

*MULTIPLE AND CONCURRENT SCHEDULE  
PERFORMANCE: INDEPENDENCE FROM CONCURRENT  
AND SUCCESSIVE SCHEDULE CONTEXTS*

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Six pigeons were trained on multiple variable-interval schedules and performance was measured in the presence or absence of another variable-interval schedule (the common schedule) arranged concurrently with both components. Manipulations included varying the rate of reinforcement on the common schedule, leaving the common schedule unchanged while the components of the multiple schedule were varied, varying the multiple schedule components in the absence of the common schedule, and varying one component of the multiple schedule while the other component and the common schedule were unchanged. The normal rate-increasing and rate-decreasing effects of reinforcement rate increase were found, except that changing one multiple schedule component did not affect the response rate in the successively available common schedule component. Both concurrent and multiple schedule performance undermatched obtained reinforcement-rate ratios, but the degree of undermatching in multiple schedules was reliably greater. Allocation of responses between multiple schedule components was unaffected by the concurrent availability of reinforcement, and allocation of responses between concurrent schedules was unaffected by the successive availability of different reinforcement rates.

*Key words:* variable-interval schedules, multiple schedules, concurrent schedules, response rate, undermatching, generalized matching law, pecking, pigeons

Studies of food-reinforced key-pecking in pigeons have established that a relatively simple relation exists between response rates and reinforcement rates on multiple and concurrent interval schedules. The general relation (Baum, 1974) may be written:

$$\frac{P_1}{P_2} = c \left( \frac{R_1}{R_2} \right)^a, \quad (1)$$

where  $P_1$  and  $P_2$  are response rates on the two schedules and  $R_1$  and  $R_2$  are the reinforcement rates on those schedules. The parameter  $c$  describes bias between responses (Baum, 1974) and is typically close to 1.0 for both multiple and concurrent schedules. The parameter  $a$  describes the sensitivity of the response-rate ratio to changes in the ratio of reinforcement rates (Lander and Irwin, 1968). The value of  $a$  typically obtained across a variety of procedural variations for concurrent variable-interval (VI) schedules is between 0.7 and 1.0

(Baum, 1974; Lobb and Davison, 1975). For multiple VI schedules, Lander and Irwin (1968) found that  $a$  was 0.33.

Catania (1966) suggested that the matching law (Equation 1) for concurrent schedules could be extended to the choice between more than two responses, such that the addition of a third schedule would not affect preference (measured by ratios of responses) between the two original schedules. There is evidence to support this suggestion. Davison and Hunter (1976) showed that the way in which changes in reinforcement rate in a pair of concurrent VI schedules affect responding (Equation 1) was the same whether two or three schedules were arranged simultaneously. In other words, the way in which responses are allocated between a pair of concurrent VI schedules is unaffected by the simultaneous or concurrent reinforcement context in which the performance occurs. Of course, the total number of responses allocated to a pair of concurrent schedules does depend on the context of other schedules, with fewer responses allocated when greater reinforcement rates are available elsewhere.

Pliskoff, Shull, and Gollub (1968) studied multiple VI VI schedule performance when

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another VI schedule was arranged concurrently with both multiple schedule components and reported that matching (that is,  $a = 1$  in Equation 1) occurred in the within-component concurrent schedules. However, Pliskoff *et al.* analyzed their data as relative response rates ( $P_1/P_1 + P_2$ ), rather than as response rate ratios ( $P_1/P_2$ ), a procedure that Baum (1974) has shown to give misleading results. A re-analysis of the Pliskoff *et al.* data by the present authors using Equation 1 gave an exponent  $a$  of about 0.61 and a multiplier,  $c$ , close to 1.0 with 94% of the (log ratio) data variance accounted for; both concurrent and multiple data from their concurrent multiple schedules were taken into account. The value of the exponent,  $a$ , is close to that normally found for concurrent schedules (Lobb and Davison, 1975), but higher than that found for multiple VI VI schedules (Lander and Irwin, 1968). The parameters of Equation 1 for response allocation in concurrent schedules may, then, also be unaffected by other preceding or succeeding reinforcers, that is, by the successive reinforcement context in which it occurs. On the other hand, Pliskoff *et al.* (1968) found that multiple schedule response allocation was affected by simultaneously available reinforcers, that is, the concurrent context of reinforcement (their Figure 5). As the common schedule reinforcement rate was increased, relatively more responses were allocated to the multiple schedule component having the higher reinforcement rate.

The present experiment used multiple VI VI schedules with and without concurrently available VI schedules to investigate more closely the effects of simultaneously available reinforcers on multiple-schedule performance and of successively available reinforcers on concurrent schedule performance. In the four parts of the present experiment we attempted to answer the following questions:

1. When a VI schedule is arranged concurrently with a multiple schedule, how does the rate of reinforcement on the common schedule affect performance in each component of the multiple schedule? (Part 1.)

2. When a VI schedule is arranged concurrently with a multiple schedule, how does changing the distribution of reinforcers in the multiple schedule affect performance in the multiple schedule? (Part 2.) This question requires a control in which the same multiple

schedule manipulations are carried out in the absence of a common schedule (Part 3). Part 3 also constitutes a systematic replication of the results reported by Lander and Irwin (1968).

