RELATIVITY OF RESPONSE RATE AND REINFORCEMENT FREQUENCY IN A MULTIPLE SCHEDULE[1]

GEORGE S. REYNOLDS

HARVARD UNIVERSITY

A change in a pigeon's rate of key pecking in one component of a multiple schedule that results from a change in a second component has been called an interaction (Herrnstein & Brady, 1958; Reynolds, 1960). One kind of interaction is called a contrast. As an example, the rate of responding on a *constant* schedule of reinforcement during the presentation of a red key increases when a change in schedule causes a decrease in the rate of responding during the presentation of an alternated green key. However, the increase in rate during red occurs only when the absolute frequency of reinforcement correlated with green decreases (Reynolds, 1960). Thus, the rate of responding during the presentation of red appears to increase as the *relative frequency* of reinforcement associated with red increases, even though the absolute frequency of reinforcement associated with red is constant. The present data show that this relation holds over a wide range of relative frequencies of reinforcement. Moreover, in these data, the *relative rate* of responding on a constant schedule during the presentation of red turns out to approximate a linear function of the relative frequency of reinforcement associated with red.

METHOD

Subjects

Two adult male, White Carneaux pigeons (No. 36 and 37) were maintained at 80% of their free-feeding body weights. Each bird had a history of reinforcement on multiple schedules.

Apparatus

The experimental chamber (Ferster & Skinner, 1953) was enclosed in a modified picnic icebox. A standard response key (0.75 inch in diameter), operated by a force of 20 grams, was mounted on one wall of the chamber. Beneath the key was a 2-inch-square opening through which the pigeon was occasionally given access to grain for 3 seconds. The key could be transilluminated with red or green lights fixed behind it. Two 6-watt white lights illuminated the chamber except during periods of access to grain. White noise masked most extraneous sounds.

Procedure

The procedure consisted of two series of multiple schedules in which the first component was a variable-interval (VI) schedule and the second component was a fixed-ratio (FR) schedule. In the first series, the VI was maintained at a constant value while the FR was varied. In the second series, the FR was maintained at a constant value, while the mean interval of the VI was varied.

Series 1. Pigeons 36 and 37 were reinforced daily on 30 cycles of a two-component multiple schedule. In each cycle the response key was red for 3 minutes and then green for 3 minutes. During the presentation of the red key, responding was always reinforced on a

VI schedule with a mean interval of 3 minutes. During the alternating 3-minute presentations of the green key, the schedule was either FR 75, FR 150, or extinction. Table 1 summarizes the multiple schedules in Series 1 and also gives the number of sessions during which each schedule was in effect. The schedule was changed when the performance appeared stable. After the first 25 sessions, the session length was shortened from 30 to 20 cycles.

Table 1

Multiple Schedules in Series 1

Multiple Schedule		Number of Sessions	
Pigeon 36	Pigeon 37	Pigeon 36	Pigeon 37
VI 3 FR 75	VI 3 FR 75	13	13
VI 3 FR 150	VI 3 FR 150	12	12
VI 3 FR 75	VI 3 FR 75	13	13
VI 3 FR 150	VI 3 FR 150	10	7
VI 3 FR 75	VI 3 Extinction	8	8
VI 3 FR 150	VI 3 FR 150	9	9
VI 3 Extinction	VI 3 Extinction	7	7

When a reinforcement was set up and not collected during one VI component, it was not still available at the start of the next VI component. When only part of a ratio was completed during one FR component, the responses counted toward the first ratio in the next FR component.

Series 2. Pigeon 37 was reinforced daily on 15 cycles of a two-component multiple schedule. During each cycle, the key was red for 3 minutes, and responding was reinforced on a VI schedule. Then, the key was green, and responding was reinforced on an FR 150 schedule. After one FR reinforcement during green, the key color returned to red and the schedule to VI. The value of the FR was constant throughout Series 2. The VI schedule varied: 1.5 minutes, 3 minutes, 6 minutes, and extinction. Table 2 summarizes the multiple schedules in Series 2.

