

**AN ANALYSIS OF RESPONSE AND TIME MATCHING TO
REINFORCEMENT IN CONCURRENT
RATIO-INTERVAL SCHEDULES¹**

CHARLES E. LABOUNTY AND G. S. REYNOLDS

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Key pecks by six pigeons were reinforced on concurrent fixed-interval fixed-ratio schedules. The value of the fixed-interval was held constant at 4 min while the fixed-ratio varied from 25 to 450 responses. All of the pigeons responded on, with pecks reinforced under, both of the schedules over most of the concurrent pairings, and four of the six distributed responses between the schedules such that matching was obtained between the proportions of responses and reinforcements. Previous studies using concurrent variable-interval schedules have shown that when response-reinforcement matching occurs, a comparable match of time to reinforcement proportions is obtained. In the present study, time devoted to each response alternative was measured from the first response on that alternative to a subsequent response on the other alternative. Using that measure, large differences existed in the local rates of responding on the two schedules, and a time-reinforcement match was not produced. These results indicate that in a situation where response-reinforcement and time-reinforcement matching are incompatible, the measurement of response proportions is the better means of evaluating the effects of reinforcement.

Experiments investigating responding under concurrent variable-interval (VI) schedules of reinforcement have shown repeatedly that, provided the response alternatives and the associated reinforcers are quantitatively equal, responses are distributed in such a manner that the proportion of responses emitted on each alternative matches the proportion of reinforcements provided by the schedule associated with that alternative (Herrnstein, 1970; Catania, 1966). If, for example, a pigeon's pecks on two response keys are reinforced on concurrent VI schedules, the bird distributes its pecks between the keys as follows:

$$\frac{P_R}{P_R + P_L} = \frac{R_R}{R_R + R_L} \quad (1)$$

where P is the total number of pecks on a key, R the total number of reinforcements provided for responses, and the subscripts R and L designate right and left keys.

Another matching relationship in concurrent VI schedules has been demonstrated between the proportion of time devoted to each

of the alternatives and the proportions of Equation (1) (Catania, 1963a). If T represents the time spent responding on each key:

$$\begin{aligned} \frac{P_R}{P_R + P_L} &= \frac{R_R}{R_R + R_L} \\ &= \frac{T_R}{T_R + T_L} \end{aligned} \quad (2)$$

A measure of the distribution of time between schedules occasions some procedural difficulties because it may be useful to assume that the organism engages in behaviors other than the recorded alternatives. If it is assumed that the tendency to emit such other behaviors (*i.e.*, pausing with regard to key pecking) is proportional to the frequency of key pecking under each schedule, then the inclusion of these times would not affect the proportional relationship between times devoted to the recorded alternatives. Time on each schedule could then be delimited (as in the present study) by the cumulative times between a response on one of the alternatives and a subsequent response on the other. On the other hand, attempts may be made to eliminate the times not devoted to one of the schedules. For example, interresponse times longer than a given duration may be excluded (Catania, 1961), or only those periods that the organism

¹This research was supported by NSF Grant GB-14099. The authors thank Alan J. Limpo for providing initial training of the pigeons. Reprints may be obtained from G. S. Reynolds, Department of Psychology, University of California, San Diego, P. O. Box 109, LaJolla, California 92037.

spends in specific schedule-related areas of the experimental space may be recorded (Baum and Rachlin, 1969).

However, since all of these experimental procedures depend upon various suppositions as to the nature, duration, and distribution of times spent in behaviors other than responding on one of the scheduled alternatives, the obtained proportions of time devoted to each of the two concurrent schedules must be viewed as, at best, an approximation dependent upon the measurement procedures.

Assuming that the present procedures provide a good approximation of the distribution of time between the schedules, the three-way relationship between responses, reinforcements, and times shown in Equation (2) is possible only if the local rates of responding on each key are the same. More specifically, the response-reinforcement matching described in Equation (1) may be interpreted as the result of distributing a roughly constant rate of responding between the two alternatives in blocks of time that are proportional to the relative rates of reinforcement (Catania, 1966).

If, however, one of the two schedules maintains a significantly higher rate of responding during the time devoted to it, a match between time and reinforcement proportions would result in an excess of response to reinforcement proportions on the schedule maintaining the higher rate. Conversely, a match between responses and reinforcements could be obtained only by distributing excess amounts of time to the schedule maintaining the lower rate of response.

While differences in local response rate are generally negligible in concurrent VI schedules, substantial rate differences might be expected if one of the alternatives is a ratio schedule. But there exists only sparse evidence concerning whether matching of either responses or time to reinforcement is obtained in concurrent ratio-interval schedules. Catania (1963*b*) reinforced pigeons' key pecking with a variety of concurrent fixed-interval fixed-ratio and variable-interval fixed-ratio schedules. The results indicated that, in general, as the rate of reinforcement increased for one of the alternatives, the proportion of responses on it increased while the proportion on the other decreased, but data confirming matching were not provided. Herrnstein (1970) reported that response-reinforcement matching by pigeons

was obtained over some values of concurrent variable-interval variable-ratio schedules. In that study, the variable ratio ranged from 20 to 160 responses and the variable interval from 15 sec to 2 min. Through most of the pairings, the birds responded exclusively on one key or the other, but, under a few of the conditions, responses were distributed between the keys in proportions close to those predicted by Equation (1). However, since the local rate of responding on the ratio key was approximately twice as high as that on the interval key, a time-reinforcement match was not obtained.

