PERFORMANCE IN CONCURRENT FIXED-INTERVAL SCHEDULES¹

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Six pigeons were trained on a variety of concurrent fixed-interval fixed-interval schedules. Matching between response or time ratios and ratios of obtained numbers of reinforcements was found for eight of 12 schedules studied. Cumulative records showed both typical burst-and-break patterns and also atypical response patterns in which response rate was constant between reinforcements on a schedule. Matching occurred only when the same pattern was present on both concurrent schedules. When different response patterns were generated by the two schedules, the pigeons consistently emitted fewer responses to the shorter fixed-interval than required by matching.

The matching principle, which states that ratios of responses (or of time) match ratios of obtained numbers of reinforcements (Herrnstein, 1970; Rachlin, 1971), has been shown to apply to performance in concurrent schedules in which reinforcements are aperiodically available for two operants (concurrent variable-interval or VI schedules). It has also been shown to apply to cases in which one operant is reinforced aperiodically and, concurrently, another operant is reinforced periodically on a fixed-interval (FI) schedule (Nevin, 1971; Trevett, Davison, and Williams, 1972). If P_1 and P_2 are the numbers of responses to the two schedules in a session, and R_1 and R_2 are the numbers of reinforcements obtained on the two schedules in the session, then for concurrent VI VI schedules:

$$\frac{P_1}{P_2} = \frac{R_1}{R_2}; \quad (1)$$

for concurrent FI VI schedules, if subscript 1 refers to the FI key:

$$\frac{P_1}{P_2} = c \frac{R_1}{R_2} \quad (2)$$

or:

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$$\frac{P_1}{P_2} = \frac{R_1^{0.5}}{R_2^{0.5}} \quad (3)$$

Equation 2, in which c is a constant, was given by Trevett, *et al.*, (1972), Equation 3 by Nevin (1971). These three equations are all special cases of a more general relation:

$$\frac{P_1}{P_2} = c \frac{R_1^a}{R_2^a} \quad (4)$$

The present experiment investigated whether concurrent FI FI performance conformed to the matching principle and, if so, what form of Equation 4 was appropriate.

METHOD

Subjects

Six homing pigeons numbered 21 to 26 were maintained at 80% $\pm$ 15g of their free-feeding body weights.

Apparatus

The experimental chamber, which was situated remote from conventional relay control equipment, was sound attenuated and external noise was masked by an exhaust fan. The chamber contained two translucent response keys 0.75 in. (2 cm) in diameter, 5.25 in. (13 cm) apart and 9 in. (22.5 cm) from the floor. Both keys could be illuminated by colored lights. Pecks on lighted keys exceeding 0.098 N closed a microswitch behind the keys and provided auditory feedback from a relay situated inside the chamber. A food magazine was situ-

ated midway between the two keys and 4 in. (10 cm) from the grid floor.

Procedure

All subjects had extensive histories of training on concurrent schedules, so no key-peck or schedule training was necessary. The animals were placed directly on the first experimental condition.

Concurrent schedules were arranged according to the changeover method (Findley, 1958) in which a response to the left-hand (white) key alternated schedules and their associated (red or green) stimuli on the right-hand key. The two keys are known as the changeover and main keys respectively. The schedules arranged on the main key in the various parts of the experiment are shown in Table 1. In all except one condition, described below, the concurrent schedules were mutually independent and were operative simultaneously. The animals thus had continual access via the changeover key to both schedules and associated main-key stimuli. Bursts of responding on the changeover key were prevented by arranging that changeover responses were effective only after at least one response on the main key.

A changeover delay (Herrnstein, 1961) followed every response on the changeover key. This specified that a response on the main key could not be reinforced, even if a reinforcement had been arranged by the schedule, for 3 sec after a changeover response.

During reinforcement, which consisted of 3-sec access to a hopper containing wheat, the hopper was illuminated and the response keys were dark and inoperative. The numbers of reinforcements per session were varied in different experimental conditions (Table 1) so that the maximum session time was about 50 min and the maximum number of reinforcements obtained was 60. Supplementary feed of maize was given, when necessary, immediately after daily training sessions.

For each session, response data were calculated as the number of responses on the red main key relative to the total number of main key responses. A stability criterion required that the median of the proportion of responses on one schedule in five sessions did not differ by more than 0.05 from the median in the previous five sessions. Such a criterion had to be met five (not necessarily consecutive) times by all birds before the schedules were altered.

