

*MATCHING TO RELATIVE REINFORCEMENT
FREQUENCY IN MULTIPLE SCHEDULES WITH A
SHORT COMPONENT DURATION¹*

CHARLES P. SHIMP AND KIMBAL L. WHEATLEY

UNIVERSITY OF UTAH

Three pigeons performed on two-component multiple variable-interval variable-interval schedules of reinforcement. There were two independent variables: component duration and the relative frequency of reinforcement in a component. The component duration, which was always the same in both components, was varied over experimental conditions from 2 to 180 sec. Over these conditions, the relative frequency of reinforcement in a component was either 0.2 or 0.8 (± 0.03). As the component duration was shortened, the relative frequency of responding in a component approached a value equal to the relative frequency of reinforcement in that component. When the relative frequency of reinforcement was varied over conditions in which the component duration was fixed at 5 sec, the relative frequency of responding in a component closely approximated the relative frequency of reinforcement in that component. That is, the familiar matching relationship, obtained previously only with concurrent schedules, was obtained in multiple schedules with a short component duration.

The function relating the relative frequency of responding to the relative frequency of reinforcement is different for multiple variable-interval variable-interval (*mult VI VI*) and concurrent variable-interval variable-interval (*conc VI VI*) reinforcement schedules. In multiple schedules, this function is approximately linear for relative reinforcement frequencies between 0.2 and 0.8 and has a slope of roughly 0.4 and a y-intercept of, roughly, 0.3 or 0.4. (See Fig. 3a in Reynolds, 1963, and Fig. 2 in Lander and Irwin, 1968. Reynolds' data have been re-plotted elsewhere to show clearly the individual behavior. See Fig. 13 in Herrnstein, 1970, and Fig. 3 in Lander and Irwin, 1968.) In concurrent schedules, on the other hand, this function not only is linear over the entire range of relative reinforcement frequencies from 0.0 to 1.0, but it has a slope of 1.0 and a y-intercept of 0.0 (Herrnstein, 1961).

One wonders why these functions are different. One procedural difference immediately comes to mind. In multiple schedules, the experimenter controls component duration, which he often sets to a value measured in

minutes. Three minutes is a particularly common component duration (Lander and Irwin, 1968; Reynolds, 1963). However, in concurrent schedules, the subject itself can be said to switch components and the time the subject spends in a component often is only a few seconds.

Therefore, the present experiment was designed to investigate the effect of component duration in multiple schedules on the function between relative frequency of responding and relative frequency of reinforcement. It was anticipated that a multiple schedule with a component duration of the same order of magnitude as that ordinarily found in concurrent schedules might produce behavior more like that found in concurrent schedules. Specifically, if the component duration in a multiple schedule were shortened from a few minutes to a few seconds, the relative frequency of responding in a component might shift towards a value more nearly equal to the relative frequency of reinforcement in that component.

METHOD

Subjects

Three White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. They had been used previously

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in an experiment in which three interresponse times were concurrently reinforced on a single white key.

Apparatus

Electromechanical relay circuitry arranged stimuli and reinforcements and responses were recorded on electromechanical counters. White noise helped to mask extraneous sounds. The experimental chamber was a Lehigh Valley Electronics two-key pigeon chamber in which only the right key was used.

Procedure

The reinforcement schedule was a two-component multiple variable-interval variable-interval (*mult VI VI*).

VI schedule. A separate VI schedule was associated with each component. The probability of reinforcement was independent of time-since-reinforcement in both schedules, which were constant reinforcement-per-opportunity VI schedules (Catania and Reynolds, 1968; Farmer, 1963). In such a schedule, there is a probability, p , of a reinforcement assignment every t sec. Frequently, this arrangement applies only to post-reinforcement times that are not too long. At long post-reinforcement times, the probability p increases when the VI is scheduled by a finite, punched tape. In the present experiment, this increase was avoided by replacing the punched tape by an electronic timer to produce the t -sec intervals and a probability generator to produce the probability p . That is, every t sec, an output pulse from the electronic timer queried the probability generator as to whether or not to assign a reinforcement. The electronic timer for a schedule ran all the time, but queried the probability generator only when that schedule was in effect. Therefore, a reinforcement could not be assigned to a component while the other component was in effect. That is, each VI schedule could arrange reinforcements only when its associated keylight was on. Both parameters, that is p and t , could be varied independently for each VI. There was an unlimited hold on each VI schedule: once arranged, a reinforcement was held until it was collected. The reinforcer consisted of 2-sec access to mixed grain.

