the first 14 responses were followed by blackouts while the fifteenth response resulted in reinforcement. On the FI schedule, all responses which occurred less than 30 sec after the previous reinforcement produced blackouts. Included in the 30-sec FI was the time spent in these blackouts, so that the interreinforcement interval was 30 sec of *real* time. Since very few responses were emitted during the blackouts, and since these responses had no scheduled consequence, they were omitted from all calculations.

The independent variable was the duration of the response-produced blackouts. The durations, in the order presented, together with the number of sessions at each duration, were as follows: 0 sec, *i.e.*, no blackout (72 sessions), 0.34 sec (36 sessions), 0.64 sec (51 sessions), 1.13 sec (37 sessions), 2.13 sec (45 sessions), 4.96 sec (50 sessions), 0.34 sec (50 sessions), and 0 sec (53 sessions). These blackout conditions were identical for both FI and FR groups.

This procedure attempted to separate the effects of interreinforcement time and interreinforcement responses by independently manipulating them in the following way. On the FR schedule, a constant 15 responses were emitted between reinforcements while interreinforcement time varied with blackout duration. (Note that interreinforcement time is defined as the average real time, including both light-on and blackout, between reinforcements. The 2.9 sec of grain presentation was not included in the interreinforcement-time calculation.) For example, when the blackout was 0.34 sec on the FR schedule, the minimum time between reinforcements was 4.76 sec (0.34 sec multiplied by 14); it was 69.44 sec when the blackout duration was 4.96 sec. Under the FI schedule, on the other hand, the interreinforcement time was always approximately 30 sec, while the number of interreinforcement responses varied with blackout duration. For example, when the blackout was 0.34 sec, the maximum number of responses that could be emitted in a 30-sec period was 88 (30 sec divided by 0.34 sec); only six responses per reinforcement could be emitted when the blackout was 4.96 sec. Hence, under this FR schedule, interreinforcement responses were constant while interreinforcement time varied, whereas under this FI schedule, the opposite was true.

RESULTS

The two measures of behavior were response latency after reinforcement (the average interval between termination of reinforcement and emission of a response) and response latency after blackout (average interval between termination of blackout and emission of a response). (When the blackout duration was 0 sec, post-blackout response latencies were actually interresponse times.) Each point in Fig. 1 and 2 shows the geometric mean of a bird's latencies over the last five sessions at each blackout duration; the lines in these and the following figures connect the geometric mean latencies of each group.

Figure 1 shows that increasing the duration of blackout under the fixed-ratio schedule caused the response latencies after both reinforcement and blackout to increase. On the other hand, Fig. 2 shows that when the same blackouts were presented on the fixed-interval schedule, responding was unaffected: both post-reinforcement and post-blackout response latencies remained approximately constant.

The blackouts alone did not produce these effects. In the presence of identical blackout conditions, response latencies changed under the FR schedule but were unaffected under the FI. However, since the blackouts were used to manipulate interreinforcement time and interreinforcement responses independently, one of these variables might account for the obtained results. Figure 3 shows response latencies as a function of the average time be-

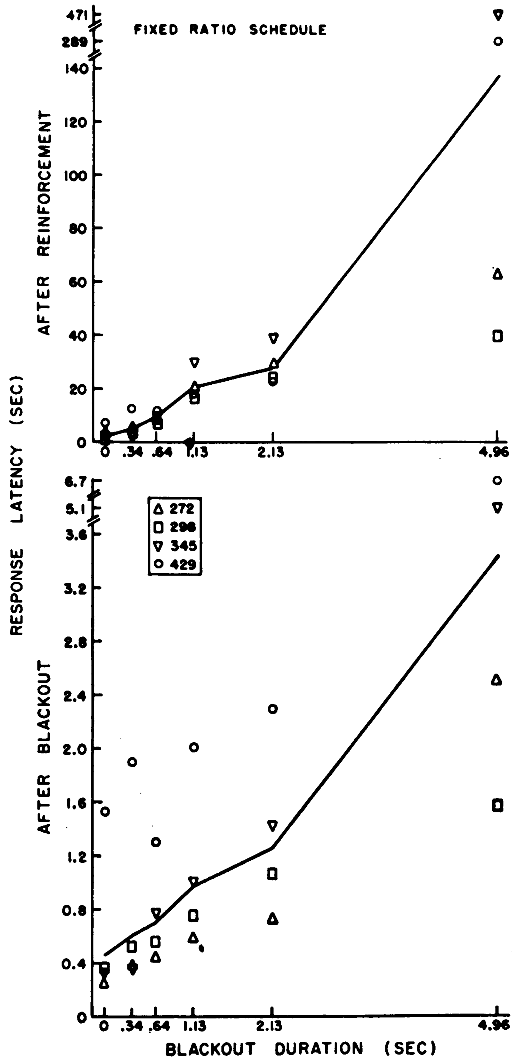

Fig. 1. Response latencies after reinforcement (upper) and after blackout (lower) as functions of the duration of response-produced blackouts. (Strictly, when blackout equalled 0 sec, the post-blackout response measure was an interresponse time.) Reinforcements were presented after every fifteenth response. Note the different units on the ordinates of the two graphs.