In all conditions, the number of responses, the time spent responding and the number of reinforcements obtained on the two main key schedules, and the number of changeover responses, were recorded. During the final session of each experimental condition, either a cumulative record or an event record of performance was taken.

As some animals in one condition (*conc* FI 12-sec FI 120-sec) ceased responding to the schedule providing the lower reinforcement rate, the condition was replicated later in the experiment with non-independent concurrent schedules (Stubbs and Pliskoff, 1969). In this procedure, both tapes stopped when either of them scheduled a reinforcement, and neither could be restarted until this reinforcement had been obtained.

RESULTS

All data (Table 1) are reported as the sum of the various measures over the final five sessions of each experimental condition. All other measures are derived from these sums.

Figure 1 shows the ratio of responses emitted on the two main key schedules as a function of the ratio of numbers of reinforcements obtained on these schedules, both co-ordinates being drawn logarithmically (Baum and Rachlin, 1969). Time data are not shown in this figure because, on these measures, they conformed very closely with response ratios (Table 1). The heavy diagonal line shows the relation between response and reinforcement ratios specified by Equation 1. The group data shown in the lower panel are the means of the response ratios for each bird derived from Table 1. Also shown are the equations for the best-fitting straight lines (by the method of least squares) and the percentage of the data variance that they account for.

While the fitted lines in Figure 1 appear to account for most of the data variance in both the individual and group preferences, four of the data points seem to deviate consistently from the main diagonal (Equation 1), and the obtained reinforcement proportions (Table 1). If straight lines are fitted to the present data without using these four deviant points, the variance accounted for increases, for individual animals, from between 81 to 94% to between 94 and 99%, and for the group from 93 to 99.9%. The slope of the line fitted to

Fig. 1. Response ratios to the two schedules as arranged in the various conditions of the experiment as a function of the ratios of reinforcements obtained. Both ordinate and abscissa are logarithmic. The heavy lines show matching according to Equation 1. Data from the six animals are shown individually and as a group. Next to each graph are shown the equations of the best-fitting straight lines and the percentage of the data variance they account for (see text). One data point for Bird 21 fell far outside this figure and is not shown, although it was used in the line-fitting calculations.

the group data is now 1.03, instead of 0.81 and the intercept at a reinforcement ratio of unity is 1.08 instead of 0.96.

Representative cumulative records of stable performance in some of the experimental conditions are shown in Figure 2. These records do not always show typical FI performance, described by Schneider (1969) as a pause after reinforcement followed by a run of responses at a constant rate terminating with the next reinforcement. Very often there was no change in response rate between reinforcements on the schedules, and the performance was reminiscent of concurrent VI VI schedules (Catania, 1966).

DISCUSSION

While matching according to Equation 1 between response (or time) allocation to the two schedules and the number of reinforcements obtained on the two schedules was demonstrated for the majority of the present experimental conditions, four conditions produced data that deviated from matching.

How did the conditions that did not produce matching differ from the conditions that did? The effect is not a result of the absolute size of the interval schedules arranged, because matching was found on both *conc* FI 480-sec FI 240-sec and *conc* FI 36-sec FI 48-sec. Matching may occur only when one schedule provides twice, or less than twice, the reinforcement rate of the schedule arranged concurrently. No such effect has been noted in previous research on concurrent schedules, and the suggestion is not supported by the two conditions of *conc* FI 12-sec FI 120-sec in which matching occurred. However, this explanation cannot be ruled out because, as discussed below, performance in *conc* FI 12-sec FI 120-sec may constitute a special case.

An explanation that is more consistently supported by the present data is indicated by the relation between the performance as shown in Table 1 and in Figure 1, and the pattern of behavior shown in the cumulative records. On the basis of whether typical FI or VI-like patterns were shown, the cumulative records (Figure 2) could be divided into three groups. In the first (*conc* FI 36-sec FI 48-sec, and the two conditions of *conc* FI 12-sec FI 120-sec) typical FI performance occurred on both schedules. In the second (*conc* FI 90-sec FI

Table 1

Sequence of experimental conditions, number of sessions of training per condition, number of responses and time (seconds) allocated to the schedules, number of reinforcements obtained and number of changeover responses. The final five columns show the proportions of responses emitted, times spent responding, and reinforcements obtained, all to the red key, and the deviations of the response and time proportions from the reinforcement proportions.