The present study examined responding by pigeons under concurrent fixed-interval fixed-ratio (*conc* FI FR) schedules in order to evaluate the effects of time and response parameters in matching. In addition, some limiting factors in the maintenance of concurrent responding under such schedules were evaluated.

METHOD

Subjects

Six adult male, White Carneaux pigeons were each maintained at approximately 80% of their free-feeding body weights. Each had previously been exposed to a variety of schedules of reinforcement.

Apparatus

The experimental chamber was a converted picnic ice-chest equipped with two response keys located 9 in. (22 cm) above the floor and 4 in. (10 cm) apart. The keys were transilluminated by colored lights mounted behind them. The key associated with the FR schedule (the left key) was blue, and that associated with the FI key, orange. During presentation of the reinforcer, 3 sec of access to mixed grain, the stimulus lights were turned off and the feeder opening illuminated. Standard electromechanical scheduling and recording equipment were located in a separate room.

Procedure

Each daily session provided a total of 30 reinforcements. Pecks were first reinforced on *conc* FI 4-min FR 150 responses until responding was stable from day to day with each pigeon distributing pecks between the keys and reinforcements occurring on both the FR and FI schedules. The fixed-ratio requirement was then varied over six additional values (25,

50, 100, 200, 300, and 450 responses) for each bird while the fixed-interval was held constant at 4 min. The order of presentation of the various FR conditions was determined by a 6×6 Latin Square design. A changeover delay (COD) was imposed during which reinforcement could not occur for 2.5 sec after a switch from responding on either key to responding on the other.

The reinforcement provided by each concurrent schedule was non-dependent upon the behavior being reinforced according to the other schedule. For example, a peck on the key associated with the FI 4-min schedule was reinforced if it occurred at least 4 min after the last FI reinforcement regardless of the number of reinforcements of pecks on the ratio key during the interval. Conversely, if the pigeon switched to the interval key after completing fewer than the required number of responses on the ratio key, those responses were still counted toward the completion of the ratio when the bird returned to the ratio key.

The constraint of the COD occasioned a possibility that if a pigeon completed the FR shortly after a switch from the interval key, responses in excess of the FR requirement might be emitted before the FR reinforcement. However, this rarely occurred during any of the experimental conditions.

After completion of all six FR conditions, every pigeon was exposed to an FI 4-min schedule with only the FI key illuminated and operative.

RESULTS

The data for each pigeon in each of the conditions are presented in Table 1. The data in Table 1 represent mean performances obtained over the final four sessions of each condition. For example, the proportion of FI responses was obtained by dividing the total number of pecks on the FI key by the total number of pecks on both keys during these four sessions.

Concurrent responding was obtained from all birds over a wide range of ratio requirements concurrent with the FI 4-min. Only when the FR schedule was FR 25 and FR 50 did the pigeons peck exclusively on either key. During these two conditions (with the exceptions of Pigeon 877 at *conc* FI 4-min FR 25

responses and Pigeons 877 and 867 at *conc* FI 4-min FR 50 responses) all of the birds pecked entirely on the ratio key. Over the remaining five values of the FR, all of the birds except one responded on, and received reinforcements under, both the ratio and interval schedules. The single exception was Pigeon 866 under *conc* FI 4-min FR 450 responses. In this condition, the bird made a few responses on the ratio key, but never enough during any session to obtain reinforcement.

Figure 1 shows cumulative records of responding by all the pigeons during the final session under *conc* FI 4-min FI 150-responses. The behavior represented here is typical of the pattern of responding obtained when the ratio values were FR 100, FR 150, and FR 200. All birds tended to peck the ratio key during the early part of each fixed interval. Responding on the ratio key was characterized by uninterrupted responding through complete ratios with changeovers to the FI key occurring after reinforcement under the ratio. During the early part of the interval, responses on the interval key usually occurred in short bursts after each FR reinforcement. Later in the interval there were longer, steady periods of responding that were terminated by FI reinforcement. Each pigeon occasionally spent an entire 4-min interval responding only on the FI key.

With larger ratios (FR 300 and FR 450), the characteristic behavior seen in Figure 1 was no longer apparent. Completed ratios without changeovers were infrequent, the number of changeovers increased, and the behavior of each pigeon became more idiosyncratic. Figure 2 contains portions of the cumulative records produced by each bird during the final session of *conc* FI 4-min FR 450. With the exception of Pigeon 866, all birds responded on both keys and received reinforcements under both schedules during this condition, but the patterns of responding differed widely among the pigeons. Pigeon 877 consistently emitted one to three moderately long periods of responding on the FR key (not necessarily completing the ratio, however) during the early part of each fixed interval, then responded exclusively on the interval key until FI reinforcement. Pigeon 867 alternated between periods of rapid response-burst exchanges between the keys and long periods of responding only on the FI key. Pigeons 875 and 447 made frequent

Table 1

Order of schedules; proportions of reinforcements, responses and time associated with the FI key; mean FI responses per interval; local rates of responding (responses per minute) on each key; changeovers per minute and number of sessions for each pigeon in each condition.