tween reinforcements. (Note that the values plotted along the abscissa are the interreinforcement times actually experienced by the subjects.) Under the FR schedule (triangles), response latencies after reinforcement and after blackout increased as approximately linear functions of average interreinforcement interval. Under the FI schedule (circles), in which interreinforcement time was constant, these response measures remained approximately constant. Therefore, performances under both schedules were highly correlated with interreinforcement time.

Under neither schedule could response latencies be predicted from the average number of responses emitted between reinforcements. Figure 4 shows response latencies after reinforcement and after blackout as functions of the number of responses per reinforcement actually emitted by the subjects. Under the FR schedule (triangles), in which interreinforcement responses were a constant 15, response latencies varied; under the FI schedule (circles), in which the number of interreinforcement responses varied, response latencies were approximately constant. These results suggest that performances in the present experiment were not influenced by the number of interreinforcement responses.

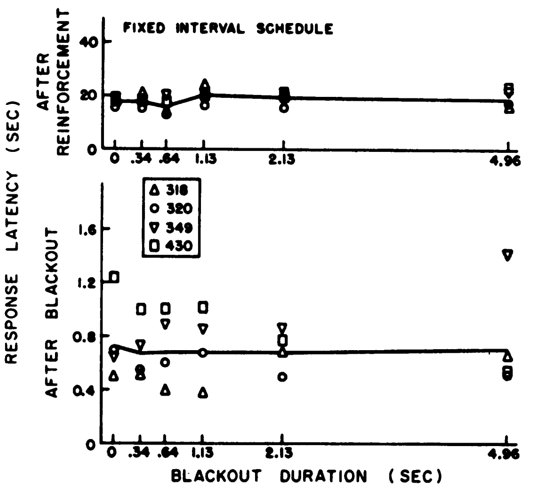

Fig. 2. Response latencies after reinforcement (upper) and after blackout (lower) as functions of the duration of response-produced blackouts. Reinforcements were presented on a 30-sec fixed-interval schedule.

Blackout durations were increased, in the above conditions, from 0 sec to 4.96 sec. This increase caused interreinforcement responses under the FI schedule and interreinforcement time under the FR schedule to change in opposite directions: the number of interreinforcement responses decreased under the FI while interreinforcement time increased under the FR. To determine whether these directions of change influenced the obtained results, the blackout durations were *decreased* first to 0.34 sec and then to 0 sec. Figure 5 shows that the direction of change had little or no effect. The points originally obtained with increasing

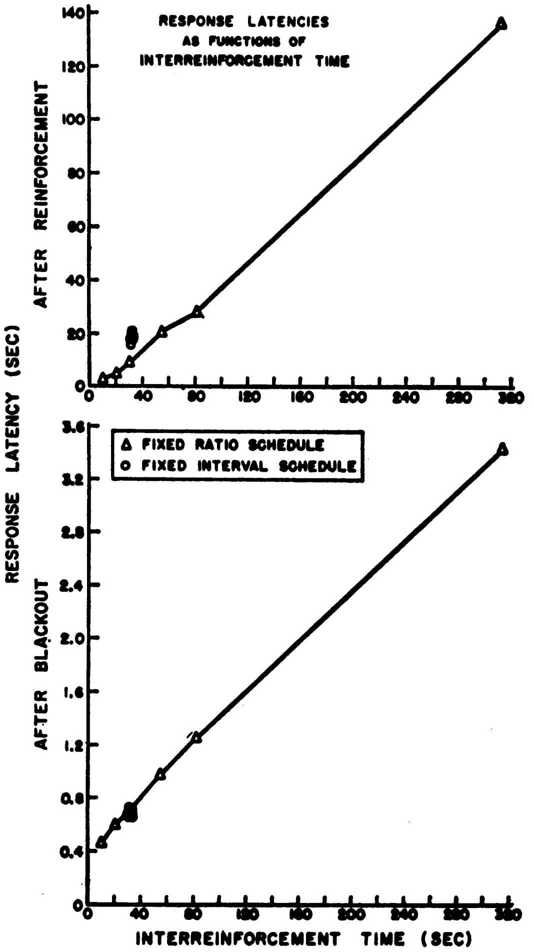

Fig. 3. Response latencies after reinforcement (upper) and after blackout (lower) as functions of the average time between reinforcements. The lines connecting the triangles show performance under the fixed-ratio schedule. The overlapping circles show performance under the fixed-interval schedule.