Condi- tions	Schedules (Sec)		Number of Sessions	Animal	Reinforce- ments Obtained				Changeover Responses	Proportions			Deviations (c-a) (c-b)			
	Red	Green			Responses		Time			Responses (a)	Time (b)	Reinforce- ments (c)				
					Red	Green	Red	Green								
1	FI 90	FI 120	29	21	10900	7572	5312	4279	145	105	889	0.59	0.55	0.58	-0.01	+0.03
				22	8777	6080	5615	4059	146	104	642	0.59	0.58	0.58	-0.01	0
				23	11224	9544	5076	3561	144	106	836	0.54	0.59	0.58	+0.04	-0.01
				24	9109	4292	6495	3271	150	100	579	0.68	0.67	0.60	-0.08	-0.07
				25	13603	6679	5477	4233	151	99	600	0.67	0.56	0.60	-0.07	+0.04
				26	14610	10399	5392	4104	143	107	834	0.58	0.57	0.57	-0.01	0
2	FI 25	FI 120	26	21	3732	2645	3033	1116	253	47	399	0.59	0.73	0.84	+0.25	+0.11
				22	4223	2013	2949	1248	252	48	402	0.68	0.70	0.84	+0.16	+0.14
				23	5856	2767	2485	1538	250	50	459	0.68	0.62	0.83	+0.31	+0.21
				24	2494	1640	2467	1567	250	50	420	0.60	0.61	0.83	+0.23	+0.22
				25	7340	2870	2910	1139	252	48	380	0.72	0.72	0.84	+0.12	+0.12
				26	6592	3290	2520	1456	250	50	415	0.67	0.63	0.83	+0.16	+0.20
3	FI 120	FI 25	34	21	3202	7979	1278	2872	49	251	391	0.29	0.31	0.16	-0.13	-0.15
				22	2309	4067	1437	2652	51	249	409	0.36	0.35	0.17	-0.19	-0.18
				23	3553	8197	1401	3698	53	247	399	0.30	0.27	0.18	-0.12	-0.09
				24	1595	4184	1087	3000	46	254	263	0.28	0.27	0.15	-0.13	-0.12
				25	3893	4992	1673	2777	53	247	403	0.44	0.38	0.18	-0.26	-0.20
				26	4405	8608	1418	2592	51	249	407	0.34	0.35	0.17	-0.17	-0.18
4	FI 130	FI 120	25	21	13271	12708	5571	5233	108	117	643	0.51	0.52	0.48	-0.03	-0.04
				22	7015	9524	4719	6314	106	119	488	0.42	0.43	0.47	+0.05	+0.04
				23	9622	11747	4892	5959	106	119	813	0.45	0.45	0.47	+0.02	+0.02
				24	7381	7069	4472	6128	107	118	218	0.51	0.42	0.48	-0.03	+0.06
				25	10242	11283	4864	5984	103	122	329	0.48	0.45	0.46	-0.02	+0.01
				26	14138	16527	4714	5809	108	117	748	0.46	0.45	0.48	+0.02	+0.03
5	FI 35	FI 120	17	21	6258	4907	3374	2292	236	64	486	0.56	0.60	0.79	+0.23	+0.19
				22	6642	3343	3752	1919	238	62	432	0.67	0.66	0.79	+0.12	+0.13
				23	8566	6057	3057	2584	234	66	506	0.59	0.54	0.78	+0.20	+0.24
				24	5985	2813	2772	2765	235	65	397	0.68	0.50	0.78	+0.10	+0.28
				25	8603	3334	3551	2003	236	64	351	0.69	0.64	0.79	+0.10	+0.15
				26	7037	7233	2726	2733	235	65	473	0.49	0.50	0.78	+0.29	+0.28

