SHORT-COMPONENT MULTIPLE SCHEDULES: EFFECTS OF RELATIVE REINFORCEMENT DURATION¹

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Pigeons were exposed to multiple variable-interval 2-min variable-interval 2-min schedules of food presentation in which relative duration of food presentation was manipulated. When components alternated every 5 sec and were scheduled on separate response keys, relative response rates closely matched relative reinforcement duration in three of four pigeons. On the other hand, relative response rates were insensitive to relative reinforcement duration when components scheduled on a single response key alternated every 5 sec, and when components scheduled on separate response keys alternated every 2 min. Thus, both rapid alternation and spatial separation of components were necessary to produce approximate matching of relative responding to relative reinforcement duration. This finding contrasts with previous findings that only rapid component alternation is necessary for matching when relative rate of reinforcement is manipulated.

Key words: reinforcement duration, component duration, relative response rates, multiple schedules, key peck, pigeons

When pigeons are exposed to concurrent variable-interval variable-interval (*conc VI VI*) schedules (Herrnstein, 1961), the proportion of responses associated with each component often equals the proportion of reinforcements delivered in that component. Herrnstein (1970) labelled this relationship the "matching law". On the other hand, when pigeons are exposed to a multiple variable-interval variable-interval (*mult VI VI*) schedule (Lander and Irwin, 1968; Reynolds, 1961), responses are more evenly distributed between the components than are reinforcements. This relationship has been termed "undermatching" (Baum, 1974).

These different outcomes have been of particular interest because of the formal similarity between multiple and concurrent schedules. Catania (1966) noted that "concurrent schedules . . . may be considered multiple schedules . . . in which the control of the alternation from one schedule to another is in the beak of the organism rather than in the hands of the

experimenter (p. 222)". Recent investigations of multiple and concurrent schedules have focussed on determining which of the procedural differences between these schedules are responsible for the different outcomes with respect to matching. Killeen (1972), Shimp and Wheatley (1971), and Todorov (1972) found approximate matching in multiple schedules when the components alternated every 2 to 10 sec, a similar rate of alternation to that typically found in concurrent schedules. Such matching apparently depends on the frequency with which the schedules alternate. Several differences between the short-component multiple schedules used in the above studies and concurrent schedules appeared to be unrelated to matching. For instance, the pigeons could not control component alternation and were not required to switch keys between components in the multiple schedules. Also, in two of the above studies, the probability that a peck would be reinforced in one component increased only during that component, whereas reinforcement probability for both components increases continuously in the concurrent schedule. The fact that matching was obtained despite these differences suggests that the only feature of concurrent schedules necessary for matching may be rapid component alternation.

The effect of varying relative duration or amount of reinforcement in concurrent and multiple schedules has been somewhat less certain. Matching has been reported under con-

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current schedules, and undermatching under multiple schedules, when the component VI schedules arrange equal frequencies but different durations of reinforcement. Catania (1963) found matching between relative response frequency and relative reinforcement duration in a concurrent schedule. Undermatching, comparable to that reported by Lander and Irwin (1968) resulted when different durations of reinforcement were presented in the two components of a multiple schedule (Shettleworth and Nevin, 1965). It might be predicted from these results that relative response rates would match relative durations of reinforcement in a multiple schedule with short components in a manner analogous to results from studies with relative frequency of reinforcement (Shimp and Wheatley, 1971). This prediction is compromised by the fact that, in some recent studies, reinforcement duration has had a less-potent effect on the distribution of responding than did reinforcement rate when one (Fantino, Squires, Delbrück, and Peterson, 1972) or both (Schneider, 1973; Todorov, 1973) were varied.

The present experiment began with a single-key, short-component multiple schedule in which different durations of reinforcement were associated with the two components. When this schedule produced undermatching similar to that found by Shettleworth and Nevin (1965), the two components were associated with separate response keys. Under the latter procedure, a closer approximation to matching was found.

METHOD

Subjects

Four adult White Carneaux pigeons were maintained at 80% of their free-feeding weights. All had previously been exposed to a variety of reinforcement schedules.

Apparatus

A two-key experimental chamber, 37 cm long, 30 cm wide, and 35 cm high, contained a feeder centered on the front wall 7 cm above the floor. The two response keys were located 23 cm above the floor and 7.5 cm from the center of the front wall. Each key required a minimum force of 15 g (0.15 N) for operation. A white houselight was centered 32 cm above the floor on the front wall and was shielded so that the light was directed toward the chamber ceil-

ing. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

The two-component *mult* VI VI schedule was in effect from the first session.

