MATCHING WITH A TRIO OF CONCURRENT VARIABLE-INTERVAL SCHEDULES OF REINFORCEMENT¹

STANLEY S. PLISKOFF AND THOMAS G. BROWN²

UNIVERSITY OF MAINE, ORONO

A trio of concurrent variable-interval schedules of reinforcement was arranged according to a changeover-key procedure, including a changeover delay of 1.5 sec. The three schedules provided a combined maximum reinforcement rate of 45 reinforcements per hour. With that restriction, the nine experimental conditions included several combinations of variable-interval schedules, sometimes including extinction. The pigeons matched relative response rate and relative time to relative reinforcement rate. Relative time appeared to match somewhat better than relative response rate. Performance adjusted rapidly from one experimental condition to the next, whether the change involved two or all three schedules of the concurrent trio.

Key words: concurrent schedules, matching, variable interval, pigeons

Concurrent schedules of reinforcement involve at least two independent operants. Reinforcement of each operant is determined by its schedule, and the several schedules operate independently and simultaneously. Interest in concurrent schedules of reinforcement was spurred by Herrnstein's (1961) finding that, under certain conditions, rate of responding on a variable-interval schedule was linearly related to the rate of reinforcement associated with that schedule. An implication of that finding received more notice, *i.e.*, the relative rate of responding (the per cent of the total number of responses) for one of the operants approximated the relative rate of reinforcement (the per cent of the total number of reinforcements) of that operant. Much of the earlier research on concurrent schedules of reinforcement was summarized by Catania (1966; see also Herrnstein, 1970, 1971 for extensions of the earlier work).

We know of no parametric studies using more than two schedules concurrently, aside from the procedure reported by Menlove, Moffitt, and Shimp (1973) in which each member of a concurrent pair was itself composed of two concurrent schedules. Catania (1973) reported a three-schedule procedure in the

context of a discussion on inhibitory properties of reinforcement, but only the case involving 20 reinforcements per hour for each of the three operants was studied (and compared with two- and one-operant procedures).

When each of the concurrent schedules provides not food but access to a unique stimulus in the presence of which pecking is reinforced with food, the procedure is called concurrent chains (Autor, 1960, 1969). Only the initial members of the chains are concurrent; the terminal members are mutually exclusive. Reynolds (1963) and Davison and Temple (1974) reported results obtained with a trio of concurrent chain schedules. Reynolds found a close correspondence (match) between the relative rates of responding on the initial-link variable-interval schedules and the relative rates of conditioned reinforcement, *i.e.*, occurrences of terminal-link stimuli. Davison and Temple, however, did not find a simple matching relation between the relative response rates in the initial chain links and the relative terminal-link reinforcement rates. The present experiment was not concerned with chain schedules. Rather, three variable-interval schedules of reinforcement were arranged as in the traditional case of the concurrent pair.

METHOD

Subjects

Three White Carneaux pigeons, which had been used in an experiment on delay of rein-

¹Reprints may be obtained from S. S. Pliskoff, Dept. of Psychology, University of Maine, Orono, Maine 04473. The experiment was supported in part by Project Award #R625-264 from the Faculty Research Funds Committee, University of Maine.

²Now at Utica College of Syracuse University.

forcement like that reported by Chung and Herrnstein (1967), were maintained at about 80% of free-feeding weights.

Apparatus

The ventilated animal space inside the chamber measured 34.2 cm wide, 33.0 cm from floor to ceiling, and 30.5 cm from the panel to the rear. A Lehigh Valley Electronics feeder was mounted behind the panel, and the bottom of the opening for the pigeon's head was 8.9 cm above the mesh floor. Two Gerbrands pigeon keys were centrally mounted on the panel 6.4 cm apart on center and 22.9 cm above the floor. A force of 0.15 N was required to operate either key. A relay mounted behind the panel was operated by a pulse former each time a response occurred, except when the feeder was raised. Each of the keys could be transilluminated from behind by Sylvania 28 PSB slide base bulbs, two bulbs per color. Standard electromechanical equipment arranged the experimental dependencies. The experimental chamber was located in a room next to that for the electromechanical equipment. A floor-standing speaker delivered white noise to the chamber room at all times.

Procedure

Three tape drives arranged the concurrent variable-interval schedules of reinforcement. Each schedule was constructed by multiplying the following sequence of numbers by a value chosen to yield the average interreinforcement interval for the variable-interval schedule in question: 2, 6, 11, 5, 9, 3, 7, 1, 4, 12, 0, 10, 8. The variable-interval schedules thus generated were: 1.33 min, 1.5 min, 1.88 min, 2.4 min, 4.0 min, 6.67 min, 12.0 min, 15.0 min; an extinction schedule was also used.

During each of the experimental conditions, the three schedules together allowed a maximum of 45 reinforcements per hour. The main key on the right, to which the three schedules were assigned, could be yellow, green, or red. The color of the key and schedule assignment might change as a consequence of a single peck on the left-hand key, the changeover key, which was white.

The probability that a changeover peck would produce a schedule change was 0.66; given a schedule change, either of the remaining schedules could result with equal probability. The probability that a changeover peck

Table 1

The nine conditions of the experiment—each a concurrent trio of VI schedules (in minutes).