6	FI 170 FI 120	17	21	9366	14455	4975	7419	90	135	576	0.39	0.40	0.40	+0.01	0
			22	6790	11701	4509	7581	90	135	773	0.37	0.37	0.40	+0.03	+0.03
			23	9380	18083	4722	7062	92	133	1105	0.34	0.40	0.41	+0.07	+0.01
			24	7322	10448	4679	7079	90	135	695	0.41	0.40	0.40	-0.01	0
			25	10972	13850	3804	7877	90	135	731	0.44	0.33	0.40	-0.04	+0.07
			26	13690	18623	4884	6819	95	130	973	0.42	0.42	0.42	0	0
7	FI 12 FI 120	20	21	4788	10	1773	2	299	1	1	1.00	1.00	1.00	0	0
			22	2910	69	1798	62	297	3	19	0.98	0.97	0.99	+0.01	+0.02
			23	5184	683	1541	275	278	22	122	0.88	0.85	0.93	+0.05	+0.08
			24	3229	345	1503	324	281	19	122	0.90	0.82	0.94	+0.04	+0.12
			25	6495	197	1662	87	289	11	40	0.97	0.95	0.96	-0.01	+0.01
			26	4961	325	1718	93	292	8	42	0.94	0.95	0.97	+0.03	+0.02
8	FI 220 FI 120	21	21	3916	14113	2067	9009	66	129	336	0.22	0.19	0.34	+0.12	+0.15
			22	6874	8750	5458	7588	70	125	801	0.44	0.42	0.36	-0.08	-0.06
			23	6171	12914	3664	7344	70	125	772	0.32	0.33	0.36	+0.04	+0.03
			24	4310	9216	3276	7813	65	130	419	0.32	0.30	0.33	+0.01	+0.03
			25	6544	13868	4812	6683	66	129	342	0.32	0.42	0.34	+0.02	-0.08
			26	11441	15740	5400	7865	70	125	806	0.42	0.41	0.36	-0.06	-0.05
9	FI 50 FI 120	18	21	7211	3862	5528	2383	224	76	343	0.65	0.70	0.75	+0.10	+0.05
			22	7085	3064	5562	2338	222	78	381	0.70	0.70	0.74	+0.04	+0.04
			23	5735	3881	4909	2718	223	77	454	0.60	0.64	0.74	+0.14	+0.10
			24	4575	2893	4206	3250	218	82	330	0.61	0.56	0.73	+0.12	+0.17
			25	10792	5070	4813	2817	222	78	376	0.68	0.63	0.74	+0.06	+0.11
			26	8995	8499	4197	3269	215	85	414	0.51	0.56	0.72	+0.21	+0.16
10	FI 12 FI 120	16	21	4435	378	1786	147	271	29	64	0.92	0.92	0.90	-0.02	-0.02
			22	3117	262	2016	255	275	25	80	0.92	0.89	0.92	0	+0.03
			23	5229	562	1581	358	272	28	240	0.90	0.82	0.91	+0.01	+0.09
			24	2553	274	1754	176	273	27	88	0.90	0.91	0.91	+0.01	0
			25	4105	457	1875	164	272	28	76	0.90	0.92	0.91	+0.01	-0.01
			26	6912	456	1695	230	273	27	100	0.94	0.98	0.91	-0.03	+0.03
11	FI 480 FI 240	24	21	3397	11322	1631	7309	30	60	316	0.23	0.18	0.33	-0.10	-0.15
			22	3264	8043	2891	6691	30	60	330	0.29	0.30	0.33	+0.04	+0.03
			23	4019	9925	2972	6284	30	60	512	0.29	0.32	0.33	+0.04	+0.01
			24	2077	7578	1866	7337	30	60	143	0.22	0.20	0.33	+0.11	+0.13
			25	4664	10778	2853	6556	30	60	154	0.30	0.30	0.33	+0.03	+0.03
			26	3748	11735	1853	7394	30	60	270	0.24	0.20	0.33	+0.09	+0.13
12	FI 36 FI 48	27	21	4133	2118	1712	1385	176	124	260	0.66	0.55	0.59	-0.07	+0.04
			22	3485	2961	1800	1627	170	130	235	0.54	0.53	0.57	+0.03	+0.04
			23	3740	2746	2069	1443	181	119	275	0.58	0.59	0.60	+0.02	+0.01
			24	2899	2072	1799	1729	166	134	208	0.58	0.51	0.55	-0.03	+0.04
			25	4624	4631	2032	1544	171	129	237	0.50	0.57	0.57	+0.07	0
			26	6027	5094	1929	1489	184	116	341	0.54	0.56	0.61	+0.07	+0.05