Pigeon	Schedule	Proportion of FI Reinforcements	Proportion of FI Responses	Proportion of Time on FI key	Mean FI Responses per Interval	Local FI Rate	Local FR Rate	CO's per Minute	Number of Sessions
867	FI 4 FR 150	0.575	0.769	0.797	375.4	114.2	138.0	1.09	15
	FI 4 FR 100	0.167	0.283	0.357	199.2	126.1	183.9	3.47	15
	FI 4 FR 300	0.767	0.769	0.847	317.2	90.1	151.4	0.53	6
	FI 4 FR 200	0.925	0.940	0.960	263.6	66.2	102.7	0.33	9
	FI 4 FR 25	0.000	0.000	0.000	—	—	136.0	—	9
	FI 4 FR 50	0.083	0.171	0.204	114.5	107.0	145.8	1.99	13
	FI 4 FR 450	0.733	0.727	0.795	439.7	132.8	194.5	2.24	25
	FI 4 Alone	—	—	—	437.3	107.6	—	—	49
464	FI 4 FR 150	0.217	0.291	0.566	223.3	95.0	329.0	2.20	15
	FI 4 FR 200	0.308	0.360	0.660	255.2	92.3	336.7	1.36	7
	FI 4 FR 450	0.867	0.858	0.944	423.1	111.5	315.5	0.16	50
	FI 4 FR 300	0.750	0.772	0.878	342.6	95.4	205.6	0.42	10
	FI 4 FR 50	0.000	0.000	0.000	—	—	232.3	—	9
	FI 4 FR 100	0.108	0.245	0.270	142.0	108.9	257.6	2.58	10
	FI 4 FR 25	0.000	0.000	0.000	—	—	268.3	—	8
	FI 4 Alone	—	—	—	195.2	106.1	—	—	49
875	FI 4 FR 150	0.500	0.659	0.825	293.9	86.8	224.5	0.53	15
	FI 4 FR 300	0.917	0.891	0.963	243.3	62.3	199.4	0.25	24
	FI 4 FR 25	0.000	0.000	0.000	—	—	205.6	—	6
	FI 4 FR 450	0.483	0.416	0.490	352.2	172.1	232.3	2.93	22
	FI 4 FR 100	0.117	0.134	0.239	119.2	98.2	209.8	2.82	11
	FI 4 FR 200	0.308	0.363	0.574	256.8	102.2	252.3	3.84	20
	FI 4 FR 50	0.000	0.000	0.000	—	—	232.4	—	10
	FI 4 Alone	—	—	—	246.7	60.5	—	—	42
877	FI 4 FR 150	0.433	0.419	0.617	141.9	55.1	126.0	0.70	15
	FI 4 FR 450	0.750	0.509	0.698	161.2	56.8	126.2	0.57	30
	FI 4 FR 50	0.150	0.359	0.455	159.0	75.9	124.3	1.65	51
	FI 4 FR 25	0.025	0.026	0.043	25.9	73.9	139.3	0.64	15
	FI 4 FR 200	0.583	0.569	0.707	189.3	66.2	122.4	1.12	36
	FI 4 FR 300	0.575	0.389	0.576	144.0	59.6	127.2	1.15	30
	FI 4 FR 100	0.392	0.519	0.626	167.4	67.1	108.1	1.39	16
	FI 4 Alone	—	—	—	196.0	48.4	—	—	8
447	FI 4 FR 150	0.533	0.641	0.757	238.0	76.3	137.4	0.93	15
	FI 4 FR 25	0.000	0.000	0.000	—	—	245.4	—	6
	FI 4 FR 100	0.300	0.516	0.679	251.4	88.4	188.5	1.95	30
	FI 4 FR 50	0.000	0.000	0.000	—	—	201.2	—	12
	FI 4 FR 300	0.675	0.636	0.616	268.4	104.2	95.0	2.13	19
	FI 4 FR 450	0.750	0.613	0.600	249.2	101.0	94.3	2.79	24
	FI 4 FR 200	0.383	0.373	0.427	192.2	105.9	133.8	5.18	25
	FI 4 Alone	—	—	—	312.9	76.8	—	—	23
866	FI 4 FR 150	0.350	0.347	0.687	147.1	50.7	219.8	1.35	15
	FI 4 FR 50	0.000	0.000	0.000	—	—	228.8	—	6
	FI 4 FR 100	0.450	0.344	0.682	129.0	46.2	194.4	1.08	20
	FI 4 FR 200	0.117	0.119	0.321	103.1	63.6	242.0	2.67	14
	FI 4 FR 450	1.000	0.996	0.995	169.0	42.0	—	0.08	52
	FI 4 FR 25	0.000	0.000	0.000	—	—	196.7	—	7
	FI 4 FR 300	0.742	0.667	0.788	211.2	65.7	122.9	2.82	42
	FI 4 Alone	—	—	—	151.4	37.1	—	—	20