Schedules. An independent VI 2-min schedule was associated with each component of the multiple schedule. Availability of food was arranged by 20-interval, constant-reinforcement-per-opportunity tapes that used values derived from Catania and Reynolds (1968). The tapes ran only during the associated components, and were stopped from the time reinforcement became available until it was delivered. Reinforcements that had become available but had not been delivered when a component changed were available when that component next appeared. Reinforcement, which was not available during the first 1 sec of each component, consisted of a timed period of access to Purina Pigeon Chow.

Stimuli. A response key was transilluminated with blue light in one component, and yellow light in the other. During five conditions of the experiment, only the right key was operative, and it was alternately transilluminated with a blue and a yellow light. In all other conditions, both keys were alternately operative, with the left key yellow and the right key blue. The inoperative key was always dark. During reinforcement, the white feeder light was on, and the keylight and houselight were extinguished.

Components. Periods of blue and yellow keylight alternated, and within a session were always of equal length. Component lengths of 5 sec were scheduled for both the single-key and two-key multiple schedules. Component lengths of 2 min were used only with the multiple schedule which was arranged on two keys. If a component ended during reinforcement delivery, the start of the next component was delayed until the end of reinforcement. When components changed every 2 min, each component was presented 12 times in every session. With 5-sec alternations, session length was set at 48 min by a clock, with the result that total exposure to the two components could differ by as much as 5 sec each session.

Reinforcement duration. Within each of the three scheduling procedures used (two-key, 2-min alternation; two-key, 5-sec alternation;

single-key, 5-sec alternation) the relative duration of reinforcements assigned to the two components was manipulated. The sum of the durations of reinforcement in the two components always equalled 10 sec. To prevent a confounding of color preference and reinforcement duration, the longer reinforcement duration was associated with different keycolors in different conditions.

Order of conditions. The conditions, their sequence, and the number of sessions per condition are shown in the first six columns of Table 1. Relative responding was examined under several values of relative reinforcement duration for single- and two-key short-component multiple schedules and for the two-key, 2-min component multiple schedule. In Conditions 3 and 14, component length and relative reinforcement duration were held constant while the schedule was changed from a single-key to a two-key multiple schedule. This allowed closer examination of the role of spatial separation of the multiple-schedule components. Each condition was terminated when all four pigeons showed stable relative responding in the last five sessions.

RESULTS

Table 1 shows the mean response rates in the presence of the blue and yellow response keys over the last five sessions of each condition. The table also shows the mean response rates during the first second of each component for those conditions with 5-sec component lengths. In Conditions 1 and 2, rates during the first second and the subsequent 4 sec of each component were very similar. Beginning with Condition 3, response rate during the first second was higher than the subsequent rate in 84 of the 88 comparisons. In addition, response rate during the first second of the component with the longer reinforcement duration was higher than that associated with the shorter duration reinforcement in 41 of 44 comparisons.

Figure 1 shows relative responding over the last five sessions of each condition as a function of the relative duration of reinforcement. Each column shows the data from one pigeon. The top row of figures shows responding under the two-key multiple schedule with 5-sec component alternation; the second row, under the single-key multiple schedule with 5-sec component length, and the third row, under the two-

key multiple schedule with 2-min component alternation. Since obtained relative frequency of reinforcement was 0.5 ± 0.04 in 52 of 56 observations, relative scheduled duration of food presentation is essentially the same as relative access to food.

The dashed 45-degree line for each pair of axes represents the locus of perfect matching, and the heavy solid line is the best fitting linear regression line. The formula for the regression line is given in the lower part of each figure. The data of Pigeons 2, 3, and 5 under the 5-sec, two-key procedure lie close to the matching line. The slopes of the regression lines vary from 0.81 to 0.89. On the other hand, under the 2-min, two-key schedule and the 5-sec, single-key schedule, all pigeons showed substantial undermatching.

DISCUSSION

The present data from the multiple schedules with 2-min components agree with those of Shettleworth and Nevin (1965). These experimenters used slightly different procedures, including a single-key, both 2- and 3-min component lengths, and a single program tape to schedule reinforcement. Nevertheless, the regression line calculated from their tabular data by the present authors is $y = 0.36x + 0.30$, very close to the mean regression line from this condition in the present study, $y = 0.41x + 0.24$.