120-sec, *conc* FI 130-sec FI 120-sec, *conc* FI 170-sec FI 120-sec, *conc* FI 220-sec FI 120-sec, and *conc* FI 480-sec FI 240-sec), typical FI patterns occurred on neither of the two schedules. All the experimental conditions producing these first two types of performance conformed closely with Equation 1 (Table 1 and Figure 1). In the third group (the two conditions of *conc* FI 25-sec FI 120-sec, *conc* FI 50-sec FI 120-sec, and *conc* FI 35-sec FI 120-sec), performance on the shorter FI schedule showed typical FI patterns, while performance on the longer showed VI-like patterns. None of the conditions in this third group conformed to Equation 1.

This analysis is also supported by the changeover data in Table 1. We would expect that the number of changeovers per reinforcement would be greatest when both performances were VI-like, lower when only one of the performances was VI-like, and lowest (approaching one changeover per reinforcement) when both performances were typical FI patterns. The data in Table 1 order the experimental conditions in exactly this way.

This experiment has shown two distinct conditions under which matching occurs in concurrent FI FI schedules: when typical FI patterns of behavior occur on both schedules, and when typical VI-like patterns occur on both schedules. When the patterns of responding on the two schedules are different, the matching relation does not hold. It remains to predict the conditions under which these patterns occur. Generally, when the schedule on the green key was FI 120-sec, typical FI patterning was shown on the red key in intervals shorter than 50 sec. The only case in which typical FI patterning was seen in FI 120-sec was when this schedule was concurrent with FI 12-sec. When these schedules were independent, the animals very occasionally responded on the FI 120-sec schedule, normally sometime after reinforcement became due. When the schedules were non-independent, the animals generally responded on the FI 12-sec schedule until more than 12 sec had elapsed without reinforcement. At this point, they changed over to the FI 120-sec schedule and responded until reinforcement was presented. In this latter performance, then, reinforcement omission on one schedule was probably discriminative for the availability of reinforcement on the other schedule (Catania, 1966,

Fig. 2. Typical cumulative records from the various concurrent FI FI schedules. Each pair of records is of responses on the red key (upper) and the green key (lower) in one session. The number of the animal is shown by each pair of records, and the experimental condition is shown below each pair of records.

p. 230). While both of these performances might constitute special cases, typical FI patterning also occurred on *conc* FI 36-sec FI 48-sec without the availability of reinforcement on one key being signalled either by reinforce-

ment or its omission on the other key. This is shown by substantially more reinforcements being obtained on the FI 36-sec schedule than on the FI 48-sec schedule (Table 1). The reasons for the different patterns of behavior therefore remain obscure, although we might suggest that typical FI patterning might be the rule for all schedules shorter than 50 sec when they were run concurrently. The present research suggests that, for all these schedules, performance would conform to Equation 1.

Finally, the present results and those reported by Trevett *et al.*, (1972), highlight the importance of the pattern of responding in determining whether two concurrent schedules produce performance which conforms to Equation 1. Trevett *et al.*, studying concurrent FI VI schedule performance, reported typical FI patterns of responding on the FI schedule, and found a constant proportional preference for the VI schedule (Equation 2). Essentially the same effect occurred in the present experiment for the four conditions in which performance was patterned differently on the two concurrent schedules. If these data are graphed as in Figure 1, but towards the schedule with the typical FI pattern, all the points fall below the matching line, and Equation 2 or 3 would be a reasonable approximation to these data. These results suggest that whether a concurrent interval schedule performance conforms to Equation 1, or to some other form of Equation 4, may be dependent on the patterns of behavior produced rather than the schedules arranged.

REFERENCES

- Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.
- 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.
- Findley, J. D. Preference and switching under concurrent operants. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 123-144.
- Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 267-272.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.
- Nevin, J. A. Rates and patterns of responding with concurrent fixed-interval and variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 241-247.
- Rachlin, H. C. On the tautology of the matching law. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 249-251.
- Schneider, B. A. A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 677-687.
- Stubbs, D. A. and Pliskoff, S. S. Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 887-895.
- Trevett, A. J., Davison, M. C., and Williams, R. J. Performance in concurrent interval schedules. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 369-374.

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