MATCHING UNDER CONCURRENT FIXED-RATIO VARIABLE-INTERVAL SCHEDULES OF FOOD PRESENTATION¹

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Four pigeons were exposed to concurrent fixed-ratio, variable-interval schedules of food presentation. The fixed-ratio requirement was either 25, 50, 75, or 100 responses, with the variable-interval schedule parameter held constant at 4 minutes. A delay time was imposed between a changeover from one schedule to the other and subsequent food availability. The delay time was varied at each ratio requirement over four values; no delay, 0-second delay, 1.5-second delay, and 5.0-second delay. As the fixed-ratio requirement or the delay time increased, a greater proportion of the total responses and time spent responding occurred under the variable-interval schedule relative to the proportion of food deliveries under that schedule. Neither relative overall response rate nor relative time spent responding equalled the relative frequency of food presentation, as would be predicted by a linear "matching" model. Rather, these data were described by power functions with slopes of approximately 1.0 and intercepts greater than 1.0. In the terms of Baum's (1974) analysis, these deviations from linear matching represent bias in favor of responding under the interval schedule. Bias, as reflected in the intercept of the power function, was greater for the ratio of time than the ratio of responses.

Key words: concurrent schedules, fixed-ratio schedule, variable-interval schedule, change-over delay, matching, pigeons

Under concurrent schedules, reinforcement is typically arranged by two independent and simultaneously operating schedules of reinforcement. Of major interest in the investigation of behavior controlled by concurrent schedules has been the quantitative relation between response rate and reinforcement frequency called matching. According to one formulation (Herrnstein, 1961, 1970), the proportion of responses emitted under a schedule is equal to the proportion of reinforcements under that schedule. This relation is expressed as

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

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where P represents number of responses or overall response rate and R represents number of reinforcements or overall reinforcement frequency. The subscripts refer to different schedules. A considerable amount of data from concurrent variable-interval variable-interval schedules (*conc VI VI*) support this formulation (*cf.* Herrnstein, 1970). An alternative formulation expresses the relation between responding and reinforcement under concurrent schedules as a power function (Baum, 1974). In this case,

$$\frac{P_1}{P_2} = k \left[\frac{R_1}{R_2} \right]^a \quad (2)$$

Again, P is number of responses, R is number of reinforcements, and the subscripts refer to different schedules. When the coefficient k and the exponent a both equal 1.0, then equation (2) can be written as equation (1). Thus, equation (2) expresses a more general quantitative relation. There are also data supporting this formulation (*cf.* Baum, 1974).

Most experiments with concurrent schedules other than *conc VI VI* do not support a linear matching function as described by Equation 1. For example, Baum's (1974) analysis of re-

sponding maintained under concurrent fixed-interval fixed-ratio schedules (*conc* FI FR; LaBounty and Reynolds, 1973) indicated that slopes of the functions relating both the response and the time ratios to the reinforcement ratio were consistently less than 1.0. In addition, the intercepts showed a "response bias" toward the FI schedule. This bias was greater for the ratio of time spent responding under the FI schedule than it was for the ratio of responses emitted during that schedule. Under *conc* FI VI schedules (Nevin, 1971; Trevett, Davison, and Williams, 1972), a similar analysis indicated similar effects; functions relating responses and time ratios with reinforcement ratios had slopes less than 1.0 and intercepts that indicated a "response bias" toward the VI schedule. Deviations from a linear matching function have been reported for responding under *conc* FI FI schedules (White and Davison, 1973), *conc* VI VR schedules (Baum, 1974), and *conc* VR VR schedules (Herrnstein and Loveland, 1975). In fact, of the 10 possible concurrent pairings of VI, VR, FI, and FR schedules for which quantitative data are available, the only pairing for which data are consistent with a linear matching function are from *conc* VI VI (but see Trevett *et al.*, 1972). Quantitative data are available on all but *conc* FI VR and *conc* VI FR schedules (see Herrnstein, 1970 for *conc* VI VR and a theoretical discussion of *conc* FR FR schedules). The present experiment supplied data from *conc* VI FR schedules.