Stimuli. During one component, the key was red; during the other, it was green. A house-light provided additional illumination except

during reinforcement, when both it and the keylight were turned off. Both the keylight and the houselight were turned off for approximately 40 millisecc after a response to provide some visual feedback.

Component alternation. The red and green components alternated and were always of the same duration. However, if the feeder was operated during what otherwise would have been the start of a new component, the new component did not begin until the end of that reinforcement. The presentation of a reinforcement in a component reduced the time during which a pigeon could respond in that component by at most 2 sec and had no effect on the corresponding time in the other component. Therefore, when more reinforcements were delivered in, say the red component than in the green component, the total time in the red component (minus reinforcement time) tended to be a little less than the corresponding time in the green component. However, the percentage of the session duration taken up by either component was always near 0.50, since reinforcement time was only a small fraction of the session duration. (Also, the components alternated so that the number of presentations of one component could not differ from the number of presentations of the other by more than plus or minus one.)

Other contingencies. A 1-sec changeover delay prevented reinforcement for the first second in each component. It prevented terminal responses in a short burst of responses from initiating reinforcement in a component different from the one in effect when the response burst started.

When a reinforcement was assigned in a component, but not collected, it was not cancelled; *i.e.*, it was again available when that component next appeared. Uncollected reinforcements are sometimes cancelled in multiple schedules (*e.g.*, Reynolds, 1963), but the present authors, like Lander and Irwin (1968), required every scheduled reinforcement to be collected. Unlike Lander and Irwin, however, we could not extend the duration of a component until a reinforcement was collected.

Subjects were run six days a week.

Experimental conditions. Table 1 shows the component durations and the values of p and t for both components in each experimental condition. Conditions 1 and 2 were conducted

Table 1
Experimental Conditions

Conditions	No. Days	Component Duration (sec)	Session Duration (min)	Parameters t (sec) - p		Equivalent VI Schedules	
				Red	Green	Red	Green
1	6	30	50	3-0.05	3-0.05	VI 1-min	VI 1-min
2	11	60	50	3-0.05	3-0.05	VI 1-min	VI 1-min
3*	17	180	42	10-0.05	3-0.05	VI 3.3-min	VI 1-min
4	10	60	48	10-0.05	3-0.05	VI 3.3-min	VI 1-min
5	6	10	48	3-0.01	3-0.05	VI 5-min	VI 1-min
6	8	5	60	3-0.01	3-0.05	VI 5-min	VI 1-min
7	22	10	60	3-0.05	3-0.01	VI 1-min	VI 5-min
8	9	180	60	3-0.05	3-0.01	VI 1-min	VI 5-min
9	5	5	60	3-0.05	3-0.0125	VI 1-min	VI 4-min
10	8	30	60	3-0.05	3-0.0125	VI 1-min	VI 4-min
11	9	2	60	3-0.05	3-0.0125	VI 1-min	VI 4-min
12	21	2	60	3-0.0125	3-0.05	VI 4-min	VI 1-min
13	10	5	60	3-0.0125	3-0.05	VI 4-min	VI 1-min
14	10	5	60	3-0.025	3-0.05	VI 2-min	VI 1-min
15	12	5	60	3-0.005	3-0.05	VI 9-min	VI 1-min

*Between Conditions 2 and 3 were four other conditions conducted for reasons irrelevant to the present experiment.

to determine if there were any color preferences. Conditions 3 to 13 were given to determine if, for a relative frequency of reinforcement in the red component of either 0.2 or 0.8, the relative frequency of responding in that component depended on the component duration when it was varied from 2 to 180 sec. Conditions 14 and 15 were conducted to specify further the dependency of the relative frequency of responding in a component on the relative frequency of reinforcement in that component, when the component duration was 5 sec.

A session was terminated when a predetermined number of minutes had elapsed. As Table 1 shows, session durations varied over the first few experimental conditions. This variation was a practical necessity because the apparatus was in daily use for other experiments and seems to have had no effect on the present data. Also, as the last two columns of Table 1 indicate, the scheduled relative frequency of reinforcement in the component with the greater relative frequency of reinforcement varied from 0.83 (Conditions 5 to 8), to 0.77 (Conditions 3 and 4). Otherwise, the scheduled relative frequency of reinforcement in that component was 0.80. This variation of ± 0.03 in the scheduled relative frequency of reinforcement seems to have had no effect on the present data. (As column 2 of Table 2 shows, the average variation in the obtained relative frequency of reinforcement was only ± 0.02 .)