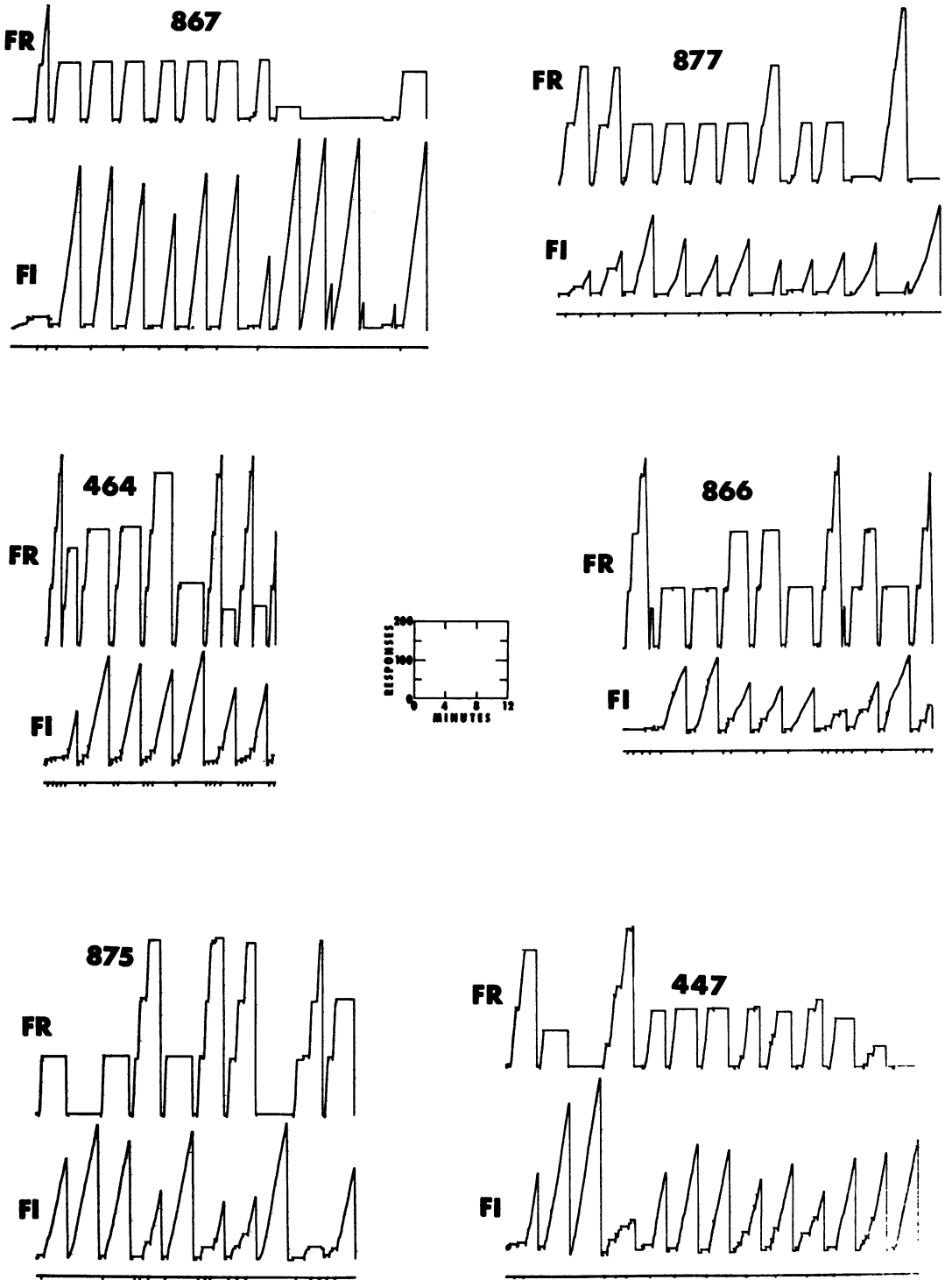


Fig. 1. Cumulative records of responding by the six pigeons during the final session under *conc* FI 4-min FR 150 responses. Deflections of the event pen designate FR reinforcement and reset of both FR and FI pens is occasioned by FI reinforcement. Diagonal marks denote changeovers.