The present experiment also studied the generality of each of the two quantitative formulations of matching. Responding on one key was maintained under a fixed-ratio schedule of food presentation and responding on another key was maintained under a variable-interval schedule of food presentation. According to Herrnstein's formulation, the occurrence of matching under these conditions should be in accordance with the following equation:

$$\frac{P_1}{P_1 + P_2} = \frac{pR_1}{pR_1 + xR_2}, \quad (3)$$

where p equals the FR requirement and x represents the responses emitted per reinforcement under the VI schedule. The value of p is fixed, being specified by the fixed-ratio requirement. The value of x is free to vary, since the organism can emit more or fewer responses

per reinforcement by varying its response rate. However, for matching according to Equation (3) to occur, x must equal p . In the present experiment, the FR requirement was varied but the average time for availability of food under the VI schedules was kept constant. That is, p was varied to assess whether the number of responses emitted under the variable-interval schedule (x) matched the fixed-ratio requirement (p).

In line with Baum's formulation, manipulation of the FR requirement should yield a power relation between the ratio of responses and the ratio of food deliveries under a schedule. Under logarithmic transformation, the power function becomes a linear function (*e.g.*, $\log (P/P) = a \log (R/R) + \log k$). When a (the slope) equals 1.0, matching is said to occur. A "bias" may also occur with values of k (the intercept) other than zero. "Bias" is a uniform displacement away from the locus of matching described by Equation 1, resulting from arrangement of qualitatively different schedules or events (Baum, 1974). "Bias" occurs when more responses are emitted per reinforcement under one schedule than under the other schedule.

Although early interest was focused on the relation between responses and reinforcement frequency (response matching), there is also recognition of a relation between time spent under each schedule and reinforcement frequency (time matching). Time matching and response matching are confounded when local response rates (based on time spent responding under each schedule) are equal. For instance, the proportion of all responses emitted under one schedule may change simply because a greater percentage of the total session time is spent responding under one or the other schedule. Time matching has been reported when responding was partially eliminated under one schedule (Silberberg and Fantino, 1970; Bauman, Shull, and Brownstein, 1975) and when responding under each schedule was absent (Baum and Rachlin, 1969; Brownstein and Pliskoff, 1968).

The present study further investigated time matching and response matching in two ways. First, by presenting food under FR and VI schedules, different local response rates would be expected under each schedule. Therefore, the confounding of the proportion of responses and the proportion of time spent re-

sponding (due to equal local response rates) was eliminated. Second, time was measured in two ways: either from time spent responding under each schedule (key time) or from time spent depressing a floor panel located beneath each key (floor time). The presence of floor panels in the present study allowed a comparison of these two measures of time within the same experiment.

A delay (changeover delay; COD) between a changeover from one schedule to the other and the possibility of reinforcement is necessary to obtain matching under *conc VI VI* schedules (Catania, 1963; Herrnstein, 1961). Increasing the COD decreases the frequency of changeovers between schedules, as well as changes in relative and overall response rate and reinforcement frequency (Allison and Lloyd, 1971; Brownstein and Pliskoff, 1968). The importance of the COD with schedules other than *conc VI VI* and the effect of changes in COD on matching under other concurrent schedules has not been reported. The present experiment studied effects of different COD durations under *conc FR VI* schedules.

METHOD

Subjects

Four adult male homing pigeons were maintained at 80% of their free-feeding weights with unrestricted access to water and grit in the home cages. Responding for all pigeons had previously been maintained under a *conc VI 2-min VI 4-min* schedule with a 1.5-sec COD.

Apparatus

The experimental space measured 37 by 61 by 26.5 cm and was surrounded by sound-attenuating particle board. Three walls were constructed of wood and painted flat black. The front wall was aluminum. The floor was constructed of two equal wood and wire-mesh panels. Each floor was hinged to the rear wall and supported underneath on two microswitches. A force of 0.15 N, measured from the sides of each panel at the center, activated each microswitch. Depression of microswitches under each panel accumulated time on separate counters. Time accumulated on another counter when both floor panels were depressed simultaneously. Two 2-W houselights were mounted on the rear wall 1.5 cm from each

corner. Also on the rear wall was a ventilation fan and an aperture of a closed-circuit television camera.

Mounted on the front wall were two Gerbrands pigeon keys (21 cm apart), which could be transilluminated by 2-W white lights. Each key required a force of 0.10 N to record a response. The center of each key was 20 cm from the closer side and 11 cm from the floor. Two 7- by 5-cm apertures through which mixed grain could be made available were centered below each key 5 cm above the floor. Experimental events were arranged with solid-state circuitry (K-Logic, Digital Equipment Corp.). The experimental chamber was located in a room supplied with white noise, isolated from programming and recording devices.