As may be noted in Table 1, the component with the greater relative frequency of reinforcement was signalled sometimes by a red and sometimes by a green keylight.

An experimental condition was terminated when the relative frequency of responding in a component, plotted against days, looked stable for three or four days.

RESULTS

Table 2 shows the number of responses per minute (corrected for reinforcement times) in both components on each of the last two days of each condition. The number of responses per minute in a component was calculated by dividing the total number of responses in that component by the time during which that component was in effect. The time during which a particular component was in effect was recorded by an elapsed time meter that ran whenever the stimulus for that component was lit. Thus, reinforcement time was excluded from this calculation. Table 2 also shows the number of reinforcements in both components on each of these same days, and the obtained relative frequency of reinforcements in the red component, averaged over the three birds and all days of the condition. (By "relative frequency of reinforcement in the red component," we mean the relative number of reinforcements in the red component computed from the frequencies in Table 2.) The relative

Table 2
Response Rate and Number of Reinforcements

Condition	Obtained Relative Frequency of Reinforcement in Red Component (Over Entire Condition)	Number of Reinforcements on Last Two Days						Responses per Minute (Corrected for Feeder Time) on Last Two Days of Each Condition					
		Bird 13		Bird 15		Bird 20		Bird 13		Bird 15		Bird 20	
		Red	Green	Red	Green	Red	Green	Red	Green	Red	Green	Red	Green
1	0.47	30	28	24	29	29	24	24.8	29.0	18.2	18.7	26.7	24.9
		21	22	32	25	17	18	19.9	26.2	20.4	22.6	18.0	16.2
2	0.50	24	29	40	20	19	21	27.4	25.6	25.9	25.7	35.7	33.0
		20	23	20	23	29	28	33.8	32.9	25.8	22.8	29.7	28.7
3	0.20	6	15	3	29	7	23	32.7	68.6	16.4	21.5	21.3	46.6
		6	24	7	25	8	26	33.1	70.2	15.9	17.9	29.0	51.2
4	0.20	5	25	4	18	3	19	14.6	66.7	23.8	35.6	16.8	61.1
		5	27	10	25	10	29	19.5	50.0	19.9	33.8	24.2	54.8
5	0.22	10	13	9	22	16	23	22.8	74.5	11.5	16.8	20.5	74.8
		8	26	7	25	10	25	24.0	88.3	46.3	58.6	27.5	76.6
6	0.20	5	62	7	23	8	32	21.6	91.5	12.0	53.1	19.0	72.4
		12	52	6	56	3	49	22.1	113.0	22.6	71.9	17.8	115.5
7	0.81	31	4	24	9	28	5	66.4	26.3	64.3	20.4	85.7	22.5
		27	8	28	5	33	12	67.3	27.4	47.7	16.4	88.3	20.5
8	0.82	36	6	29	9	30	3	78.3	33.9	35.3	24.2	60.6	22.2
		44	5	21	5	29	4	94.7	32.8	30.0	23.3	62.0	19.8
9	0.82	40	8	32	9	25	6	112.8	31.0	40.6	12.5	78.0	15.4
		28	9	27	6	33	9	101.9	30.4	43.5	10.6	75.3	13.4
10	0.79	29	6	21	9	38	12	47.4	22.0	23.6	9.7	88.0	27.9
		25	8	23	2	32	4	50.7	24.9	22.2	10.7	84.1	23.7
11	0.80	22	5	32	8	65	17	89.5	32.9	63.6	11.1	155.9	35.5
		24	7	36	8	39	8	86.4	23.7	66.8	12.1	88.7	23.1
12	0.19	12	29	7	27	9	37	46.1	105.7	20.6	62.5	26.8	85.0
		6	34	3	27	8	42	42.4	101.4	21.4	77.2	29.5	97.8
13	0.22	5	35	8	37	4	32	23.9	116.4	19.2	60.6	19.2	86.6
		5	22	8	44	4	43	29.2	111.6	17.4	70.4	16.8	82.4
14	0.32	14	27	16	29	19	33	36.5	100.2	19.4	42.5	42.0	83.1
		21	29	9	33	11	26	42.6	95.5	17.2	48.6	38.2	75.8
15	0.09	4	30	1	28	4	25	10.4	124.4	7.3	71.3	12.1	69.5
		3	30	3	29	3	32	13.7	113.3	3.8	65.8	13.2	68.9

frequency of responding in a component was computed from the responses per minute shown in Table 2 by dividing the response rate in that component by the sum of the response rates in both components. The average relative frequency of responding in the red component, over Conditions 1 and 2, in which the relative frequency of reinforcement in the red component was 0.5, was 0.479, 0.500, and 0.518, for Birds 13, 15, and 20, respectively. Thus, there was no color preference of any important significance exhibited by any one of the three subjects.

