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RESPONSE RATE AS A FUNCTION OF AMOUNT OF REINFORCEMENT FOR A SIGNALLED CONCURRENT RESPONSE[1]

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Pigeons were exposed to two equal, concurrent variable-interval schedules of reinforcement on two response keys. One key was continuously illuminated. Pecking on that key produced reinforcements of constant duration. The other key was normally dark, except that availability of reinforcement was signalled by illuminating the key. The duration of access to a grain reinforcer was varied on the key that signalled reinforcement. Rate of response on the first key, the one that did not signal reinforcement, was found to vary inversely with duration of signalled reinforcement on the other key. The latency between the signal and the peck that produced signalled reinforcement remained about constant. These results show that responding on one key in concurrent variable-interval schedules depends on the reinforcement delivered by both schedules and is independent of responding on the other key.

A pigeon's access to grain reinforcement may be varied by varying the rate of reinforcements, each of fixed duration, or by varying the duration of reinforcements presented at a fixed rate. As Premack (1965) has pointed out, either variable can be expressed as seconds of access to grain per unit time. With two concurrent variable-interval (VI) schedules of reinforcement for key pecking, the pigeon distributes its pecks on the two keys in proportion to its access to reinforcement, varied by either of the two methods. Herrnstein (1961) varied rate of reinforcement and Catania (1963*b*) varied duration.

In other words, the proportion of the total number of pecks a pigeon makes on either key is equal to the proportion of the total reinforcement it receives from that key. If P stands for rate of pecking, A for amount, and R for rate of reinforcement, then

$$\frac{P_1}{P_1 + P_2} = \frac{A_1}{A_1 + A_2}$$

and

$$\frac{P_1}{P_1 + P_2} = \frac{R_1}{R_1 + R_2} \tag{1}$$

where the subscripts 1 and 2 stand for the two keys.

The above equations deal only with the distribution of the pecks on the two keys; they say nothing, by themselves, about the rate of pecking on either key. However, Catania (1963*a*) with concurrent schedules and Herrnstein (1964) with concurrent-chain schedules rather than simple concurrent schedules, have extended equation (1) to account for absolute rate of pecking on either of the keys as a function of rate of reinforcement on the two keys. Premack's (1965) argument that rate and amount of reinforcement are interchangeable would imply that a similar extension could be made for amount. However, the experiments upon which Catania and Herrnstein based their equations varied rate of reinforcement only.

In order to extend equation (1) to absolute rates of pecking, both Catania and Herrnstein assumed that the overall rate of pecking, when summed over both keys, could be a function of the overall reinforcement obtained from both keys but was independent of the particular distribution of reinforcements and responses on the two keys. Within the limits of the particular schedules they used, Catania and Herrnstein found the following functions for overall pecking rate as a function of overall reinforcement rate:

Catania: $$(P_1 + P_2) = K(R_1 + R_2)^{1/6} \tag{2}$$

Herrnstein: $$(P_1 + P_2) = K \tag{3}$$

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Combining (2) and (3) with (1):

$$\text{Catania:} \quad P_1 = \frac{KR_1}{(R_1 + R_2)^{5/6}} \tag{4}$$

$$\text{Herrnstein:} \quad P_1 = \frac{KR_1}{R_1 + R_2} \tag{5}$$

The equations for P_2 are symmetric.

Ignoring for the moment the difference between equations (4) and (5), both equations express rate of responding on one key (P_1) as a function only of the reinforcements on the two keys. According to both (4) and (5), pecking on either key is independent of pecking on the other. Furthermore, if the reinforcement rate on either key is held constant, responding on that key should vary inversely with rate of reinforcement on the other key. In this respect, schedules presented concurrently would be similar to schedules presented successively. Reynolds (1963), for example, found that responding during one component of a multiple schedule was dependent on the rates of reinforcement in both components and was independent of rate of responding in the other component. If it were indeed true that rate of responding in one component of two combined schedules depends on the parameters of the schedules being combined, and not on performance in the other component, the problem of relating performance on multiple schedules to performance on concurrent schedules would be simplified. In a more general sense, the problem of relating simultaneous to successive discrimination would become easier. Since several such attempts are now underway (Herrnstein, personal communication; Nevin, personal communication; Pliskoff, Shull, and Gollub, 1968) it is important to check the validity and generality of the assumption implicit in equations (4) and (5), that rate of responding in either component of concurrent schedules is a function of the independent variables—the reinforcement schedules imposed—and not a function of responding in another component, a variable that is usually beyond the experimenter's control.