Procedure

Responding on the right key was maintained under a VI 4-min schedule and responding on the left key was maintained under an FR 25, 50, 75, or 100 schedule. The VI schedule was composed of 20 intervals drawn from an arithmetic distribution arranged in an irregular order. Reinforcement consisted of a 2.5-sec presentation of grain. During food delivery, keylights and houselights were turned off and the hopper below the key on which the response was to be reinforced was raised into place. A 2-W light illuminated the hopper. The VI tape programmer stopped while reinforcement was set up. The sequence of conditions and the number of sessions in each condition are shown in Table 1. When COD was varied, the changeover response could produce food under the "no-COD" condition, whereas at least two responses were required to produce food under the "0-sec COD" condition. The first response on the key switched to initiated the delay time under the 1.5-sec and 5.0-sec COD conditions. Time spent responding under a particular schedule was accumulated beginning with a response under one schedule and stopping with a response under the other schedule. Time spent standing on a floor panel was accumulated when one floor panel was depressed, and stopped when that floor panel was released and the other floor panel was depressed.

Sessions terminated after 45 food deliveries or 1 hr, whichever occurred first, and were conducted seven days a week.

Table 1

Order of exposure to and number of sessions conducted in each experimental condition for all subjects.

<i>FR</i>		<i>Number of Sessions</i>			
<i>Requirement</i>					
<i>COD</i>		<i>50K</i>	<i>51K</i>	<i>52K</i>	<i>53K</i>
	<i>VI VI →</i>	<i>134</i>	<i>131</i>	<i>129</i>	<i>133</i>
25	- 1.5	38	40	40	41
25	- 0	49	47	60	84
25	- NO	40	40	28	26
50	- 1.5	38	51	40	21
50	- 0	35	21	34	31
50	- NO	22	22	22	22
75	- NO	33	22	22	20
75	- 0	32	29	32	30
75	- 1.5	44	54	50	50
100	- NO	25	22	42	46
100	- 0	6*	44	41	31
100	- 1.5	—	31	20	28
25	- 5	—	26	26	25
50	- 5	—	23	22	22
75	- 5	—	24	30	20
100	- 5	—	22	21	22

*Subject 50K died during this condition.

RESULTS

Table 2 shows major effects of each ratio requirement and COD value. Columns show average effects for the last five sessions under each condition. Local rates were calculated by dividing by time spent under a particular schedule; overall rates were calculated by dividing by the total session time.

Figure 1 shows the relation between overall response rate under each schedule and the frequency of reinforcement under the FR schedule. Response rate under the VI schedule (solid lines) decreased and response rate under the FR schedule (dotted lines) increased as the reinforcement frequency under the FR schedule increased. When reinforcement frequencies under each schedule were approximately equal (15 reinforcements per hour), overall response rates were higher under the VI schedule than under the FR schedule.

Changes in COD (indicated by different symbols) had no systematic effect on overall response rates. Frequency of reinforcement under the FR schedule was inversely related to the FR requirement (Table 2, columns 3 and 4). Overall reinforcement frequency under the VI schedule, however, remained constant as the FR requirement changed (Table 2, column 2). The general decrease in response rate under the VI schedule shown in Figure 1,

therefore, did not result from decreases in overall reinforcement frequency under the VI schedule.

Figure 2 shows the relation between the proportion of total responding under the VI schedule (relative response rate) and the proportion of total reinforcement obtained under the VI schedule (relative reinforcement frequency). In all cases, perfect response matching would be described by a function passing through the origin with a slope of 1.0. Note that relative overall response rate is mathematically equivalent to the relative number of responses, since the time base used in calculating overall rates under each schedule is the same.

In the present experiment, a negatively accelerated, increasing function described the relation between relative overall response rate and relative reinforcement frequency (Figure 2, top row). Thus, relative overall response rate under the VI schedule was not directly proportional to relative reinforcement frequency under that schedule. Relative local response rate (bottom row) was unaffected by changes in relative reinforcement frequency.

Figure 3 shows relations between proportion of total reinforcement obtained under the VI schedule (relative reinforcement) and proportion of total time spent both responding (key time) under the VI schedule (top row) and standing on the panel in front of the response key (floor time) associated with the VI schedule (second row). In general, relative time spent responding under the VI schedule and relative time spent standing in front of the VI key were both a negatively accelerated, increasing function of relative reinforcement obtained under the VI schedule, although the relative floor time functions were more variable. Neither of the two measures of relative time spent under the VI schedule was directly proportional to relative reinforcement under the VI schedule.

