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A COMPARISON OF VARIABLE-RATIO AND VARIABLE-INTERVAL SCHEDULES OF REINFORCEMENT[1]

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Four pigeons responded under a two-component multiple schedule of reinforcement. Responses were reinforced in one component under a variable-ratio schedule and in the other component under a variable-interval schedule. It was found that when rates of reinforcement were equal in the two components, the rate of response in the variable-ratio component was nearly twice that in the variable-interval component. Furthermore, for three of the four subjects, the function relating response rate to relative rate of reinforcement in the variable-ratio component had a slope 2.5 to 3 times the slope of the corresponding function for the variable-interval component.

A basic finding in the study of schedules of reinforcement is that over a wide range of reinforcement frequencies, ratio schedules of reinforcement generate higher rates of response than do interval schedules (Skinner, 1938; Anger, 1956; Malott and Cumming, 1964; Reynolds, 1968). The purpose of the present experiment was to study this difference in response rate between ratio and interval schedules of reinforcement and to formulate a quantitative description of it.

One way to compare behavior under the two schedules is to present an organism with two operanda and to reinforce responses to one under a ratio schedule and responses to the other under an interval schedule. Such a concurrent schedule was investigated by Ferster and Skinner (1957, pp. 705-708) and Catania (1963; 1966, pp. 231-234). However, in these studies frequencies of reinforcement under the two schedules were not equal, and differences in response rate could be attributed either to differences in the contingency or to differences in the frequency of reinforcement.

In a second method, the frequency of reinforcement is equated by the use of a yoked-box procedure (Ferster and Skinner, 1957, pp. 399-407; Killeen, 1969). In these studies, two birds were placed in separate experimental chambers. The first bird's responses were reinforced under a ratio schedule. Whenever a response by the first bird was reinforced, the next response of the second bird would be reinforced. Thus, responding by the first bird was under a ratio schedule while that of the second bird was under an interval schedule, the value of which was determined by the behavior of the first bird. Furthermore, given that the second bird responded at a moderate rate, the frequency of reinforcement would be the same for the two birds. In these studies, the subjects under the ratio schedule responded 1.2 to 3.3 times as rapidly as did the subjects under the interval schedule. However, this finding is limited to those cases in which rates of reinforcement are equal under the two schedules.

A third procedure to compare ratio and interval schedules—the one used in the present experiment—is to alternate the two schedules in a multiple schedule. Multiple schedules in which the schedule in one component was a ratio schedule and the schedule in the other component was an interval schedule were studied by Ferster and Skinner (1957, pp. 503-510), Reynolds (1961), Thompson (1965), and Bloomfield (1967). However, except for the Reynolds (1961) study discussed below, none of these provides data from which quantitative comparisons can be drawn between response rates under the two schedules as rate of reinforcement varies.

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METHOD

Subjects

Four adult, male, White Carneaux pigeons, 275, 456, 258, and 470, were kept at approximately 80% of their free-feeding weights throughout the experiment. All subjects had varied experimental histories that included exposure to ratio and interval schedules.

Apparatus

A standard operant conditioning experimental chamber for pigeons contained one response key and a houselight. The response key could be transilluminated by either a red or a green light. During reinforcement (approximately 4-sec access to mixed grain), the keylight was extinguished and the feeder illuminated.

Procedure

The schedule of stimulus presentation consisted of 1-min periods in which the key was red, alternating with 1-min periods in which it was green. For Subjects 275 and 456, responses were reinforced under a variable-interval schedule (VI) when the key was red and under a variable-ratio schedule (VR) when the key was green; the opposite was true for Subjects 258 and 470.

A reinforcement primed but not obtained during one stimulus condition was held over until the same stimulus condition recurred. The subject began each stimulus condition at the point in the schedule where it had left off during the previous exposure to that stimulus.

The values of VR used were: VR 7, 25, 50, 75, 100, 150, and 300. The VI schedules were: VI 15-sec, VI 30-sec, VI 90-sec, VI 180-sec. Except for the VR 7 and the VR 300, the schedules were constructed in the following manner: let m equal the mean of the intervals in the schedule, in seconds for VI and in number of responses for VR. Then the intervals of the schedule in order were: 0.10 m, 1.60 m, 0.80 m, 1.00 m, 0.04 m, 1.20 m, 1.00 m, 1.96 m, 0.40 m, and 1.90 m. For example, for VR 50, the intervals were: 5, 80, 40, 50, 2, 60, 50, 98, 20, and 95.

Sessions ended when 40 reinforcements had been delivered. The subjects were given one session a day, at approximately the same time each day, six days a week.