Catania (1963*a*) tested this assumption with pigeons by presenting two concurrent variable-interval schedules with a procedure that virtually eliminated responding for one schedule. Each schedule was signalled by a different color of illumination on a single key. The pigeon could change from one schedule to the other by pecking a second key. This procedure has the properties of more conventional concurrent schedules where two schedules are presented on two keys (Findley, 1958). Henceforth, we will refer to the two "keys" of Catania's experiment with the understanding that they consisted of two colors signalling two concurrent schedules on a single key. A 2-sec change-over-delay (COD) in Catania's experiment prevented reinforcement within 2 sec after changing from either key to the other. On one key, reinforcements were presented as with an ordinary variable-interval schedule. On the other key, reinforcements were scheduled also at variable intervals, except that when a reinforcement was scheduled, a signal was presented. The pigeons soon learned to peck on the key that signalled reinforcement only when reinforcement was available. Then Catania varied the rate of reinforcement (the value of the VI) on the key with signalled reinforcement. With the usual concurrent schedules, the pigeon would distribute its pecks proportionally to the relative rate of reinforcement. With reinforcement signalled on one key, however, the pigeons pecked almost exclusively on the key with unsignalled reinforcement, no matter what the relative rates of reinforcement were. Equations (4) and (5) predict that the rate of responding on this key should vary inversely with the rate of reinforcement on the other, just as it would if the bird were pecking at high rates on both keys. Catania's experiment confirmed this prediction. In fact, the variation in response rate on a single key, when reinforcements on the other key were signalled, was the same as when reinforcements on the other key were not signalled.

One objection that could be raised to Catania's (1963*a*) experiment is that while the experiment showed that rate of responding on the key with unsignalled reinforcement does not depend on measured responding on the other key, it still may not depend exclusively on rate of reinforcement on the two keys as stated by equations (4) and (5). Even though the signalling procedure effectively reduces responding on the key that signals reinforcement, there may yet be unmeasured responses on that key, such as orienting or observing responses that vary with the frequency of signals presented on the key. These unmeasured responses could interfere with measured responding on the key with unsignalled reinforcement and reduce the rate of that responding as the frequency of signals on the other key increased. If such orienting or observing responses increased, the latency between the signal and the peck on the key would be expected to decrease. However, Catania (1963*a*) did not measure these latencies. In any case, it is possible that the varied rate of signals in Catania's experiment would interact with any variations in rate of observing response, an interaction that would make latencies difficult to predict.

The present experiment repeated the essential features of Catania's (1963*a*) experiment, except that duration, rather than rate, of signalled reinforcement was varied. The rate of signalled reinforcement was constant throughout, and any increase in attention to the signal by increases in observing or orienting responses would be reflected in reduced latencies between the signal and the peck on the key.

One purpose of the present experiment, then, was to see whether the inverse relation found by Catania (1963*a*) between responding on the key with unsignalled reinforcement and total time of signalled reinforcement holds for a situation where signalled reinforcements are presented at a constant rate. If observing responses, as reflected by latency between the signal and the response, remain constant during the reduction of responding on the key with unsignalled reinforcements, then that reduction in response rate can be ascribed to the direct influence of the duration of the signalled reinforcements.

A second purpose of the present experiment was to extend the assumptions underlying equations (4) and (5) to amount as well as rate of reinforcement. This extension would be further evidence for Premack's (1965) assertion that amount and frequency of reinforcement are interchangeable.