Figure 4 shows the relation between both ratio of overall response rate (top row) and ratio of time spent responding (bottom row) and ratio of reinforcement under the VI schedule. Points in Figure 4 are plotted in logarithmic coordinates. For 53K under *conc* FR 25 VI 4-min with CODs of 1.5 and 5.0 sec, the ratio of responses and the ratio of time equalled zero and were not included in Figure 4. The lines through the points in Figure 4

Table 2

These data are means from the last five sessions under each condition. Columns 1 and 2 are the local and overall reinforcement frequencies under the VI schedule; columns 3 and 4 show the same data from under the FR schedule. Columns 5 and 6 show the time spent responding under the VI and FR schedules in hours per session. The sum of columns 5 and 6 represents the total session time. Columns 7 and 8 show the number of food deliveries under each schedule. Local response rates under each schedule are shown in columns 9 and 10. Changeover rates between keys and switching rates between floor panels are shown in columns 11 and 12.

FR		RFT/HR				Key-Time		No. of RFTS		Local Rate		CO/Min (key)	Switch/ Min (floor)
		VI		FR		(hours)				(R/min)			
		Local	Overall	Local	Overall	VI	FR	VI	FR	VI	FR		
	COD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Subject 50K													
25	No	105.9	20.0	591.8	480.0	0.017	0.073	1.8	43.2	68.4	249.9	14.5	27.0
	0	39.3	15.1	475.6	361.6	0.056	0.090	2.2	52.8	56.5	201.9	8.6	19.1
	1.5	200.0	9.2	532.5	508.0	0.004	0.083	.8	44.2	73.8	226.2	1.2	2.3
	5	—	—	—	—	—	—	—	—	—	—	—	—
50	No	23.5	14.7	275.5	103.4	0.238	0.143	5.6	39.4	49.2	233.0	3.6	17.2
	0	24.9	13.9	304.5	134.7	0.169	0.134	4.2	40.8	52.9	256.7	4.8	16.4
	1.5	31.7	15.3	227.4	117.4	0.164	0.175	5.2	39.8	66.9	192.3	4.2	10.8
	5	—	—	—	—	—	—	—	—	—	—	—	—
75	No	20.0	14.3	170.6	48.7	0.510	0.204	10.2	34.8	22.4	215.3	2.9	18.9
	0	19.9	15.2	197.7	47.0	0.552	0.172	11.0	34.0	35.6	249.9	2.2	12.7
	1.5	16.9	14.5	139.0	19.8	0.851	0.141	14.4	19.6	55.6	172.9	1.3	12.7
	5	—	—	—	—	—	—	—	—	—	—	—	—
100	No	14.9	14.5	96.3	2.6	0.979	0.027	14.6	2.6	51.9	139.4	0.2	8.7
	0	—	—	—	—	—	—	—	—	—	—	—	—
	1.5	—	—	—	—	—	—	—	—	—	—	—	—
	5	—	—	—	—	—	—	—	—	—	—	—	—
Subject 51K													
25	No	58.5	15.3	367.2	271.3	0.041	0.116	2.4	42.6	36.8	151.5	8.6	8.5
	0	73.2	21.4	424.2	300.0	0.041	0.099	3.0	42.0	39.5	175.0	9.6	11.0
	1.5	93.5	14.0	326.7	277.9	0.023	0.131	2.15	42.8	74.9	135.2	2.8	4.5
	5	85.7	11.5	320.0	276.9	0.021	0.135	1.8	43.2	58.4	130.9	1.1	2.7
50	No	31.4	15.1	197.0	102.1	0.185	0.199	5.8	39.2	65.8	163.5	3.5	13.6
	0	21.9	15.6	182.2	53.0	0.465	0.191	10.2	34.8	54.5	151.3	3.2	12.3
	1.5	22.4	15.9	205.8	60.1	0.419	0.173	9.4	35.6	55.5	172.3	2.1	6.4
	5	11.8	14.5	160.6	21.4	0.858	0.132	14.4	21.2	53.8	133.5	0.7	4.6
75	No	16.6	14.2	105.0	14.8	0.855	0.141	14.2	14.8	53.1	133.3	1.0	10.4
	0	17.0	14.2	91.4	14.8	0.834	0.162	14.2	14.8	56.3	114.2	3.1	23.0
	1.5	15.9	13.1	101.0	9.6	0.984	0.103	14.3	10.4	62.7	126.2	0.6	9.3
	5	16.5	15.2	82.6	7.6	0.920	0.078	15.2	7.6	49.8	121.4	0.3	4.7
100	No	15.9	15.1	79.2	4.2	0.941	0.053	15.0	4.2	66.8	127.4	0.2	7.3
	0	12.0	14.5	69.0	2.0	0.975	0.029	14.6	2.0	93.7	122.6	0.3	9.2
	1.5	16.1	14.6	78.3	7.2	0.905	0.092	14.6	7.2	57.0	129.8	0.4	4.3
	5	15.8	14.8	78.8	5.2	0.932	0.065	14.8	5.2	60.2	126.8	0.3	5.4
Subject 52K													
25	No	62.9	13.6	337.0	264.2	0.035	0.127	2.2	42.8	34.7	139.8	5.2	12.2
	0	87.5	18.1	343.1	272.2	0.032	0.123	2.8	42.2	34.4	142.3	4.2	9.7
	1.5	66.7	12.6	333.3	270.4	0.030	0.129	2.0	43.0	33.7	139.1	1.3	5.4
	5	48.0	7.0	302.1	251.6	0.025	0.145	1.2	43.8	15.1	125.6	1.1	8.2
50	No	49.1	16.4	189.5	125.9	0.106	0.210	5.2	39.8	33.0	150.1	4.5	10.8
	0	36.9	14.8	188.6	113.1	0.141	0.211	5.2	39.8	51.8	156.7	4.1	9.9
	1.5	38.7	15.4	261.3	104.2	0.150	0.226	5.8	39.2	70.9	144.2	3.7	5.2
	5	22.2	14.9	368.9	49.6	0.469	0.229	10.4	34.6	52.0	126.0	1.3	5.4
75	No	29.6	14.9	99.7	49.6	0.351	0.347	10.4	34.6	40.0	123.8	5.0	8.8
	0	19.2	14.6	102.6	24.4	0.751	0.234	14.4	24.0	43.4	127.6	2.8	11.0
	1.5	18.2	14.8	104.8	19.8	0.801	0.187	14.6	19.6	60.0	132.9	1.2	8.4
	5	19.6	15.4	106.5	23.0	0.775	0.214	15.2	22.8	52.8	134.0	0.9	3.1