Surprisingly, under the 5-sec component, single-key schedule, which was based on Shimp and Wheatley (1971), the response distribution was no closer to matching than it was with 2-min components. This difference occurred despite the fact that the present experiment replicated most of the schedule features of the earlier study. The important difference appears to be that Shimp and Wheatley (1971) and Todorov (1972) found matching under multiple schedules with short components when they manipulated relative frequency of reinforcement, whereas relative duration of reinforcement was varied in the present experiment. This finding is consistent with the conclusion of Fantino *et al.* (1972), Schneider (1973), and Todorov (1973), that relative duration of reinforcement exerts less control over relative responding in concurrent schedules than does relative rate of reinforcement.

It is interesting to note that Fantino *et al.* (1972) and Schneider (1973) reached this con-

Table 1
Experimental Conditions and Response Rate (R/min)

Condi- tion	Number of Sessions	Response Keys Used	Comp Dura- tion	Rein. Duration				P-1			P-2			P-3			P-5				
				Blue Key	Yellow Key	Total	Blue Key		Yellow Key		Blue Key		Yellow Key		Blue Key		Yellow Key				
							1st Sec	Total	1st Sec	Total	1st Sec	Total	1st Sec	Total	1st Sec	Total	1st Sec	Total			
1	24	Single	5 sec	5 sec	5 sec	39.79	45.39	40.17	41.05	55.38	61.16	54.33	54.77	81.50	85.87	100.92	100.38	44.54	45.82	41.50	49.58
2	25	"	"	2 sec	8 sec	36.13	39.26	47.29	48.12	60.79	59.72	130.08	132.75	78.71	74.45	101.50	100.08	59.67	61.81	104.92	107.56
3	32	Two	"	2 sec	8 sec	30.33	30.12	95.04	59.54	43.25	33.58	160.17	125.38	31.71	27.33	111.04	79.71	34.96	26.50	182.50	120.95
4	47	"	"	7 sec	3 sec	131.83	76.84	103.17	56.81	141.75	92.92	72.54	30.78	103.04	79.50	48.88	31.62	142.08	82.40	146.46	51.87
5	45	"	"	1 sec	9 sec	73.63	40.42	186.08	100.57	21.83	24.11	207.79	155.52	10.63	11.90	88.33	70.49	36.67	19.74	165.46	112.37
6	35	"	"	5 sec	5 sec	105.83	68.77	170.50	81.57	111.33	65.87	151.83	65.23	59.00	52.64	80.54	50.61	99.25	56.57	96.08	55.36
7	37	"	"	7 sec	3 sec	120.83	75.56	145.83	71.52	112.63	74.00	137.71	52.80	76.13	61.18	61.04	34.47	154.67	86.54	64.67	36.87
8	68	"	2 min	2 sec	8 sec	35.34	59.97	68.71	68.71	58.70	38.74	62.25	62.25	18.82	18.82	58.95	38.73	76.18	38.73	76.18	38.73
9	34	"	"	7 sec	3 sec	59.97	31.96	52.69	52.69	58.70	58.70	52.23	52.23	46.01	46.01	48.02	62.88	62.88	62.88	62.88	62.88
10	32	"	"	1 sec	9 sec	31.96	31.96	81.22	81.22	29.63	29.63	69.20	69.20	13.68	13.68	70.24	70.24	26.04	26.04	73.90	73.90
11	36	Single	5 sec	1 sec	9 sec	39.88	28.90	77.50	54.36	45.04	32.58	119.46	93.14	45.29	28.54	141.79	93.14	38.50	31.63	125.79	85.08
12	38	"	"	8 sec	2 sec	90.00	61.37	56.25	37.84	113.71	87.40	44.04	37.04	74.46	53.41	53.08	33.30	128.96	84.99	72.75	48.43
13	49	"	"	3 sec	7 sec	112.33	91.37	186.46	127.58	116.83	82.61	134.71	88.53	87.75	62.70	100.08	68.57	57.04	43.95	78.33	50.12
14	112	Two	"	3 sec	7 sec	108.88	97.83	209.54	107.72	32.50	40.89	219.79	108.81	38.38	48.03	92.13	72.53	66.25	51.66	261.42	97.57