A particular multiple schedule remained in force until behavior stabilized. The criterion for a stable performance was as follows: after a subject responded for five sessions under a particular multiple schedule, the first five sessions in which each of the daily relative rates of response in one of the components (*i.e.*, the rate of response in one of the components divided by the sum of the rates in the two components) fell within a range 0.05 wide was taken as stable performance. Thus, there was a minimum of 10 sessions on each multiple schedule but no maximum.

Table 1 gives the order of schedules for each subject and the number of sessions for each schedule. In one series, the VI was held constant at VI 30-sec and the VR value was varied (Series 1), and in the other series the VR was held constant at VR 100, and the VI was varied (Series 2).

RESULTS

Table 1 presents the absolute rate of response in each component of each multiple schedule. Response rate was defined as the total number of responses in a session emitted during a component divided by the total time spent in that component, excluding time during reinforcement. The data represent the medians of the last five sessions under each multiple schedule.

Figure 1 presents the relative rate of response in the VR component, *i.e.*, rate of response in the VR component divided by the sum of the rates of response in the two components, as a function of the relative rate of reinforcement in the VR component, *i.e.*, rate of reinforcement in the VR component divided by the sum of the rates of reinforcement in the two components. Rate of reinforcement was defined as number of reinforcements per unit time, excluding time during reinforcement. The data are the medians of the last five sessions under each multiple schedule. The 45° line represents the function that would be obtained if relative rate of response equaled the relative rate of reinforcement (matching).

At 0.5 on the abscissa of Fig. 1, the rates of reinforcement in the two components are equal. At this point, the relative rate of response is between approximately 0.61 and 0.65. If the response rate in the VR component were twice that in the VI component, the relative rate of response in the VR com-

Table 1

The order of multiple schedules for each subject, the number of sessions under each, the rate of response in the VI component, and the rate of response in the VR component.

Subject	VI in sec	VR	Sessions	res/min VI	res/min VR
275					
Series 1	30	50	16	66	104
	30	100	22	67	118
	30	150	33	77	57
	30	25	14	47	165
	30	75	17	73	119
	30	7	11	50	184
Series 2	180	100	23	54	155
	90	100	11	67	157
	15	100	30	90	77
258					
Series 1	30	75	22	72	108
	30	25	10	44	167
	30	50	11	58	125
	30	100	34	74	84
	30	150	39	68	77
Series 2	30	100	18	76	114
	180	100	25	48	166
456					
Series 1	30	25	12	45	160
	30	150	11	66	51
	30	100	19	62	62
	30	75	20	58	78
	30	50	10	46	85
	30	7	13	24	168
	30	300	39	66	1
Series 2	90	100	27	64	100
	180	100	24	47	76
	15	100	10	81	0
470					
Series 1	30	150	13	110	48
	30	75	14	75	82
	30	50	13	57	104
	30	25	10	63	100
	30	100	25	95	90
Series 2	30	100	10	89	84
	15	100	20	103	68
	180	100	15	75	102
	90	100	23	80	119

ponent would be 0.666. Thus, the obtained value implies that when the rates of reinforcement in the two components are equal, the rate of response in the VR component is nearly twice the rate of response in the VI component. The comparable value in Reynolds' (1961) study is between 0.55 and 0.60.

At 0.5 on the ordinate of Fig. 1, the response rates in the two components are equal. This point corresponds on the abscissa to approximately 0.25 to 0.33. If the rate of reinforcement in the VI component were twice that in the VR component, the relative rate of reinforcement in the VR component would be 0.333. Thus, the obtained value implies that the rates of response are equal under the two schedules when the rate of reinforcement in the VI component is more than twice that in the VR component.

The function in Fig. 1 passes through the upper left quadrant, *i.e.*, the area bounded by 0 and 0.5 on the abscissa, and 0.5 and 1.0 on the ordinate. All points in this quadrant represent performances in which the subject responds in the VR component at a rate equal to or greater than the rate in the VI component, although the rate of reinforcement in the VR component is equal to or less than the rate of reinforcement in the VI component. The function is asymmetrical in that it does not pass through the lower right quadrant.