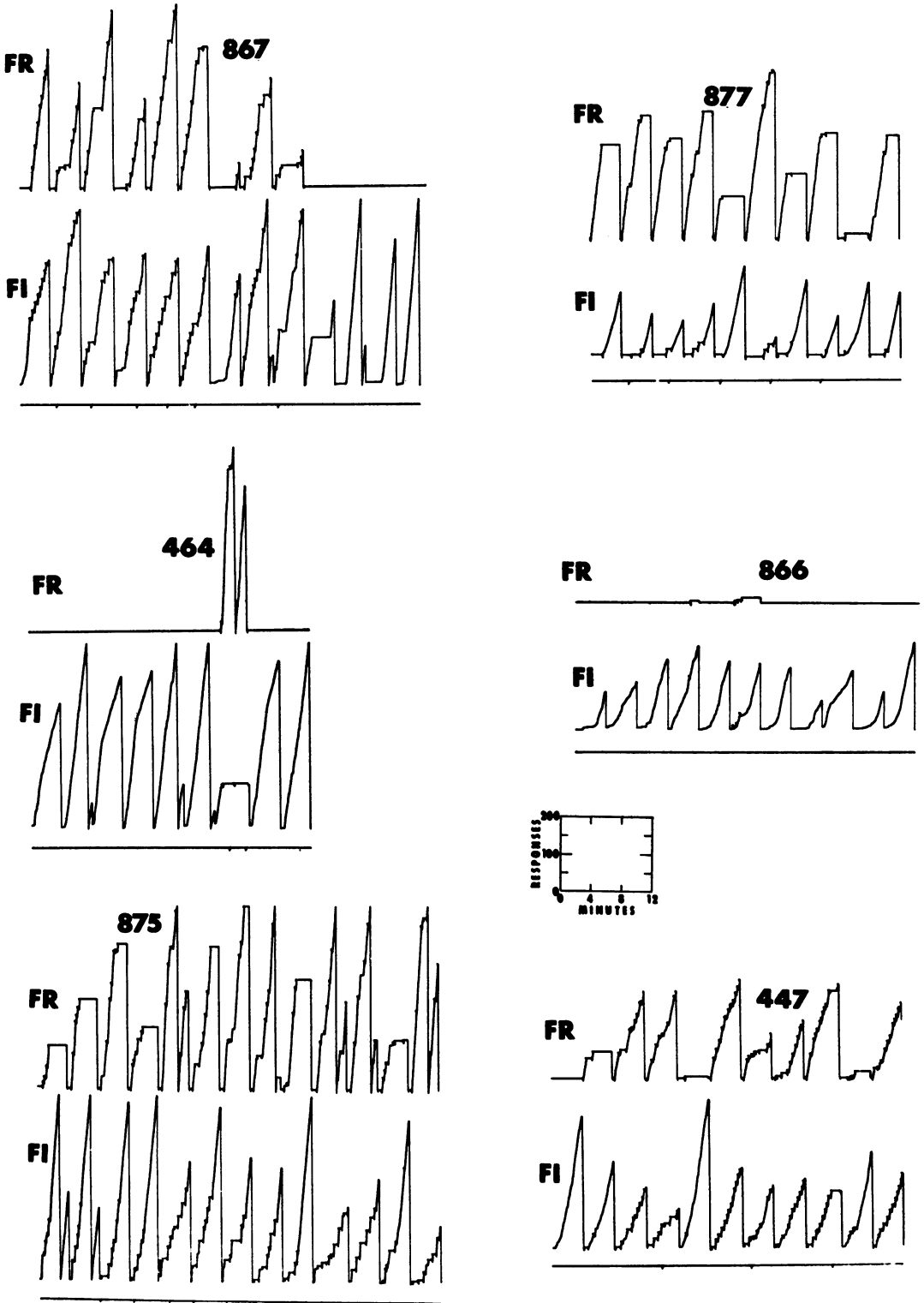


Fig. 2. Portions of the cumulative records of responding by the six pigeons during the final session under conc FI 4-min FR 450 responses.

changeovers but responded more often on the FI key during the later part of each interval. Pigeon 464 pecked only occasionally on the FR key, but these responses generally were emitted in complete ratios, as appears in Figure 2.

With such divergent patterns of responding between subjects, it would appear improbable that sufficient similarity exists among the pigeons for all to meet the constraints required by matching. However, four of the six closely approximated a division of responses between the keys that matched the relative proportions of reinforcements delivered by each schedule. Figure 3 shows, for each pigeon, the proportion of responses on the FI key as a function of the proportion of reinforcements actually obtained from the FI schedule. One point is shown for each of the pairings of concurrent FI FR schedules. The figure shows that the performances of Pigeons 867, 464, 875, and 866 approximated the response-reinforcement matching function.

Despite much individuality in patterns of responding, the performances of the four birds that matched responses to reinforcement were similar in two ways. First, the greater the ratio requirement, the higher the proportion of reinforcements gained from the FI schedule. Second, as the ratio size increased, the number of responses on the FI key during each interval also increased. Among these four pigeons, the major deviation from this relationship between FR requirement and FI responding was produced by Pigeon 866. For this bird, the number of FI responses per FI reinforcement increased up to FR 300, but then decreased substantially from FR 300 to FR 450, when all but a few responses were emitted on the FI key. However, since all reinforcements, and nearly all responses were associated with the FI schedule during this condition, matching occurred, if only trivially.

The two pigeons that did not match tended to average a relatively constant number of FI-key responses per interval regardless of the ratio requirement. Thus, when the ratio requirement was low, the proportion of responses to reinforcements was larger for the FI than the FR, and when the ratio requirement was high, this relationship reversed.

When there is response-reinforcement matching, a corresponding time-reinforcement match can occur only if the local rate of responding is the same on each alternative. Figure 4

depicts the local rates of FI and FR responding for the pigeons over all seven variations of the FR requirement. The local rate is determined by dividing the total number of responses made on a key by the accumulated times between an initial peck on the key and a subsequent peck on the other key. Figure 4 shows that, in general, the rate of FR responding was higher than the rate of FI responding.

Since differences existed between the local rates of responding on the two keys, a disproportionate amount of time must have been spent on the key with the lower response rate in order for the pigeons to have matched response-reinforcement proportions. Figure 5 shows the proportion of the total session duration spent on the FI key as a function of the proportion of the reinforcements gained from the FI schedule. The four pigeons that matched response-reinforcement proportions (Figure 3) all spent amounts of time on the FI key in excess of that predicted by the time-reinforcement matching function.

DISCUSSION

The failure of two pigeons (447 and 877) to match either response-reinforcement or time-reinforcement proportions indicates that matching is a less-general phenomenon on concurrent interval-ratio schedules than on concurrent VI schedules. These birds may have failed to match because their responding was not significantly controlled by changes in the ratio schedule. Over a wide range of ratio values concurrent with the FI 4-min, both pigeons tended to allocate consistently moderate proportions of both responses (Figure 3) and time (Figure 5) to the FI key. That is to say, large variations in the ratio schedule appeared to have little effect on how these birds distributed responses or time between the keys. Moreover, Figure 4 shows that their rate of responding on the FR key was generally much lower than that of the other birds. The only conditions under which either of these two pigeons responded at a substantial rate on the FR key was when the ratio requirement was small (*i.e.*, Pigeons 477 at FR values of 25 to 100). It would appear, then, that over the majority of the concurrent schedules, the behavior of these two pigeons was primarily under control of the fixed-interval schedule, with responding on the ratio key occurring