Table 2

Multiple Schedules in Series 2

Multiple Schedule		Number of Sessions
VI 3	FR 150	31
VI 1.5	FR 150	22
VI 6	FR 150	21
VI 3	FR 150	15
VI 6	FR 150	8
Extinction	FR 150	10

In each series, the number of responses and the number of reinforcements in each component of the multiple schedule were recorded. In Series 2, the time to complete the ratio of 150 responses and the time after the onset of the green light to emit the first 5 responses in the ratio were also recorded. This latter time measures the pause in the ratio with minimal confounding by false starts.

<center>RESULTS</center>

In a multiple schedule, the rate of responding on a constant schedule of reinforcement in one component varies when the schedule in the other component is changed. Figure 1 shows that the rate on the VI 3-minute schedule in Series 1 increased as the *relative frequency* of reinforcement in the VI component increased. The various values of relative frequency were obtained by varying the value of the FR schedule with which the VI schedule alternated. Increasing the FR (or extinguishing) decreased the frequency of reinforcement in the FR component of the multiple schedule. Since the same absolute number of reinforcers was always delivered in the VI component, the relative frequency in the VI component increased when the frequency in the FR component decreased. The rate of responding supported by VI 3 minutes increased from 36 to 80 responses per minute. Each point in Fig. 1 (and in all the others) is based on averaged data from the last four sessions on a given multiple schedule.
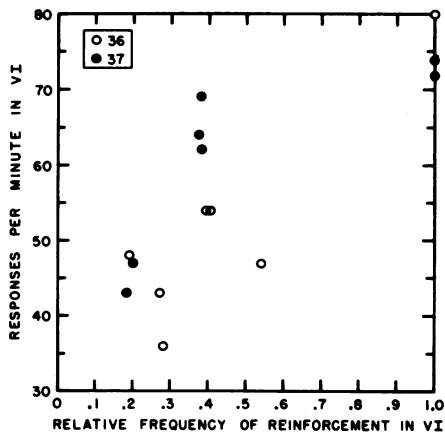

Figure 1. Rate of responding in a VI 3-minute component of a multiple schedule in Series 1 as a function of the relative frequency of reinforcement in that component. A constant VI 3 minutes is alternated with FR 75, FR 150, or extinction.

Figure 2a shows that the rate of responding generated by FR 150 in Series 2 also increased as the relative frequency of reinforcement in the FR component increased. The range of rates for the one pigeon in this procedure was from 79 to 112 responses per minute. The relative frequency of reinforcement in the FR component increased when the mean interval of the VI in the other component became longer. Figure 2b shows that a systematic decrease in the pause at the start of each ratio component accounts for some of the increase in rate on FR 150 (*cf.* Schuster, 1959). The average value of the pause shortens from 40 seconds to 17 seconds as the relative frequency of reinforcement in the ratio component

increases from 0.35 to 1.0. The remainder of the increase in rate in Fig. 2a is due to increases in the terminal rate in the ratio.

The rate of responding varied in the component in which the schedule of reinforcement varied. Figure 3a shows that the rate in the FR component in Series 1 is a generally increasing function of the absolute rate of reinforcement in that component. The ordinate at zero represents the rate of responding in extinction. Figure 3b shows that for Pigeon 37 the rate maintained by VI in a VI FR multiple schedule is a generally increasing function of the rate of reinforcement. The crosses in Fig. 3b give the mean rates of responding (two pigeons) after more than a month of performance on different VI schedules in *isolation* (replotted from Herrnstein, 1955).