Figure 1 shows the data from the last two days of each condition. It shows the relative frequency of responding in the red component in conditions 3 to 13, plotted against the component duration on a logarithmic scale. That is, Fig. 1 shows the effect of component duration on the relative frequency of respond-

ing in a component, for a scheduled relative frequency of reinforcement in that component of either 0.8 or 0.2 (± 0.03). The individual data are reasonably well represented by the panel showing the data averaged over the three subjects. Figure 1 shows that the relative frequency of responding in a component approximately equalled the values previously obtained by Reynolds (1963) and by Lander and Irwin (1968) for multiple schedules, with a component duration of 180 sec. The range of these previous values is indicated in Fig. 1 by brackets. As the component duration decreased, Fig. 1 shows that the relative frequency of responding in a component deviated away from the range of values obtained previously in multiple schedules toward the values ordinarily obtained in the concurrent schedules. These latter values, that is the matching values, are indicated in Fig. 1 by dashed horizontal

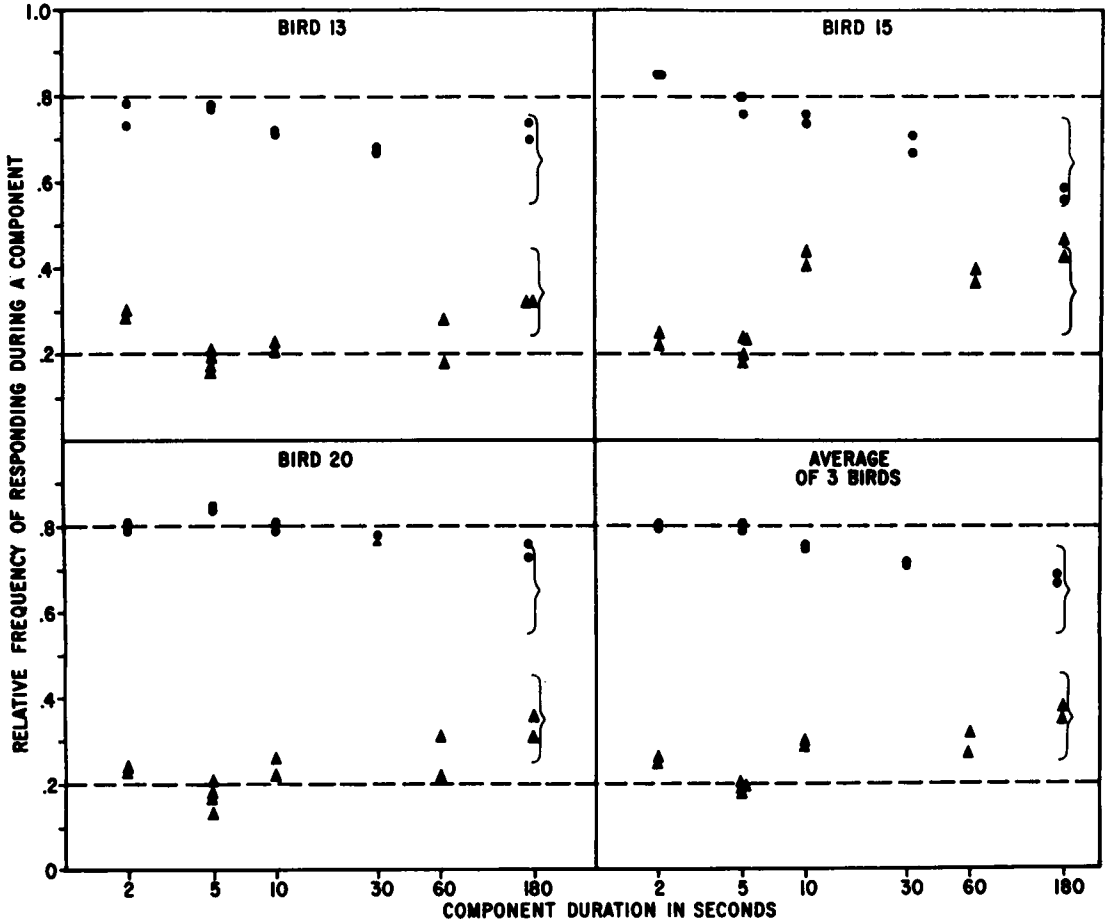


Fig. 1. The relative frequency of responding during the red component of a *mult* VI VI as a function of the component duration on a logarithmic scale. The circles and triangles show results from conditions in which the relative frequency of reinforcement in the red component was 0.8 and 0.2, respectively. The brackets indicate the range of values obtained previously with a component duration of 180 sec (Reynolds, 1963; Lander and Irwin, 1968). The dashed horizontal lines indicate the values that would be obtained in *conc* VI VI schedules with relative frequencies of reinforcement of 0.8 or 0.2.

lines. For a component duration of 5 sec, the relative frequency of responding in a component very closely approximated the relative frequency of reinforcement in that component. That is, the relationship between the relative frequency of responding and the relative frequency of reinforcement, for a component duration of 5 sec, was the same as that obtained in *conc* VI VI schedules. When the component duration was 2 sec, the relative frequency of responding in a component sometimes was not quite as close to the relative frequency of reinforcement in that component as when the component duration was 5 sec, but it was still fairly close to the matching value.