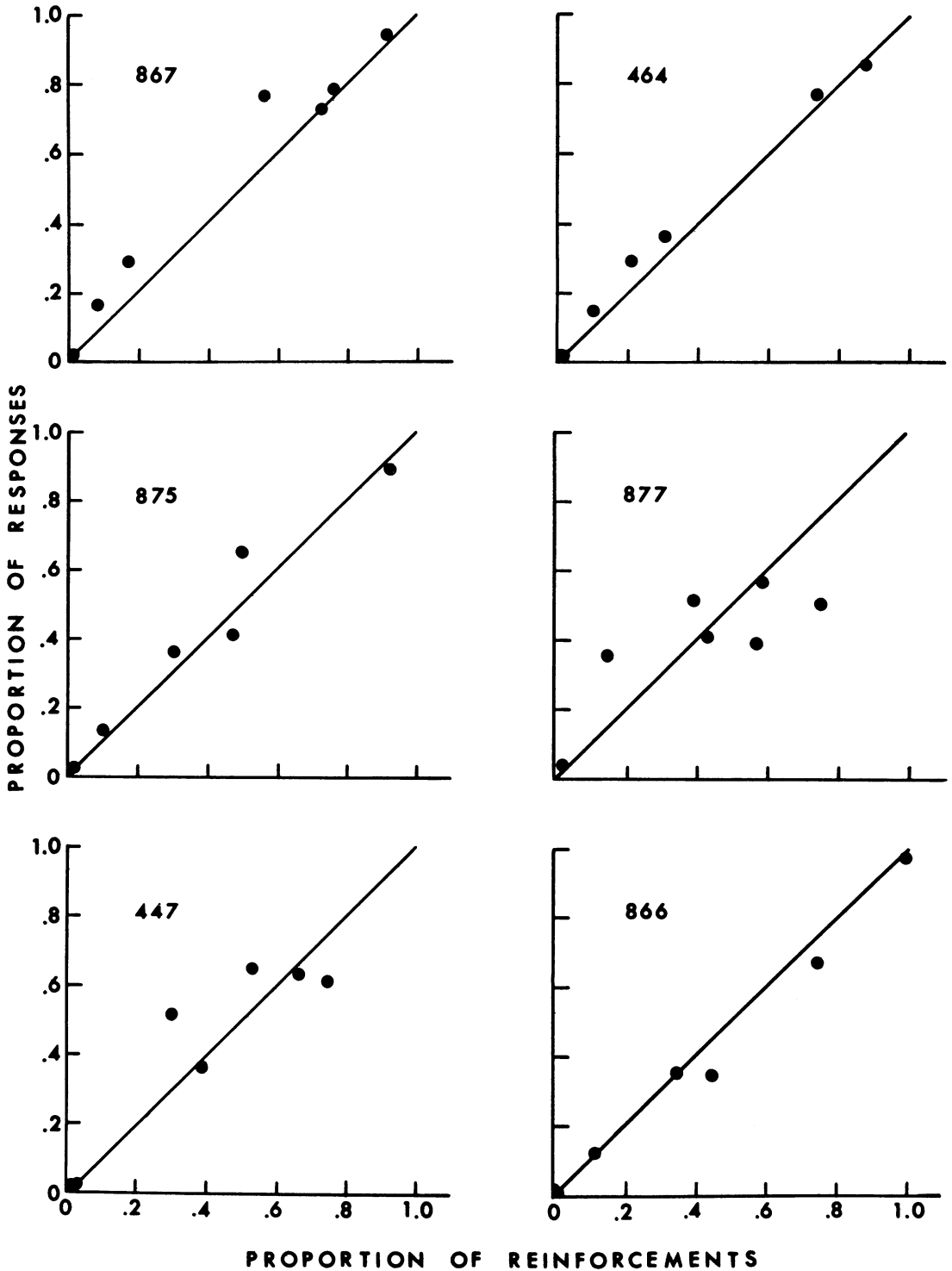


Fig. 3. Proportions of the total responses on the fixed-interval key by each pigeon as a function of the proportion of reinforcements delivered by the fixed-interval schedule. Each point represents the average of the final four sessions under each condition. The diagonal line represents matching between proportions.