A simple summary of the data from both series of procedures is obtained by considering the *relative rate* of responding in the constant component as a function of the relative frequency of reinforcement in that component. Figure 4 shows that this function approximates a straight line over a range of relative reinforcement frequencies from 0.18 to 1.0. The slope of the line is 0.8 and the intercept is 0.13 (least-squares fit). The open and filled circles in Fig. 4 show the data from the constant VI 3-minute component for Pigeons 36 and 37 in Series 1. The filled triangles give the data from the constant FR 150 component for Pigeon 37 in Series 2. In each case the ordinate is the rate of responding in the constant
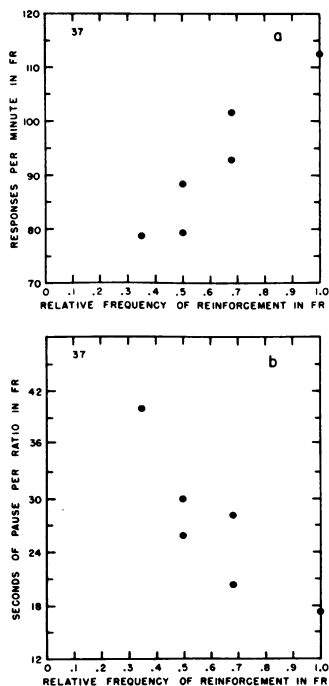

Figure 2. Rate of responding (a) and pause (b) in an FR 150 component of a multiple schedule in Series 2 as a function of the relative frequency of reinforcement in that component. A constant FR 150 is alternated with VI 3 minutes, 6 minutes, 1.5 minutes, or extinction.
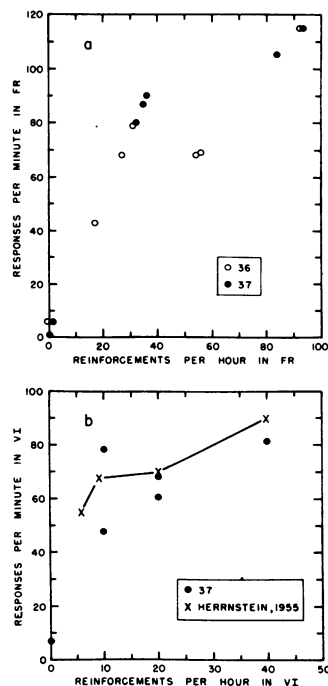
Figure 3. Rate of responding on (a) a variable FR in Series 1 and (b) a variable VI in Series 2 as functions of the absolute rate of reinforcement. The crosses in 3b give the rates maintained by VI's in isolation (from Herrnstein, 1955).
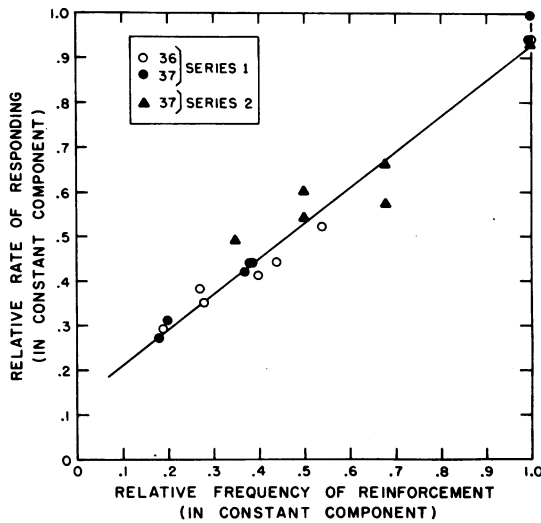
Figure 4. Relative rate of responding in one component of a VI FR multiple schedule as a function of the relative frequency of reinforcement in that component.

component divided by the sum of the rates from each component. The abscissa is the number of reinforcements in the constant component divided by the total reinforcement frequency in both components. The present birds divide their responding between the constant and variable components proportional to the relative frequency of reinforcement in each component.

DISCUSSION

One type of function in the results (Fig. 1 and 2a) shows that the rate of responding on a constant VI or FR schedule in one component of a multiple schedule increases as the relative frequency of reinforcement in that component increases. Two of the points in each of these functions represent an effect that has been called "behavioral contrast" (*cf.* Reynolds, 1960; Skinner, 1938). Contrast is usually produced as a by-product of a discrimination procedure (*e.g.*, Smith & Hoy, 1954). The rate in a constant component increases when the other component becomes extinction, and the relative reinforcement frequency in the constant component increases to a value of 1.0. Figures 1 and 2a show that contrast is produced in a constant component by any increase in the relative frequency of reinforcement.