Figure 2 shows the outcomes of Conditions

6, 9, 13, 14, and 15, over which the relative frequency of reinforcement in the red component was varied while the component duration was fixed at 5 sec. For each bird, the relative frequency of responding in the red component closely approximated the obtained relative frequency of reinforcement in that component. Thus, the ordinary function for concurrent VI schedules was obtained from multiple schedules when the component duration was 5 sec.

DISCUSSION

The present data show that component duration in a *mult* VI VI schedule changes the way

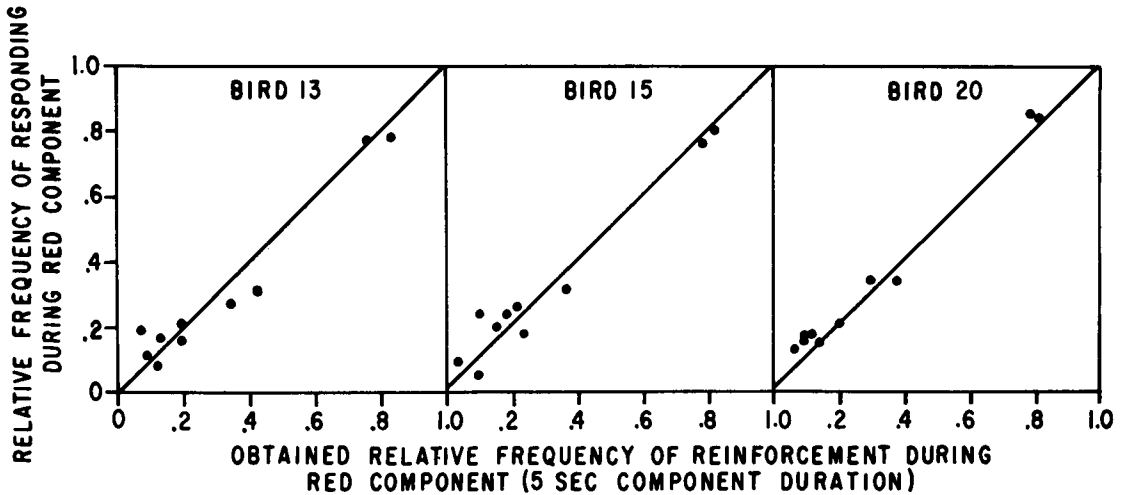


Fig. 2. The relative frequency of responding during one component of a *mult* VI VI as a function of the relative frequency of reinforcement in that component, when the component duration was 5 sec. The solid diagonal lines indicate the matching relationship previously obtained only in *conc* VI VI schedules.

in which the relative frequency of responding in a component depends on the relative frequency of reinforcement in that component. As the component duration decreases, the relative frequency of responding in a component moves toward a value equal to the relative frequency of reinforcement in that component. For component durations of 2 and 5 sec, there actually is an approximate equality between the relative frequency of responding and of reinforcement.

If one assumes that reducing component duration increases interaction between components, then this dependency on the component duration is in at least qualitative agreement with a recently espoused response-strength view of operant behavior (Herrnstein, 1970). This theory predicts that as interaction between components in a *mult* VI VI increases, the relative frequency of responding in a component will approach the relative frequency of reinforcement in that component. This prediction accurately describes the present results.

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