METHOD

Subjects

Four adult male, White Carneaux pigeons were maintained at 80% of free-feeding weight. All were experimentally naive.

Apparatus

The experimental chamber was a modified standard apparatus designed for pigeons (Ferster and Skinner, 1957). Two response keys, mounted 3.5-in. apart, each operable by pecks of a force greater than 15 g, could be transilluminated. The reinforcer was access to a standard grain magazine for various durations.

Procedure

After initial training with the food magazine and the response keys, the subjects were exposed to concurrent 3-min variable-interval schedules of reinforcement that operated separately for each key. There were 14 intervals for each schedule, distributed as in Fleshler and Hoffman (1962). A VI tape that assigned a reinforcement was stopped until the end of the feeder cycle representing that reinforcement. The right key was transilluminated with white light continuously except during reinforcement. The left key was transilluminated by red light only when reinforcement could be produced by a peck on that key. At other times it was dark and inoperative. Thus, the red light signalled immediate availability of reinforcement. To minimize pecks on the key that signalled reinforcement, there was no change-over delay in the present experiment. The daily experimental session lasted 1 hr, during which the pigeon produced about 20 reinforcements for pecks on each key.

The duration of reinforcement produced by pecking the right (unsignalled) key was 4 sec throughout the experiment. The duration of reinforcement produced by pecking the left (signalled) key was also 4 sec for the first 14 days and then was changed every 14 days through two cycles of variation between 1 and 16 sec, returning to 4 sec after each excursion. The entire series of durations (in sec) follows: 4, 1, 4, 16, 4, 1, 4, 16, and 4. Visual observation of a test pigeon revealed that some grain remained in the hopper even after 16 sec of eating.

RESULTS

Responding on the signalled key remained nearly constant throughout the experiment, usually equalling the number of signalled reinforcements (about 20 per session), and occasionally exceeding the number of reinforcements by one or two pecks.

The rates of responding (number of pecks divided by session time excluding time for reinforcements) of three of the four subjects on the unsignalled key varied inversely with duration of reinforcement on the signalled key. For the fourth subject, this inverse relationship was maintained only during the first cycle of reinforcement durations. Figure 1 shows, on logarithmic coordinates, the absolute rates of responding on the unsignalled key as a function of the amount of reinforcement on the signalled key for the four birds for both cycles of reinforcement duration. On the average, the birds weighed about 10 g more at the end of a session where the duration of signalled reinforcement was 16 sec than when duration of signalled reinforcement was 1 sec.