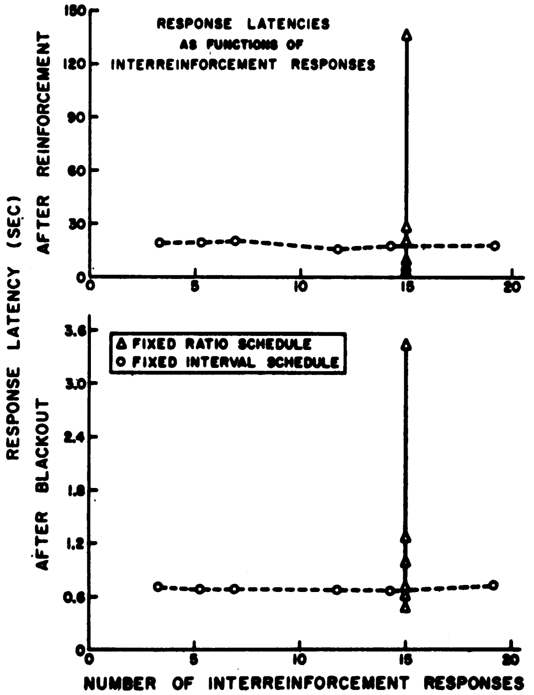

Fig. 4. Response latencies after reinforcement (upper) and after blackout (lower) as functions of the average number of responses emitted between reinforcements. The solid lines connecting the triangles show performance under the fixed-ratio schedule. The broken lines connecting the circles show performance under the fixed-interval schedule.

duration were approximately recovered when blackout durations decreased.

DISCUSSION

A basic problem for the experimental analysis of behavior is to determine which aspects of the environment control behavior. The present experiment examined the relative importance of two common variables, interreinforcement time and interreinforcement responses. To determine the separate and unconfounded effects of each variable, brief blackouts were presented after each nonreinforced response under both fixed-ratio (FR) and fixed-interval (FI) schedules. On the FR schedule, this procedure allowed independent manipulation of interreinforcement time without affecting the number of interreinforcement responses. On the FI schedule the opposite was true; the number of interreinforcement responses varied while interreinforcement time remained constant. Response latencies were found to be linearly related to interreinforcement time on both schedules (Fig. 3), whereas they were not correlated with the number of interreinforcement responses (Fig. 4). It must be emphasized that since the blackouts were identical under both schedules, the different effects produced could not be attributed to blackouts alone.

Two aspects of the present procedure might have influenced the results. First, as blackout duration was increased, interreinforcement responses and interreinforcement time varied in opposite directions. Figure 5 shows that the directions of these changes were not, however, critical. Second, under the FR schedule—as, indeed, under all ratio schedules

—interreinforcement time partly depended upon the rate at which the subject responded; under the FI, as under all interval schedules, the number of responses emitted per reinforcement partly depended upon the subject's response rate. However, under both schedules, response latencies were correlated with interreinforcement time and were not correlated with interreinforcement responses. It is unlikely, therefore, that the response-rate dependencies determined the present results.

The importance of reinforcements measured in time is supported by the operant literature. Anger (1956) showed that interresponse times were correlated with reinforcements per unit time and not with reinforcements per response.

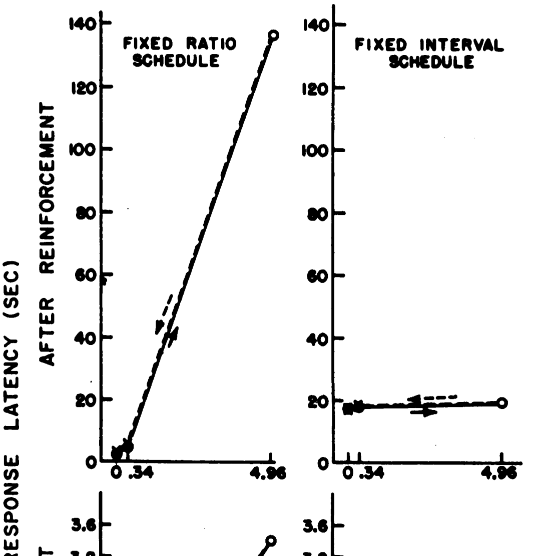

Fig. 5. Response latencies after reinforcement (upper) and after blackout (lower) as functions of the duration of response-produced blackouts under both fixed-ratio (left) and fixed-interval (right) schedules. The solid lines connecting the circles show performance when blackout duration increased. The broken lines connecting the crosses show performance when the duration of blackout decreased.