The form of the present function relating rate and frequency of reinforcement on a VI (Fig. 3b, filled circles), though obtained in a multiple schedule, closely resembles the form of the function for VI schedules obtained in isolation (crosses in Fig. 3b, replotted from Herrnstein, 1955). This fact suggests that the VI schedules are independent of the constant FR with which they alternate, even though the rate of responding on the FR varies from 79 to 112 responses per minute (Fig. 2a). (In the absence of data from pigeons reinforced on varying values of FR in isolation, it is only speculation that the FR function in Fig. 3a is independent of the constant VI 3 minutes with which the FR alternated.)

Once the independent VI function is given, the form of the behavioral contrast function (Fig. 2a) is determined by the relativity law expressed in Fig. 4. Two characteristics of this

function are of interest. It does not pass through the origin. The relative frequency of re-sponding in the constant VI or FR component will not take on a value of zero because each of these schedules will always maintain some responding even at very high frequencies of reinforcement in the other component. This is a reasonable assumption, since the multiple-schedule procedure forces the pigeon to remain in the presence of the stimulus correlated with the constant schedule throughout every other 3-minute period. However, the function in Fig. 4 could pass through the point (1,1) if the rate of responding in the variable com-ponent became zero during extinction. But this rarely occurs, especially when the alter-nated schedule is a VI (Morse, 1955; Reynolds, 1960). Induction from the constant com-ponent and maintenance of some responding by the constant schedule keep the slope of the curve in Fig. 4 less than 1.0 and the intercept a positive value rather than zero. Therefore, the pigeons cannot exactly *match* the relative frequency of reinforcement with the relative frequency of their responding in a multiple schedule when one component is held constant. They succeed only in maintaining a proportionality between these two variables.

SUMMARY

Pigeons were reinforced on two series of VI FR multiple schedules. In Series 1, VI 3 minutes was alternated with FR 75, FR 150, and extinction. In Series 2, FR 150 was alternated with VI 1.5 minutes, VI 3 minutes, VI 6 minutes, and extinction.

The rate of responding in the constant component (VI in Series 1, FR in Series 2) in-creased as the relative frequency of reinforcement in that component increased. The rate in the variable component (FR in Series 1, VI in Series 2) increased as the absolute frequency of reinforcement in that component increased. The shape of this function for VI was similar to the shape of the same function obtained with VI schedules in isolation. The relative rate of responding in the constant component approximated a linear function with a positive slope and intercept of the relative frequency of reinforcement in that component, even though the absolute frequency of reinforcement in that component was constant.

REFERENCES

Ferster, C. B., and Skinner, B. F. *Schedules of reinforcement.* New York: Appleton-Century-Crofts, 1957.

Herrnstein, R. J. Behavioral consequences of the removal of a discriminative stimulus. Unpublished doctoral dis-sertation, Harvard Univer., 1955.

Herrnstein, R. J., and Brady, J. V. Interactions among components of a multiple schedule. *J. exp. anal. Behav.,* 1958, 1, 293–301.

Morse, W. H. An analysis of responding in the presence of a stimulus correlated with periods of non-reinforce-ment. Unpublished doctoral dissertation, Harvard Univer., 1955.

Reynolds, G. S. An analysis of interactions in a multiple schedule. Unpublished doctoral dissertation, Harvard Univer., 1960.

Schuster, C. Response latencies as a measure of the interaction of components on a multiple fixed-ratio schedule. *J. exp. anal. Behav.,* 1959, 2, 259 (Abstract).

Skinner, B. F. *Behavior of organisms.* New York: Appleton Century Co., 1938.

Smith, M. H., and Hoy, W. J. Rate of response during operant discrimination. *J. exp. Psychol.,* 1954, 48, 259–264.