Conditions	Color of Main Key			Sessions
	A Yellow	B Green	C Red	
1	VI 4	VI 4	VI 4	33
2	VI 2.4	VI 12	VI 4	50
3	VI 12	VI 2.4	VI 4	27
4	VI 1.5	EXT	VI 12	31
5	VI 15	VI 1.88	VI 6.67	46
6	VI 15	VI 6.67	VI 1.88	50
7	VI 1.33	EXT	EXT	32
8	EXT	VI 1.33	EXT	34
9	VI 4	VI 4	VI 4	42

would not produce a schedule change was 0.34; the probability that a second peck on the changeover key would not change the schedule assignment on the main key was 0.03. (To our knowledge, the feature by which a changeover response might not result in a schedule change for the main key has never been part of a two-schedule procedure. It was included here only to accommodate a later procedure that yielded little of interest.) It was not necessary for a peck on the main key to occur between successive changeovers; any number of the latter could occur in succession.

No response on the main key could be reinforced during 1.5 sec following a changeover peck. In the event another changeover peck occurred before 1.5 sec elapsed, the delay was initiated anew. Reinforcement available during the 1.5 sec was not cancelled but was only delayed until the first peck after the 1.5-sec changeover delay. During reinforcement, both keys were dark and inoperative. Daily sessions were terminated after 60 reinforcements.

Experimental conditions were changed when the graphs showing relative response rates suggested stable performance over about a 10-day period for each bird. Table 1 shows the sequence of experimental conditions, each a concurrent set of three schedules including variable-interval (VI) with or without extinction (EXT), and the number of sessions devoted to each.

RESULTS AND DISCUSSION

Table 2 summarizes the results of the experiment. The numbered conditions one through nine and the schedules A, B, and C are keyed to Table 1. Each "time" entry is a proportion

Table 2

The basic results of the experiment (data were averaged over last seven sessions of each condition).

Schedule		Condition								
		1	2	3	4	5	6	7	8	9
BIRD #7										
Time	A	0.33	0.47	0.17	0.82	0.12	0.15	0.97	0.01	0.32
	B	0.34	0.17	0.53	0.04	0.69	0.20	0.01	0.98	0.36
	C	0.33	0.36	0.30	0.14	0.19	0.65	0.02	0.01	0.32
Resp per min	A	34.8	37.1	14.1	39.8	6.21	9.23	33.5	0.35	31.0
	B	32.7	12.1	48.0	1.26	34.2	17.3	0.24	24.0	29.0
	C	35.0	33.1	35.0	14.5	18.0	40.8	0.58	0.35	32.0
Rfts per min	A	0.27	0.41	0.08	0.68	0.06	0.07	0.75	0.00	0.25
	B	0.27	0.08	0.41	0.00	0.54	0.15	0.00	0.74	0.25
	C	0.25	0.25	0.25	0.09	0.15	0.53	0.00	0.00	0.25
CO's per min	A	5.04	5.91	6.84	3.00	3.90	4.38	1.06	0.66	5.67
	B	5.22	6.12	7.05	3.12	4.00	4.51	1.08	0.68	5.63
	C	5.09	5.94	6.89	3.01	3.90	4.35	1.06	0.66	5.61
BIRD #9										
Time	A	0.34	0.51	0.18	0.78	0.12	0.19	0.88	0.02	0.33
	B	0.32	0.23	0.53	0.06	0.67	0.25	0.06	0.96	0.39
	C	0.34	0.26	0.29	0.16	0.21	0.56	0.06	0.02	0.28
Resp per min	A	14.7	17.5	2.72	32.3	3.30	4.86	43.9	0.06	9.12
	B	25.1	16.6	34.2	0.30	30.5	7.95	0.06	47.5	16.7
	C	13.7	7.18	9.73	5.30	7.76	20.1	0.21	0.01	9.82
Rfts per min	A	0.26	0.41	0.08	0.66	0.06	0.06	0.75	0.00	0.25
	B	0.28	0.09	0.42	0.00	0.53	0.16	0.00	0.75	0.25
	C	0.26	0.25	0.25	0.09	0.16	0.52	0.00	0.00	0.24
CO's per min	A	6.93	7.28	9.50	8.92	9.11	8.95	8.89	2.20	7.42
	B	7.21	7.57	9.85	8.94	9.62	9.36	9.51	2.16	7.36
	C	7.02	7.34	9.57	8.69	9.19	9.10	9.20	2.31	7.33
BIRD #11										
Time	A	0.32	0.53	0.15	0.83	0.11	0.17	1.00	0.00	0.33
	B	0.39	0.16	0.58	0.07	0.75	0.18	0.00	1.00	0.40
	C	0.29	0.31	0.27	0.10	0.14	0.65	0.00	0.00	0.26
Resp per min	A	34.7	58.7	13.0	86.9	9.70	10.0	72.8	0.01	35.1
	B	47.6	15.6	64.0	0.11	83.6	19.8	0.08	73.3	36.7
	C	32.3	33.2	29.2	8.82	15.0	89.3	0.01	0.06	28.3
Rfts per min	A	0.26	0.41	0.08	0.68	0.06	0.06	0.75	0.00	0.25
	B	0.27	0.08	0.41	0.00	0.55	0.15	0.00	0.75	0.25
	C	0.25	0.25	0.24	0.08	0.15	0.54	0.00	0.00	0.25
CO's per min	A	5.98	4.34	4.70	2.35	2.70	4.44	0.01	0.01	6.11
	B	6.16	4.47	4.88	2.44	2.79	4.57	0.01	0.01	6.02
	C	6.00	4.35	4.70	2.38	2.71	4.42	0.01	0.01	5.89