Table 2 continued.

FR		COD		RFT/HR				Key-Time (hours)		No. of RFTS		Local Rate (R/min)		CO/Min (key) (11)	Switch/ Min (floor) (12)
				VI		FR						VI	FR		
				Local	Overall	Local	Overall	VI	FR	VI	FR				
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				
Subject 53K	100	No	16.3	15.2	68.6	4.8	0.931	0.070	15.2	4.8	54.8	111.2	1.0	4.7	
		0	16.5	15.5	71.0	4.4	0.934	0.062	15.4	4.4	56.2	112.0	0.6	5.6	
		1.5	15.8	15.3	68.6	2.4	0.961	0.035	15.2	2.4	51.6	111.6	0.3	3.2	
		5	16.4	15.0	76.4	6.8	0.912	0.089	15.0	6.8	50.1	124.9	0.4	2.0	
	25	No	112.5	17.6	502.3	423.5	0.016	0.086	1.8	43.2	69.6	212.1	12.4	9.1	
		0	106.7	15.7	498.8	425.5	0.015	0.087	1.6	43.4	97.2	212.3	11.7	10.0	
		1.5	0.0	0.0	384.6	384.6	0.000	0.117	0.0	45.0	0.0	163.8	0.0	0.0	
		5	0.0	0.0	463.9	463.9	0.000	0.097	0.0	45.0	0.0	194.8	0.0	5.0	
	50	No	80.0	15.5	289.0	233.1	0.035	0.146	2.8	42.2	89.1	242.6	7.7	9.9	
		0	69.8	15.6	281.9	218.8	0.043	0.149	3.0	42.0	146.5	236.1	7.4	9.5	
		1.5	62.1	17.8	287.5	204.9	0.058	0.144	3.6	41.4	175.3	216.2	6.0	3.2	
		5	34.8	15.4	241.9	135.1	0.132	0.167	4.6	40.4	122.5	203.0	4.0	8.6	
	75	No	38.8	14.9	177.6	109.4	0.139	0.223	5.4	39.6	76.9	222.7	3.4	10.0	
		0	34.5	15.4	152.0	83.9	0.203	0.250	7.0	38.0	81.2	194.0	3.7	9.2	
		1.5	25.1	15.9	160.2	58.6	0.383	0.221	9.6	35.4	99.2	201.2	2.3	7.5	
		5	24.2	15.5	167.3	60.3	0.380	0.214	9.2	35.8	122.6	209.4	2.2	4.6	
100	No	19.5	15.0	123.7	28.2	0.729	0.215	14.2	26.6	79.1	205.9	1.3	8.6		
	0	19.9	15.5	120.9	26.8	0.755	0.215	15.0	26.0	89.0	204.9	1.1	5.7		
	1.5	18.5	14.4	118.0	26.0	0.768	0.217	14.2	25.6	92.2	197.3	1.2	8.6		
	5	18.0	14.6	112.8	21.4	0.801	0.188	14.4	21.2	101.4	188.2	0.9	5.4		