Fig. 1. Relative frequency of responding on the blue response key as a function of the relative duration of reinforcement associated with that key. Each column shows the data from one pigeon. Each row represents a different scheduling procedure. Top row: two-key, 5-sec alternation. Second row: single-key, 5-sec alternation. Bottom row: two-key, 2-min alternation. The dashed 45-degree line represents the locus of perfect matching. The best fitting linear regression line and the equation for this line are shown in each figure.

clusion using a two-key concurrent schedule (Herrnstein, 1961) in which the two schedules are associated with different manipulanda. This schedule is formally similar to the two-key, 5-sec component multiple schedule used in the present study. The single key multiple schedule used here, and by Shimp and Wheatley (1971) and Todorov (1972), is analogous to the changeover-key concurrent schedule (Findley, 1958) that arranges reinforcements in both components for pecks on a single key. Therefore, we would expect greater differences between the effects of relative reinforcement rate and relative reinforcement duration if they were compared using the Findley procedure. Unfortunately, although Todorov (1973) used this schedule, reinforcement frequency and duration were manipulated in different ways. Reinforcement frequency bore a fixed relationship to key color throughout the experiment while the relationship between key color and

reinforcement duration was changed in each condition. This difference in treatment makes it difficult to compare the effects of the two variables.

The 5-sec component, two-key multiple schedule used here is more similar to concurrent schedules than was the multiple used by Shimp and Wheatley (1971), since in addition to a rapid alternation of components it also arranges that the pigeon switch keys between components. The switching requirement and the rapid alternation of components appear to be necessary conditions for approximate matching when the relative duration of reinforcement is manipulated.

The close approximation to matching found here under the two-key, 5-sec schedule accords well with the data of Catania (1963) and Brownstein (1971) from concurrent schedules. However, Fantino *et al.* (1972) reported substantial undermatching to relative reinforce-

ment duration in concurrent schedules. The reason for this discrepancy under similar concurrent schedules is not clear at present, although Fantino *et al.* attribute it to the longer CODs used in the previous studies.

Baum (1974) suggested that the major difference between matching and undermatching may be a difference in the discriminability of the alternatives. Since undermatching is found more frequently when reinforcement duration is varied, such an account would suggest that components that arrange different frequencies of reinforcement are more easily discriminated than those that arrange different durations. However, since the term discrimination refers to behavioral differences in the presence of different stimuli, this may be more a description of differences than an account of the results of multiple and concurrent schedules. The description in terms of discriminability may be of value in focussing investigation on the types of stimulus-stimulus correlation that could lead to the observed behavioral differences.

For example, in the single-key schedule, key color is correlated with the manipulated parameters of reinforcement; in the two-key schedule, both key color and location are correlated with these parameters. In the short-component multiple, only those properties of the key present before reinforcement enter into this correlation, since either component might be in effect at the end of reinforcement. When relative reinforcement rate is manipulated, the key properties of one component are more frequently contiguous with reinforcement onset than are the key properties of the other component. Under these conditions, relative responding closely matches relative reinforcement. When the relative duration of reinforcement is manipulated, however, the key properties of both components are equally correlated to reinforcement onset, but are differentially correlated with the time of reinforcement offset. Thus, there is a lower degree of temporal contiguity between the component stimuli and the relevant properties of reinforcement. We would predict from this analysis that relative rate and relative amount of reinforcement would have similar effects if stimuli characteristic of reinforcement amount were present at reinforcement onset. This could be arranged by dropping premeasured quantities of food into an open tray.

The high rate of responding seen here dur-

ing the 1-sec delay period of the 5-sec components resembles that found by Silberberg and Fantino (1970) during the changeover delay (COD) under concurrent schedules. This result may be due to the momentary increase in probability of reinforcement after the delay period in the multiple and the COD in the concurrent (reinforcement probability increases during the delay period in the multiple and during the alternate component and COD in the concurrent). Silberberg and Fantino (1970) also found the highest response rates in the COD of the component with the lower frequency of reinforcement. Killeen (1972) showed that the highest momentary probability of reinforcement in the above study was at the end of the COD in the low-frequency component. The present study found the highest response rates in the delay period of the long reinforcement duration component. Here, reinforcement probability after the delay period was the same in both components.

In general, the distribution of responding under the two-key multiple schedule with short components in the present study resembled very closely that found with concurrent schedules. It is interesting to note that when relative duration, rather than relative rate of reinforcement, was manipulated, it was necessary to incorporate one additional feature of concurrent schedules to achieve this similarity.

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