of the total session time accounted for by a schedule; hence, for each condition, the A, B, and C proportions sum to one. Responses per minute, reinforcements per minute, and changeover responses per minute are shown as overall rates, *i.e.*, they are based on total session time, rather than the time that a particular schedule was assigned to the main key (which would have given local rate).

The basic finding is shown in Figure 1, the "matching" diagram. Relative reinforcement rate is shown on the horizontal axis and rela-

tive response rate and relative time are on the vertical axis. Relative response rate was computed by dividing the number of responses for a given schedule by the total number of responses for all three. Relative time was computed in an analogous fashion, with the time (excluding feeder time) spent responding on each schedule divided by the total time spent in responding. All three points were plotted for each experimental condition; thus, of the 27 points in each matching diagram, only 18 are independent.

Fig. 1. Matching diagrams for Birds 7, 9, and 11. Relative response rate and relative time are plotted against relative observed reinforcement rate.

Figure 1 shows matching with three variable-interval schedules of reinforcement. For all birds, the data for both relative response rate and relative time were distributed about

the diagonals, which are the loci of points representing perfect matching. Some systematic deviations can be detected, however. The response data for Bird 7 and the time data for Bird 9 clearly show under-matching (Baum, 1974), *i.e.*, the data points deviate from the matching line in the direction of indifference. The time data for Bird 7 also show under-matching, but to a lesser degree.

An estimate of whether the relative response rate or relative time data approximated observed relative reinforcement rate more closely was made for the data of Figure 1. For each panel, the difference between the dependent variable and relative reinforcement rate was calculated for each of the 27 data points. The deviations were then squared and averaged. The values are reported as mean squared deviations (mn. sqd. dev.) in each panel of Figure 1. Only for Bird 11 were the mean squared deviations about the same for the response and time data. For the other birds, the mean squared deviations were clearly smaller for the time data.

Figure 2 shows day-by-day plots of relative response rate and relative time for Bird 7 only, because its performance was like that for the other birds. Each panel in the figure shows a different condition; the VI schedules are identified, and correspond to the second, third, and fourth conditions in Table 1 on the left of Figure 2 and Conditions 7, 8, and 9 on the right. Sessions during Conditions 3 and

Fig. 2. Relative response rate and relative time plotted against sessions. Portions of the second, third, fourth, seventh, eighth, and ninth experimental conditions are shown.

8 have been omitted; the final five sessions only are shown for Conditions 2 and 7, and the initial 10 sessions only are shown for Conditions 4 and 9. The two main points to be derived from Figure 2 are: generally speaking, performances within each experimental condition reflected on a day-to-day basis the schedules in force; also, adjustment to a new experimental condition occurred within a few sessions after inception.

The adjustment was rapid whether it involved a change in only two of the three schedules or in all three. The transition from the second to the third experimental condition involved a change in two schedules, as did the transition from the seventh to the eighth. The transitions from the third to the fourth and from the eighth to the ninth conditions involved changes in all three schedules. Figure 2 shows both types of transition.

The study of concurrent VI schedules of reinforcement has provided a rich source of theoretical ideas during recent years. There have been extensions to concurrent schedules other than variable-interval, to the relation between concurrent schedules and multiple schedules, to a concurrent pair of concurrent pairs of schedules, and to the study of conditioned reinforcement via the concurrent chains procedure. The present parametric experiment was undertaken only to determine whether the basic matching phenomenon would be found with three concurrent VI schedules of reinforcement. It is clear from the data presented that matching occurs in much the same fashion as with two schedules.

REFERENCES

- Autor, S. M. *The strength of conditioned reinforcers as a function of frequency and probability of reinforcement*. Doctoral dissertation, Harvard University, 1960. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood: Dorsey Press, 1969. Pp. 127-162.
- Baum, W. M. On two types of deviation from the matching law: bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 231-242.
- Catania, A. C. Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 213-270.
- Catania, A. C. Self-inhibiting effects of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 517-526.
- Chung, S-H. and Herrnstein, R. J. Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 67-74.
- Davison, M. C. and Temple, W. Preference for fixed-interval terminal links in a three-key concurrent chain schedule. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 11-19.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Herrnstein, R. J. Relative and absolute strength of a response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 267-272.
- Herrnstein, R. J. Quantitative hedonism. *Journal of Psychiatric Research*, 1971, **8**, 399-412.
- Menlove, R. L., Moffitt, M., and Shimp, C. P. Choice between concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 331-344.
- Reynolds, G. S. On some determinants of choice in pigeons. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 53-59.

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