The function in Fig. 1 is above the matching line from 0 to approximately 0.6 to 0.8 on the abscissa, at which point it intersects the line and above 0.8 remains below it. Therefore, for most of the function, the relative rate of response in the VR component is greater

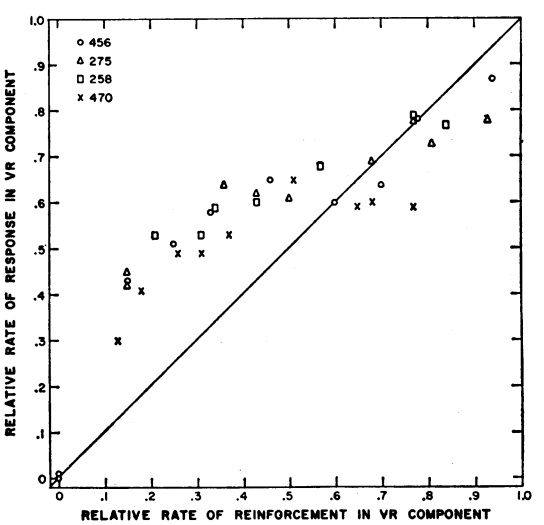

Fig. 1. Relative rate of response in the VR component (rate of response in the VR component divided by the sum of the rates of response in both components) as a function of the relative rate of reinforcement in the VR component (the rate of reinforcement in the VR component divided by the sum of the rates of reinforcement in both components). The diagonal line is the function that would be obtained if the relative rate of response equaled the relative rate of reinforcement.

than the relative rate of reinforcement in the VR component, implying that the relative rate of response in the VI component is less than the relative rate of reinforcement in the VI component. Above 0.8 this relationship is reversed. Although Reynolds (1961) reports too few data points to judge with certainty, it appears that the relationships between the function in Fig. 1 and the matching function are qualitatively similar to those obtained in his study.

Another data treatment, suggested by Reynolds' (1961) and Nevin's (1968) analyses of multiple schedules, is presented in Fig. 2. Figure 2 presents absolute rate of response in a component, C, as a function of relative rate of reinforcement in component C. Two functions are presented for each subject; one with C as the VR component and one with C as the VI component. The open points were obtained when component C was held constant and the other component was varied. The closed points were obtained when component C was varied and the other component was held constant. Since the values of both variables in Fig. 2 are dependent on the subject's behavior, the straight lines were fitted to the points by a method that minimizes the perpendicular distance of the obtained points to the fitted line (Kenney, 1947, p. 147).