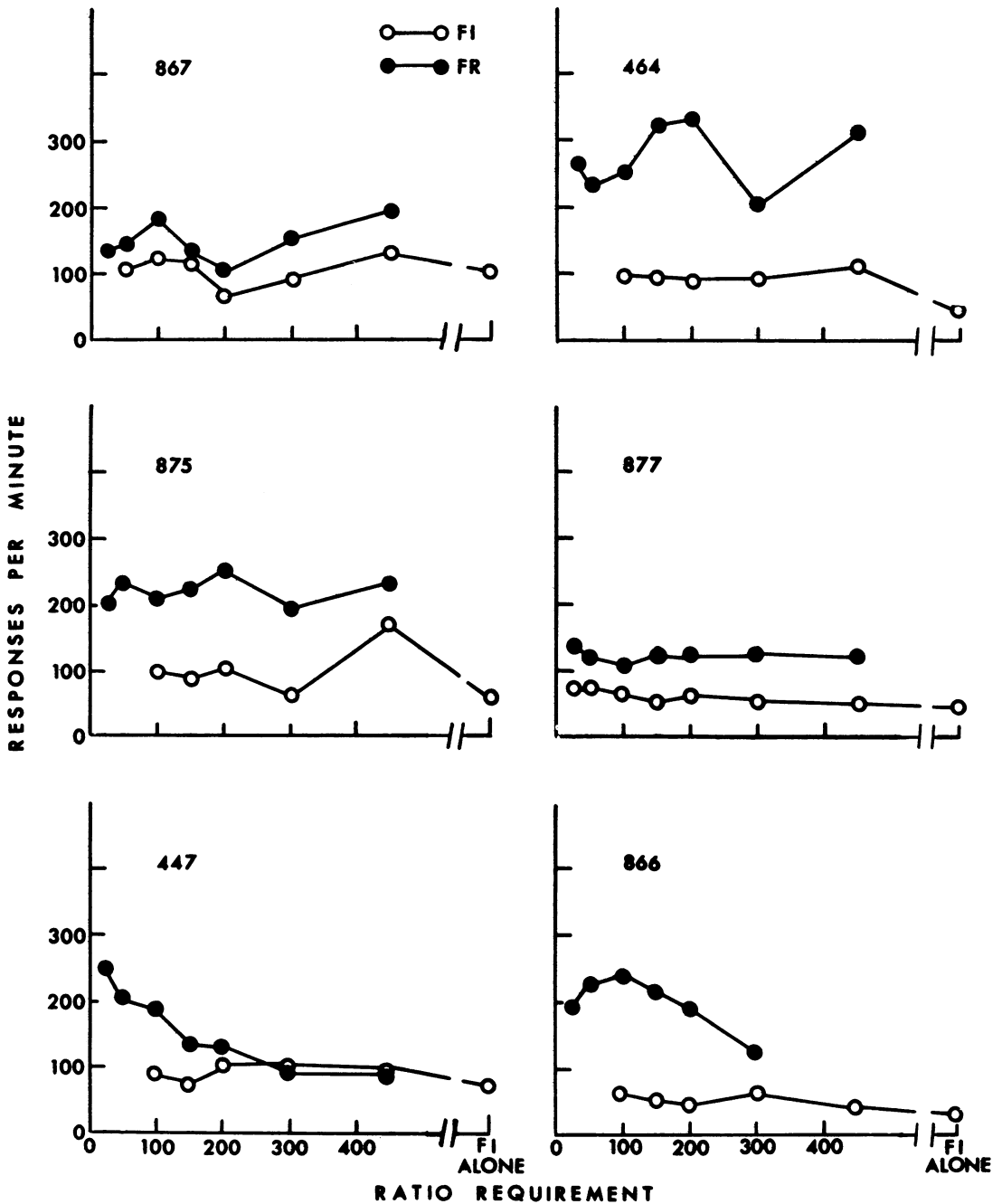


Fig. 4. Local rates of responding by each pigeon on the fixed-interval and fixed-ratio keys as a function of the fixed-ratio requirement. Also included is the rate of responding on the fixed-interval key when it was presented alone.

during what would normally be idle time in an isolated FI schedule. Under these circumstances, matching could not occur.

When the response-reinforcement matching is obtained, there are several properties of

concurrent ratio-interval schedules that make the matching process more complex than for concurrent VI schedules. For one thing, the relative frequency of reinforcement, often the primary independent variable in concurrent