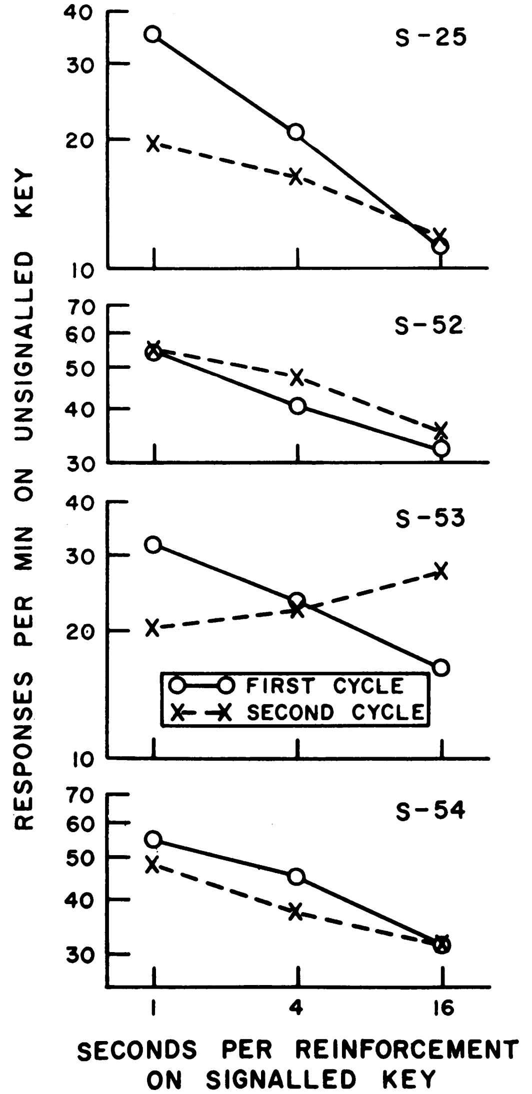

Fig. 1. Rate of responding on the key with unsignalled reinforcement as a function of duration of signalled reinforcement for the four subjects for two cycles of variation between 1 and 16 sec. After each 14-day excursion to either 1 or 16 sec, the subjects were returned for 14 days to the 4-sec value (where reinforcement was equal on the two keys). The response rates for 1 and 16 sec are medians of the last five of 14 sessions at each point. The response rates for 4 sec are averages of all three corresponding five-day medians obtained at 4 sec in each cycle.

The slopes for the first cycle are comparable with those obtained by Catania (1963*a*) where rate rather than duration of reinforcement varied. In both experiments, unsignalled reinforcements lasted 4 sec and occurred on a VI 3-min schedule.

Since rate and duration of reinforcement are both convertible to seconds of access to reinforcement per unit time, rate of responding for unsignalled reinforcement may be plotted in each experiment as a function of seconds of access to signalled reinforcement. Figure 2 shows such a plot. The solid line is the average rate of response on the unsignalled key for the four birds of the present experiment. The dotted line is the average for the three birds of Catania's (1963*a*) experiment. The two lines are quite similar in slope. The heights of the lines, representing the average absolute rates of responding, are virtually identical, although absolute rate varied considerably for individual birds.

In the present experiment, latencies were cumulated on a timer over each session. The timer reading divided by the number of reinforcements on the signalled key gives the aver-

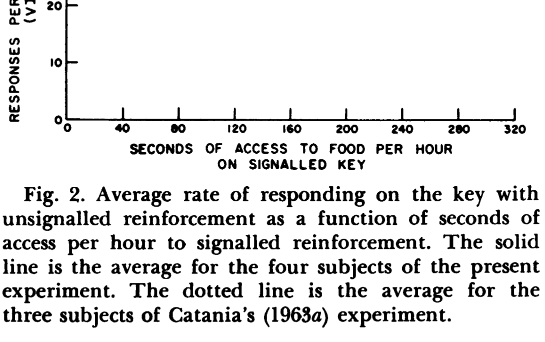

Fig. 2. Average rate of responding on the key with unsignalled reinforcement as a function of seconds of access per hour to signalled reinforcement. The solid line is the average for the four subjects of the present experiment. The dotted line is the average for the three subjects of Catania's (1963*a*) experiment.

age latency for the session. Figure 3 is a scatter plot of latencies of pecking at the signalled key against corresponding rates of response on the unsignalled key for each bird. The circles and squares represent reinforcement durations of 1 and 16 sec, the x's reinforcement durations of 4 sec. Any increase in observing responses would not only interfere with responding for unsignalled reinforcements, but would also decrease the latency of response to the signal. Therefore, low response rates on the key producing unsignalled reinforcement (abscissa values) would be accompanied by short latencies (ordinate values). It is obvious from inspection of Fig. 3 that no such correlation exists. If there is any slope at all to the plots of Fig. 3, it is negative, with low rates on one key accompanied by long latencies on the other.

DISCUSSION

The inverse relationship between responding on one key and reinforcement on the other confirms, generally, both equations (4) and (5), and extends these formulas to duration as well as frequency of reinforcement. The relatively constant latencies for all conditions of the present experiment imply that the variation in responding on the key with unsignalled reinforcement was not the result of more or less interference from observing or orienting responses to the other key. Rather, the constant latencies support the notion, implied by equations (4) and (5), that responding on one key is directly influenced by reinforcement on the other.