Behavioral contrast has been shown to depend upon reinforcements in time rather than reinforcements per response (Reynolds, 1961). Herrnstein (1964) concluded that pigeons' choices could be better predicted from reinforcement rates than from reinforcements per response. In a related study, Herrnstein (1961) obtained linear relationships between rates of responding and rates of reinforcement in a concurrent two-key situation where the responses per reinforcement were approximately equal on the two keys (see Revusky, 1963).

On the other hand, the assertion that the number of responses emitted between reinforcements is *not* an important variable appears, at first glance, to be inconsistent with several findings in the literature. First, systematic relationships have been shown between responding and the value of a ratio schedule (Boren, 1961; Felton and Lyon, 1966). However, as suggested in the Introduction, interreinforcement time, as well as interreinforcement responses, changed with ratio size. Therefore, the effects on behavior might well have been due to correlated changes in the temporal variable.

Second, response rates are typically higher under ratio schedules than under interval schedules. For example, Ferster and Skinner (1957, p. 399 ff.) found that the response rate of a pigeon on a variable-ratio schedule was systematically higher than the rate of a "yoked" variable-interval control bird, *i.e.*, a bird on a schedule with identical interreinforcement intervals. While such results suggest that the ratio contingencies exert characteristic control over responding, the results do not imply that the value of the ratio, or the number of interreinforcement responses, affects responding. Morse (1966, p. 74 ff.), for example, hypothesized that the differential reinforcement of short interresponse times found under ratio schedules of all values can account for the relatively high response rates observed. This interpretation is supported by the increase in response rates produced when a small ratio requirement is added to a long interval schedule (Ferster and Skinner, 1957, p. 415 ff.). Adding the terminal ratio contingency causes response rates to increase, even though more interreinforcement responses are emitted under this schedule than under a regular FI. The distinction between contingencies and number of responses is important, for it highlights the possibility that ratio contingencies affect responding while the number of interreinforcement responses exerts no control. Ignoring this distinction leads to the erroneous conclusion that whenever a ratio schedule is employed, responding is necessarily controlled by the value of the ratio.

Third, several studies have shown that the number of previously emitted responses, as well as the passage of time, can serve as a discriminative stimulus for a future response (Reynolds and Catania, 1962; Pliskoff and Goldiamond, 1966; Rilling, 1967). For instance, Pliskoff and Goldiamond (1966) trained pigeons to peck one key if 25 responses had been previously emitted and a different key if 75 responses had been emitted. This type of discriminative control, however, does not imply that the number of responses emitted between reinforcements controls the latency (or rate, or probability) of these same interreinforcement responses, The present experiment shows that interreinforcement response latencies are not controlled by the number of interreinforcement responses, a result not inconsistent with the fact that this number can serve as a discriminative stimulus for some future behavior.

The correlation in the present experiment between response latencies and interreinforcement time, plus the absence of correlation between response latencies and number of interreinforcement responses, suggests a general hypothesis: the time between reinforcements controls responding independently of the number of responses emitted during that time. Further research is, of course, necessary to substantiate this hypothesis and the following areas should be considered:

(1) Blackouts were used as an arbitrary tool to manipulate interreinforcement time and interreinforcement responses. Other methods of response constraint should be used.

(2) The ranges of interreinforcement times and interreinforcement responses used in the present experiment should be extended.

(3) Attempts should be made to specify the significant temporal variable. The present results suggest that the "real time" between reinforcements controlled responding. However, on more complex schedules, the average interreinforcement time may not be the appropriate temporal variable. For example, under multiple schedules in which responding is reinforced in one component and extinguished in the other, response rates in the "reinforcement" component do not decrease as the duration of the extinction component increases, *i.e.*, as interreinforcement time increases (*e.g.*, Morse, 1955). Here, response rates depend primarily on the time spent in the "reinforcement" component alone and not on total interreinforcement time.

(4) Can the interreinforcement intervals under different ratio schedules account for more of the variations in responding than can the value of the ratio? Unfortunately, the published experimental results do not provide sufficient data for such an analysis (see Morse, 1966, p. 84).

(5) In the extensive literature concerning "probability learning" in choice situations (*e.g.*, Estes, 1964), although probability and rate of reinforcement covary, the results are attributed to probability alone. Some studies show that intertrial duration and, therefore, interreinforcement time directly affect choice probabilities (Witte, 1961). Whether interreinforcement time, rather than probability of reinforcement, is the important variable in these cases must be decided by future experiments.

(6) Finally, we should determine whether the relationships obtained in the present work can be obtained when deprivation is decreased, when response effort is increased, or when responses are followed by aversive stimuli.

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