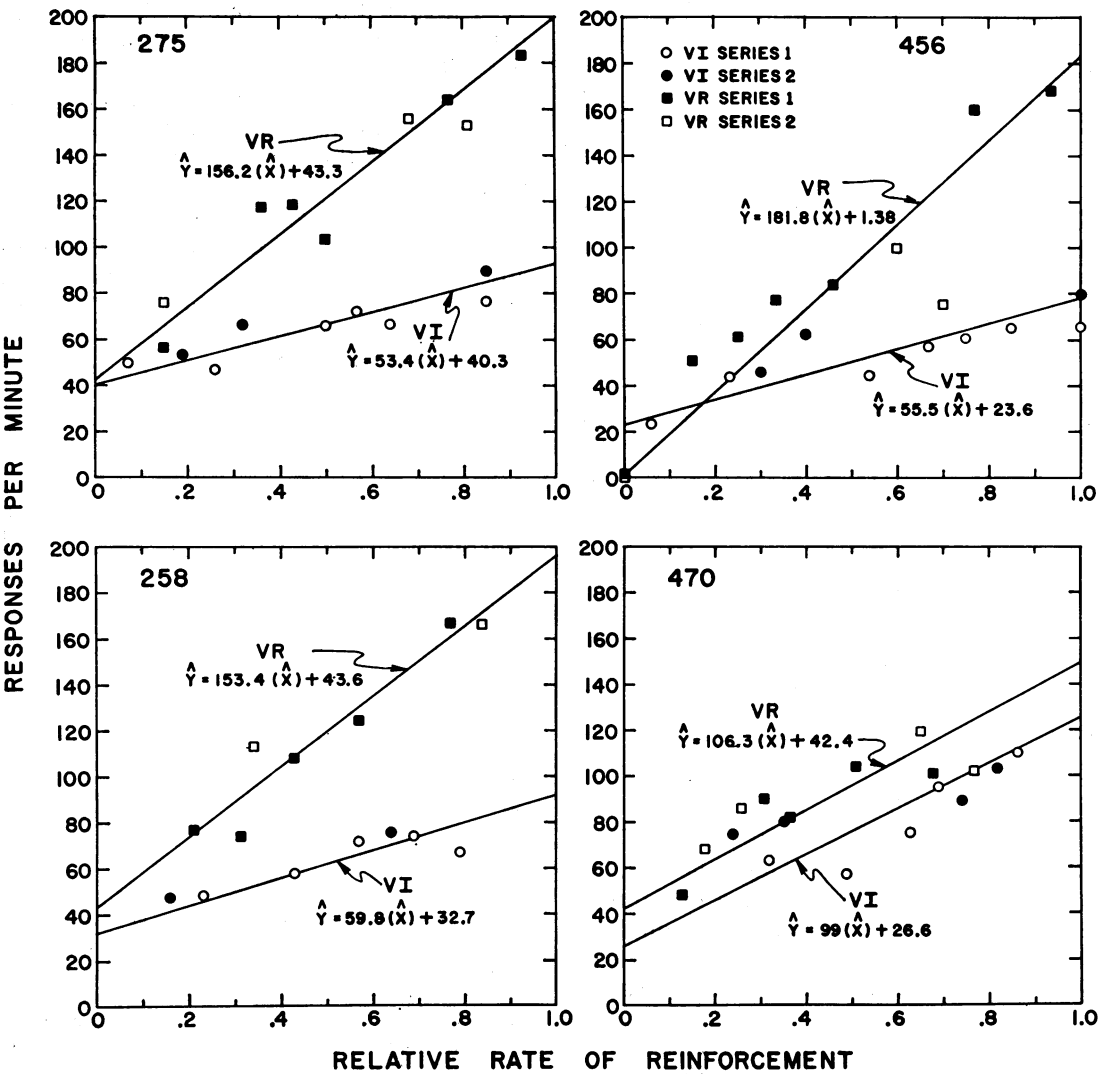

Fig. 2. Response rate as a function of the relative rate of reinforcement (rate of reinforcement in a component divided by the sum of the rates in the two components). One function is presented for the VI component and one for the VR component. The method for fitting the lines to the points is discussed in the text.

The open points and the closed points seem to fall along the same function. This implies that for the range of values used, a given relative rate of reinforcement determines a unique response rate, even though there are many combinations of absolute rates of reinforcement that yield that relative reinforcement rate.

For all four subjects, the function for the VR component is above that for the VI component. Moreover, with the exception of Subject 470, the slope of the function for VR is about 2.5 to 3 times the slope of the function for VI. For Subject 470, the functions are nearly parallel.

If the VI schedule remains constant, and the rate of reinforcement in the VR component increases, by definition, the relative rate of reinforcement in the VI component decreases. Therefore, Fig. 2 indicates that if the rate of reinforcement in the VI component remains constant, and the rate of reinforcement in the VR component increases, the rate of response in the VI component decreases. This is an example of "behavioral contrast" in the sense that response rate in one component changes in a direction opposite from the change in the rate of reinforcement in the other component (Bloomfield, 1967; Wilton and Gay, 1969).

DISCUSSION

In a wide variety of experiments with concurrent schedules, it has been found that relative rate of response equals relative rate of reinforcement (Autor, 1960; Herrnstein, 1961; 1964). With multiple schedules, on the other hand, this matching function is not obtained (Reynolds, 1963; Lander and Irwin, 1968). It is therefore not unexpected that the function in Fig. 1 is not the matching function.

Nevertheless, the use of the multiple schedule will not account for all the deviation from matching. The functions obtained by Reynolds (1963) and Lander and Irwin (1968), both with multiple variable-interval variable-interval schedules, are symmetrical around the point (0.5, 0.5) with respect to the matching line. That is, their functions from 0 to 0.5 on either axis deviate from matching to the same degree that the functions from 0.5 to 1.0 deviate from matching, but in the opposite direction.

In contrast, the function in Fig. 1 is asymmetrical with respect to the matching line, and most of the function is above it. This asymmetry is attributable to the asymmetry in the schedules used. The VR schedule generates higher rates of response than does the VI schedule, resulting in an asymmetry with a bias in favor of the VR schedule. This asymmetry is one measure of the difference between response rates under the two schedules.

A clearer measure of the difference between response rates under the VR schedule and the VI schedule is presented in Fig. 2 which plots response rate as a function of the relative rate of reinforcement. Except for Subject 470, the slope of the function for the VR schedule is about 2.5 to 3 times the slope of the function for the VI schedule. The slope is important because, in a sense, it is the "conversion factor" that transforms a given level of reinforcement into a response rate. It represents the effects on response rate of the contingencies inherent in a schedule, independent of the frequency of reinforcement. Thus, the difference found in the present study between the contingencies of reinforcement in a VR schedule and those in a VI schedule can be stated briefly: for a given change in relative rate of reinforcement ΔR, a VR schedule will transform this change into a change in response rate that is 2.5 to 3 times the transformation produced by a VI schedule for the same ΔR.

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