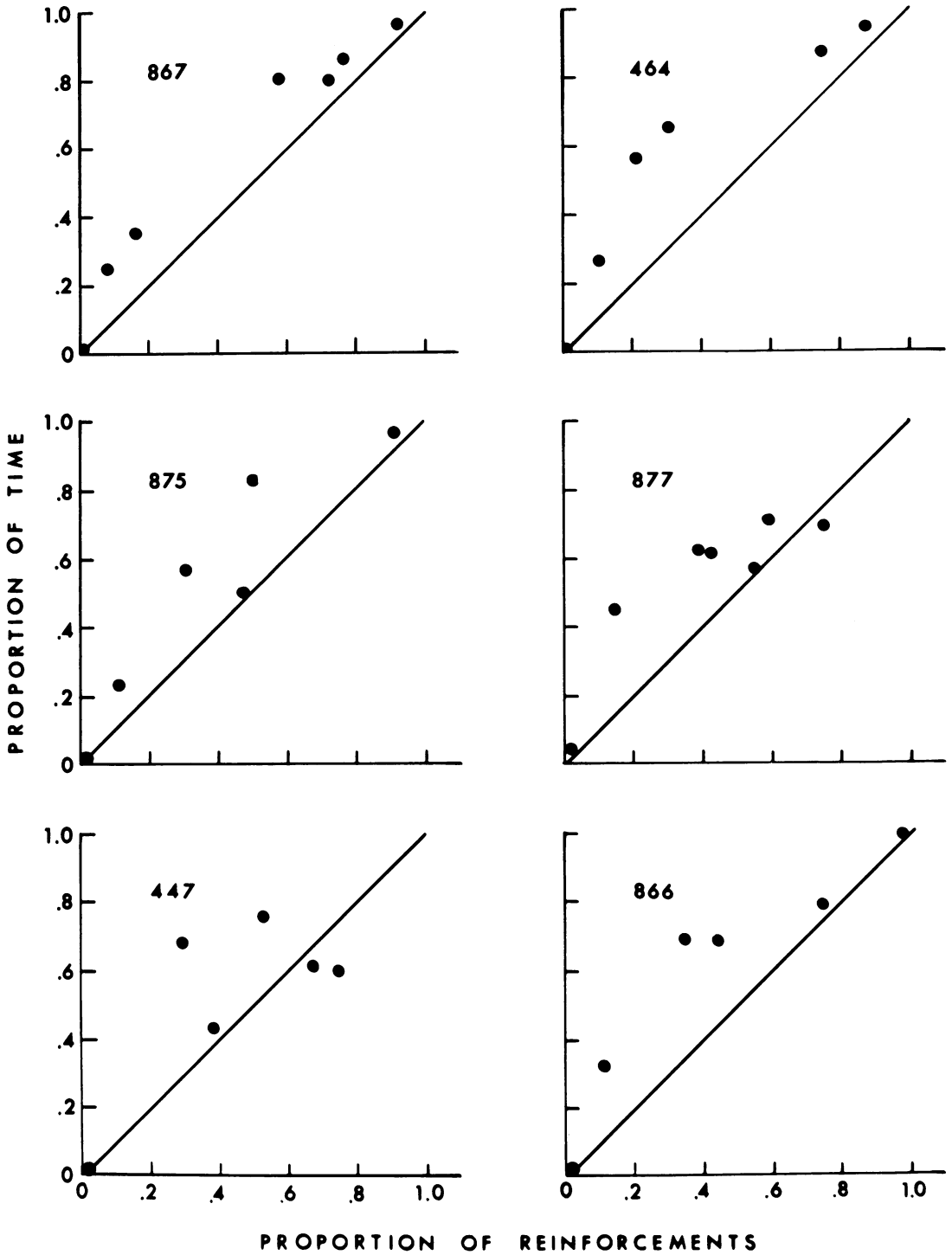


Fig. 5. Proportion of total session time spent responding on the fixed-interval key by each pigeon as a function of the proportion of reinforcements provided by the fixed-interval schedule of reinforcement. The diagonal line represents matching between proportions.

VI VI scheduling, is largely under the control of the pigeon in a concurrent FI FR situation. Since the number of reinforcements obtained for responding on the ratio key is a direct function of the overall rate of responding on that key, relative reinforcement frequencies cannot be pre-scheduled. Further, Herrnstein (1970) pointed out that the response-reinforcement matching relationship can exist in concurrent interval-ratio schedules only under certain conditions. For example, if the left key corresponds to a ratio schedule and the right to an interval schedule, the matching function becomes from equation (1):

$$\frac{P_L}{P_L + P_R} = \frac{rR_L}{rR_L + xR_R} \quad (3)$$

If r represents the required number of responses to obtain reinforcement on the ratio key, matching can occur only if $x = r$. That is, the bird must adjust its interval responding such that the mean number of responses per interval reinforcement approximates the ratio requirement.

The constraint on interval key responding just described may cause an additional problem when, as in the present experiment, large ratios are presented concurrent with relatively short intervals. In such instances, a fairly low local rate of responding on the FI alternative may make it impossible for the pigeon both to continue responding on each key and to achieve response-reinforcement matching. For example, all of the pigeons that matched response to reinforcement proportions maintained a local rate near or below 100 responses per minute on the FI key during the conditions when the FR was between 50 and 300. In general, response-reinforcement matching was maintained during these conditions by the birds' spending more time responding on the FI schedule as the ratio requirement was increased. However, when the concurrent schedules were FI 4-min FR 450 the constraints described in equation (3) make it impossible to achieve matching by the distribution of time between the keys if the pigeon's rate on the FI key remained low, because the 4-min duration of the FI would not be sufficient to enable the required 450 response average during each interval. In this instance, response-reinforcement matching could still be maintained only within two behavioral constraints. First, the pigeon might obtain reinforcement

exclusively from one of the two schedules by responding on only one of the keys, as did Pigeon 866 on the FI key under *conc* FI 4-min FR 450. Or, second, the bird may continue responding on both alternatives and continue to match by increasing its rate of responding on the FI key sufficient to emit an average of 450 responses per interval. The second method accurately describes the behavior of Pigeons 867, 464, and 875, all of which emitted a substantial rate increase on the fixed-interval key under *conc* FI 4-min FR 450 responses. In each instance, the increase was sufficient to enable an approximate response-reinforcement match.

Because of the arbitrary means of measuring time devoted to each alternative in this study, the obtained time proportions and subsequently computed local rates under each schedule must be considered only an approximation. The sizeable deviations from a time-reinforcement match indicated by these approximations, though, are supported by the substantial differences in local rate between responding on the FI and FR keys apparent from visual inspection of the cumulative records.

The tendency of the pigeons to modify their rates of responding on the interval schedule in the direction required by a response-reinforcement match and the large deviations by all the pigeons from a time-reinforcement matching function strongly indicate that the measurement of response proportions is the better means of evaluating the effects of reinforcement in such concurrent schedules. Certainly, Brownstein and Pliskoff (1968) and Catania (1963a) have shown that relative time on concurrent schedules can be controlled by reinforcement proportions, but given a situation where response-reinforcement and time-reinforcement matching are largely incompatible, the present data suggest that response-reinforcement matching is the more compelling alternative.

REFERENCES

- Baum, W. H. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.
- Brownstein, A. J. and Pliskoff, S. S. Some effects of relative reinforcement rate and changeover delay in response-independent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 683-688.

- Catania, A. C. Behavioral contrast in a multiple and concurrent schedule of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 335-342.
- Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 253-263. (a)
- Catania, A. C. Concurrent performances: an analysis of ratio and interval schedules of reinforcement. *American Psychologist*, 1963, 18, 421 (abstract). (b)
- 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.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.

Received 17 December 1971.

(Final acceptance 7 August 1972.)