were obtained from a least squares linear regression analysis. The equations for these lines are shown in the figure. The data from each COD condition were combined in obtaining the regression lines because COD (different symbols) did not systematically affect the slope or intercept. A similar analysis was not conducted for floor time because of the larger variability and indications that the intercepts and slopes calculated separately for each COD condition were larger under the 1.5- and 5.0-sec CODs than under the no- and zero-COD conditions.

The relations shown in Figures 2 and 3 can be described by a power function of the form $Y = kX^a$, which under logarithmic transformation becomes $\log Y = a \log X + \log k$. This equation describes the data as plotted in Figure 4, with the exponent a equal to the slope and the coefficient k equal to the intercept of a linear function. The slope of all regression lines in Figure 4 is approximately equal to 1.0, although slopes for relative response rate (top row) were consistently greater than those for relative time spent responding (bottom row). The intercepts, on the other hand, were greater for relative time under the VI schedule. All intercepts were greater than zero.

The intercepts of these functions further indicate that matching between relative reinforcement under the VI schedule and either relative response rate or relative time spent responding under the VI schedule was not in accordance with Equations 1 and 3. In all cases, pigeons emitted more responses and spent more time responding under the VI schedule than predicted by a matching function with an intercept equal to zero.

For all data reported, the FR schedule was correlated with responding on the left key and the VI schedule with responding on the right key. It could be argued, therefore, that irrespective of schedule conditions more responses and time would have been spent responding on the right key. Two conditions, however, suggest otherwise. First, under prior exposure to the *conc* VI 2-min VI 4-min schedule, two pigeons matched relative responses and relative time with relative reinforcement and two pigeons emitted more responses and spent more time responding under the VI 2-min schedule than would be predicted by matching. When next exposed to a *conc* FR 25 VI 4-min schedule, all pigeons emitted more responses and spent more time responding under the VI 4-min schedule, which was always

Fig. 1. Mean overall response rates (responses per minute) under each schedule as a function of overall frequency of reinforcement (reinforcements per hour) under the FR schedule. Data were derived from the means of the last five sessions under each schedule condition. Dotted lines represent response rates under the FR schedule; solid lines represent response rates under the VI schedule. Filled circles = no COD; open circles = 0-sec COD; squares = 1.5-sec COD; triangles = 5.0-sec COD.

correlated with the right key. Second, after exposure to the last conditions reported here and after administration of several drugs, the correlation of an FR 50 schedule with the left key and the VI 4-min schedule with the right key was reversed. Within several sessions, relative measures, as well as response patterns and response rates, also reversed for all pigeons. That is, more responses were emitted and more time was spent responding under a VI 4-min schedule than would be predicted by matching, regardless of whether the VI schedule was correlated with the left or right key. When the schedules were again reversed (VI-right;

FR-left) responding again followed the schedule change.

DISCUSSION

The present experiment obtained quantitative data on pigeon's key pecking under a *conc* FR VI schedule of food presentation. Pigeons spent more time responding and emitted more responses per food delivery under the VI schedule than predicted by matching using Equations 1 and 3. This was true regardless of the FR requirement and relative frequency of food presentations under the VI schedule.