To the extent that Fig. 2 distinguishes between equations (4) and (5), equation (4) is supported. Catania (1963*a*) fitted curves to the individual subject data, averaged in Fig. 2, with appropriate values of K in equation (4). Equation (5), however, predicts a steeper slope than that found in Fig. 2.

In the present experiment, almost all the responding was focused on the key with unsignalled reinforcements. Responses on the other key merely operated the hopper. It is natural to ask if the second key was needed to produce the variation in responding on the first. Suppose that in place of the signal used in the present experiment (transillumination

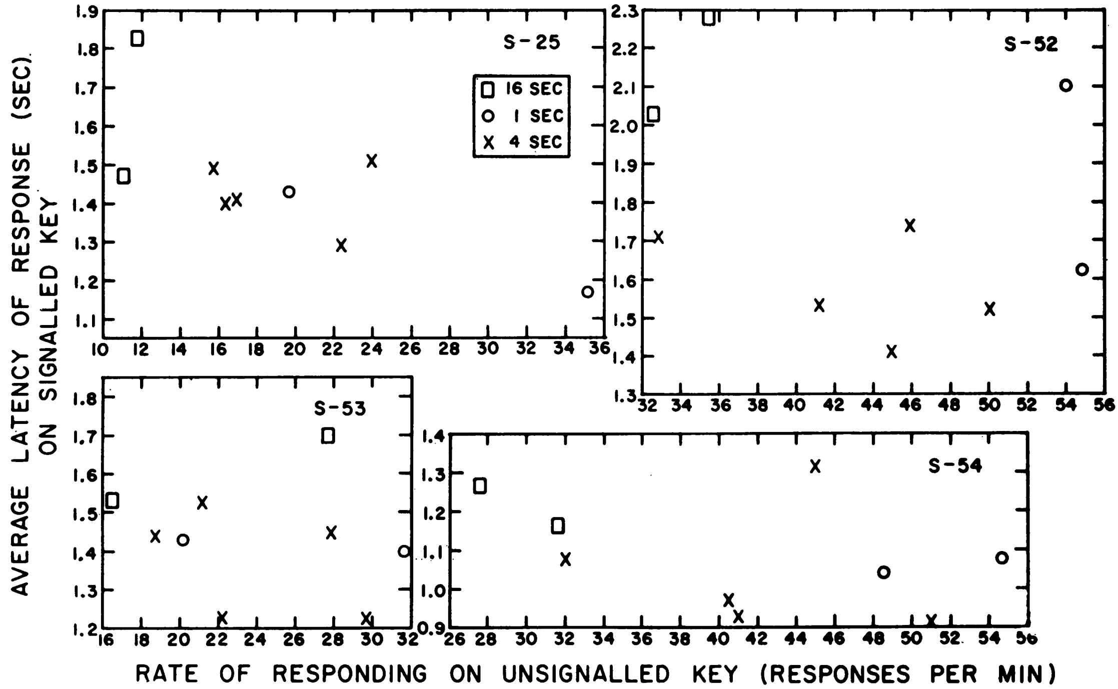

Fig. 3. Scatter plot of latencies of responding on the key with signalled reinforcement and the corresponding rates of responding on the key with unsignalled reinforcement. Each latency and its corresponding rate of response is the median of the last five days at each point. The circles, x's, and squares correspond to signalled reinforcements of 1, 4, and 16 sec.

of a second key) we had signalled reinforcement by changing the color of a single key. Would responding during the unsignalled schedule vary with rate and duration of the signalled reinforcement as it did when the signal was on another key?

Another question raised by the present experiment concerns the function of the signal itself. Suppose, instead of signalling reinforcement on the second schedule, we merely presented response-independent reinforcements according to that schedule along with the ordinary response-dependent reinforcements on a single key. Would responding on that single key vary with the rate and duration of the response-independent reinforcements as it did with the rate and duration of the signalled reinforcements in the present experiment? Further speculation on these points must await appropriate experiments.

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