Fig. 2. Relative overall response rates based on total session time and relative local response rates based on individual key time as a function of relative frequency of reinforcement. The relative measures were obtained by dividing the response rates (or reinforcement frequencies) under the VI schedule by the sum of these measures under the VI schedule and the FR schedule. The solid lines represent the theoretical matching function. Filled circles = no COD; open circles = 0-sec COD; squares = 1.5-sec COD; triangles = 5.0-sec COD.

A power function (Equation 2) with an exponent of about 1.0 described the relation between relative measures of both time spent responding and responses emitted to relative reinforcement frequency. These data support and extend previous reports of a power function relation between responding and reinforcement frequency (Baum, 1974; Baum and Rachlin, 1969; Nevin, 1971).

Analysis of responding under a variety of concurrent schedules has indicated that the exponent of the power matching function is often less than 1.0 (e.g., *conc* FI VI, Nevin, 1971; *conc* VI VI and *conc* FI VI, Trevett *et al.*, 1972; *conc* FI FI, White and Davison, 1973; and *conc* FI FR, LaBounty and Reynolds, 1973). Analysis of the present data (*conc* FR VI), as well as that from *conc* VR VI (Baum, 1974), indicated that the exponent under these conditions was more closely equal to 1.0.

The general form for matching under concurrent interval, ratio schedules according to

Herrnstein (1970) must correspond to Equation 3. In order for this form of "linear" matching to occur under *conc* FR VI schedules, x must equal p in Equation 3.

In the present study, x did not equal p . In fact, x was consistently greater than p . Each increase in p (the fixed-ratio requirement) resulted in a proportional increase in x (the number of responses per reinforcement under the VI schedule). The proportionality between x and p is represented in Figure 4 by a Y-intercept greater than zero. This type of relation has been called "biased matching" (Baum, 1974). According to a "biased matching" interpretation, the approximate slope of 1.0 in Figure 4 of the present experiment indicates matching between relative reinforcement and both relative time and relative response rate, but the intercept greater than zero reflects some form of bias toward the VI schedule. The precise conditions controlling the occurrence and direction of response bias have not been well studied, although possibilities in-

Fig. 3. Relative ($VI/VI+FR$) proportion of time spent responding on the VI key and relative time spent standing on the floor panel below the VI key as a function of relative frequency of reinforcement ($VI/VI+FR$). The relative measures were obtained by dividing the time (or reinforcements) accumulated under the VI schedule by the sum accumulated under the VI schedule plus the FR schedule. The solid lines represent the theoretical matching function. Filled circles = no COD; open circles = 0-sec COD; squares = 1.5-sec COD; triangles = 5.0-sec COD.

clude different key characteristics, spatial preferences, and schedules that are qualitatively different.

The bias found in the present experiment is not as likely to be accounted for by either physical characteristics of the apparatus or positional biases of the pigeons as by schedule characteristics, for at least two reasons. First, under exposure to a *conc* VI 2-min VI 4-min schedule, pigeons evidencing no bias or bias toward the VI 2-min (left key) all showed a change in bias toward the VI 4-min (right key) schedule after exposure to *conc* FR VI schedules. Second, a reversal of the pairing of schedules and keys indicated a complete reversal of bias. That is, bias toward the VI schedule remained the same whether the VI schedule was associated with responding on the left or right key under exposure to a *conc* FR 50 VI 4-min schedule.

In the present study, the intercepts of the

regression lines for the ratio of responses differed from the intercepts of the regression lines for the ratio of time spent responding. This result reflects differences in local response rates under each schedule. For example, if pigeons matched responses with reinforcement frequency, then the ratio of key time (VI/FR) would be greater than the ratio of responses, since local response rates under the VI schedule were lower than under the FR schedule. Similarly, if pigeons matched the time spent responding with reinforcement frequency, the ratio of responses would be less than the ratio of time for the same reason.

The present data do not clearly indicate a separation of response matching from time matching. The slopes of the regression lines for relative responses were consistently greater than those for relative key time, but both approximated a slope of 1.0. It is not possible to discriminate, therefore, between response allo-

Fig. 4. Ratios of overall response rates and ratios of key times are plotted on logarithmic coordinates as a function of the ratio of the reinforcements. Ratios were calculated by dividing the data obtained under the VI schedule by the data obtained under the FR schedule. The solid lines represent the theoretical matching function. The lines drawn through the points are the least squares regression lines for the data plotted. The equation for these lines are given in the lower right-hand corner. The data from each COD condition were used in the regression analysis. Filled circles = no COD; open circles = 0-sec COD; squares = 1.5-sec COD; triangles = 5.0-sec COD.

cation and time allocation as explanations of matching.

Both slope and intercept of Equation 2 have been theoretically related to different behavioral phenomena (Baum, 1974). However, the manipulation of either independent of the other has not been demonstrated empirically. Since it has been shown that the presence or absence of a COD will affect matching behavior (Catania, 1963; Herrnstein, 1961), the present study manipulated the COD in an attempt to determine if slope or intercept would be differentially affected. The results did not, however, conclusively answer the question of whether different variables control changes in intercept and slope. Duration of COD had no effect on either slope or intercept of the function relating relative reinforcement frequency with either relative response rate or relative time spent responding under the VI schedule. Larger variability was evident in the functions of relative floor time than in the functions for

relative key time. The data were insufficient to determine whether this difference was due to characteristics of the pigeons' response topography, to characteristics of the apparatus, or to basic differences between the behavioral measures of time allocated. Previous experiments have used both of these measures of time to compare response matching and time matching, but these two measures of time had not been compared directly (Baum and Rachlin, 1969; Brownstein and Pliskoff, 1968).

Deviations from matching have been reported when the COD is omitted, and also when the delay time is asymmetrical between two schedules (Pliskoff, 1971). Pliskoff reported that pigeons emitted more responses and spent more time in the presence of the schedule associated with the briefer COD. In the present study, the COD to the VI schedule was identical to the COD to the FR schedule. In addition to the COD, however, responding under the FR schedule entailed a further delay. This

delay resulted from the fact that a changeover response to the FR schedule was separated from food presentation by the time to complete the FR requirement. Under all conditions, responding under the FR schedule, once initiated, continued until food was presented. Instances of changeovers to the key associated with the VI schedule at times other than following food delivery under the FR schedule were rare. The minimum delay to reinforcement under each schedule was in practice asymmetrical in the present study.

According to this analysis, a comparison of the present data with *conc* VI VR schedules should show less bias in responses and time under the latter schedule, because under a *conc* VI VR schedule, delays between changeover responses and reinforcement would be less asymmetrical. As shown by Baum (1974), Herrnstein's data from *conc* VI VR schedules do show substantially less bias in responses and time than found in the present study.

Similarly, under *conc* FR FI schedules within the range of FR requirements reported in the present study, LaBounty and Reynolds (1973) found that responding under the FR schedule, once initiated, generally continued until food delivery without changeovers to the FI 4-min schedule. Responding under the FR schedule also generally occurred during the early part of the FI. Consequently, under these conditions the delay times were likely to be asymmetric, with the delay between a changeover to the FI schedule and food delivery occasionally being shorter than the delay between initiating the FR requirement and food delivery. In their study (see Baum, 1974; Figures 6 and 7), as in the present study, bias in both responses and time were found, with the bias in time consistently greater than the bias in responses. Similar findings of bias were obtained when the reinforcement contingency on each of two concurrently available keys was the termination of different length inter-response times (Moffitt and Shimp, 1971). That is, a response could be reinforced only if it terminated a time interval (2 to 3 sec, left key; 11 to 13 sec, right key) since the last response on the same key. These requirements are formally equivalent to the COD. Their data conformed to power functions with response bias toward the left key as the relative frequency of reinforcement for the shorter delay (left key) was varied between 0 and 1.0. However, an

alternative explanation of bias other than asymmetrical delays may also account for the data reviewed above: bias may result from the short interreinforcement intervals occasionally available on aperiodic, but not periodic schedules, irrespective of delay. There are insufficient data addressing these interpretations to indicate which, if either, is the more consistent description of biased matching.²

In the present study, relative overall response rate and relative time spent responding were related to relative frequency of reinforcement by a power function. The power function accounts for data from various qualitatively different schedules (Baum, 1974), as well as data from *conc* VI VI schedules. The power function, therefore, appears to be a general formulation of the relation between measures of relative responding and reinforcement under concurrent schedules. The presence of asymmetrical changeover delay times, whether arranged directly (Pliskoff, 1971) or indirectly (LaBounty and Reynolds, 1973; Moffitt and Shimp, 1971; the present study) by qualitatively different schedules, may be a major variable responsible for the occurrence of biased matching.

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