3. When a VI schedule is arranged concurrently with a multiple schedule, how does changing the reinforcement rate in one component of the multiple schedule change the response rates in the other component and in both components of the common schedule? (Part 4.)

The data considered in answering these questions are (a) the absolute response rates (responses divided by the number of minutes for which that component was available) as a function of the obtained reinforcement rates; and (b) the logarithm of the ratios of the response rates of two components as a function of the logarithm of the ratio of the obtained reinforcement rates in the two components. The log ratio analyses allow the values of  $a$  (the slope of the resulting line) and  $c$  (the intercept) in Equation 1 to be directly obtained.

## METHOD

### *Subjects*

Six homing pigeons, numbered 21 to 26, were maintained at  $80\% \pm 15$  g of their free-feeding body weights. They were given supplementary feed of mixed grain if required immediately after the daily training sessions. Water and grit were available at all times except during experimental sessions. All subjects had previously served in related experiments (Lobb and Davison, 1975) so no magazine, key-peck, or schedule training was necessary. Bird 21 died at the end of Condition 18.

### *Apparatus*

Conventional relay programming equipment was situated remote from the experimental chamber. The chamber was fitted with an exhaust fan to mask external noise and contained a food magazine 10 cm from the floor midway between a pair of 2-cm diameter response keys situated 13 cm apart and 22.5 cm from the floor. Both keys could be illuminated by colored lights. No other illumination was provided in the chamber except the magazine light during reinforcement. Pecks on lighted keys exceeding about 0.1 N produced a 30-

msec offset of the keylight and a click of a relay. During reinforcement, the keylights were turned off, and pecks on dark keys were always ineffective. Reinforcement consisted of 3-sec access to wheat, and sessions ended with the keylights turned off after a fixed number of reinforcements had been obtained. All data were recorded on impulse counters.

*Procedure*

The present experiment used multiple concurrent schedules in which all reinforcers were obtained by responding on the left key of the experimental chamber. When the left key was blue, the first multiple schedule component (m1) was in effect. Following a single reinforcement in this component, the key became green and the second multiple schedule (m2) was in effect. After a single reinforcement, the conditions reverted to the first (m1) component. The right key was white, and normally a single response to this key allowed access to the common VI schedule on the left key shown by the left key being red. When the left key was red, a peck on the white right key normally re-instated the multiple (blue or green) schedules. The common schedule component during m1 is designated c1; that during m2 is designated c2. In this procedure, the multiple schedule components did not change except when the multiple schedule was in effect on the left key.

A changeover delay (Herrnstein, 1961) arranged that reinforcements on the left key could not be obtained, even if set up by the VI schedules, until 3 sec had elapsed since a changeover response. Furthermore, a changeover (right key) response was ineffective unless at least one response had occurred on the left key since the last changeover response.

The tapes controlling the common schedule reinforcements ran continuously (except when a reinforcement had been set up) throughout the session. The tapes controlling multiple schedule reinforcers ran only during the appropriate multiple schedule component or its concurrent common schedule component. All the schedules were derived from the arithmetic progression  $a, a + d, a + 2d, etc.$ , and comprised 12 randomized intervals.

In Part 3 of this experiment, when no common schedule was arranged, the right changeover key was not illuminated and pecks on it were ineffective.

Table 1 shows the sequence of experimental conditions and to which parts of the experiment the conditions contributed. In each condition, the numbers of responses, the time spent in the component, and the numbers of reinforcements obtained were recorded. Training continued on each condition until the median proportion of the number of multiple schedule responses to total responses over five sessions did not differ by more than 0.05 from the median of the previous five sessions. When this criterion had been met five, not necessarily consecutive, times by each subject, the experimental conditions were changed for all subjects. The number of sessions in each condition is shown in Table 1.

RESULTS

The present results are in all cases the average for each animal over the final five sessions of each experimental condition. Response and reinforcement rates were calculated as the number of these events occurring in the components divided by the time for which

Table 1

Sequence of experimental conditions, the part of the experiment to which the condition contributed, the schedules arranged in the multiple and common schedule components, and the number of sessions in each condition. All schedules are in seconds.

Condition	Part(s)	Multiple Schedule Component VI		Common Schedule	Sessions
		1	2		
1	2, 4	30	30	60	24
2	2	15	45	60	22
3	2	5	55	60	19
4	1, 2	45	15	60	18
5	2	55	5	60	19
6	1	45	15	90	23
7	1	45	15	180	21
8	1	45	15	30	29
9	1	45	15	120	21
10	2	20	40	60	20
11	2	40	20	60	16
12	3	30	30	absent	19
13	3	15	45	absent	18
14	1, 3	45	15	absent	21
15	3	20	40	absent	17
16	3	40	20	absent	22
17	4	30	60	60	29
18	4	30	120	60	22
19	4	30	15	60	18
20	4	30	5	60	20
21	4	30	180	60	21

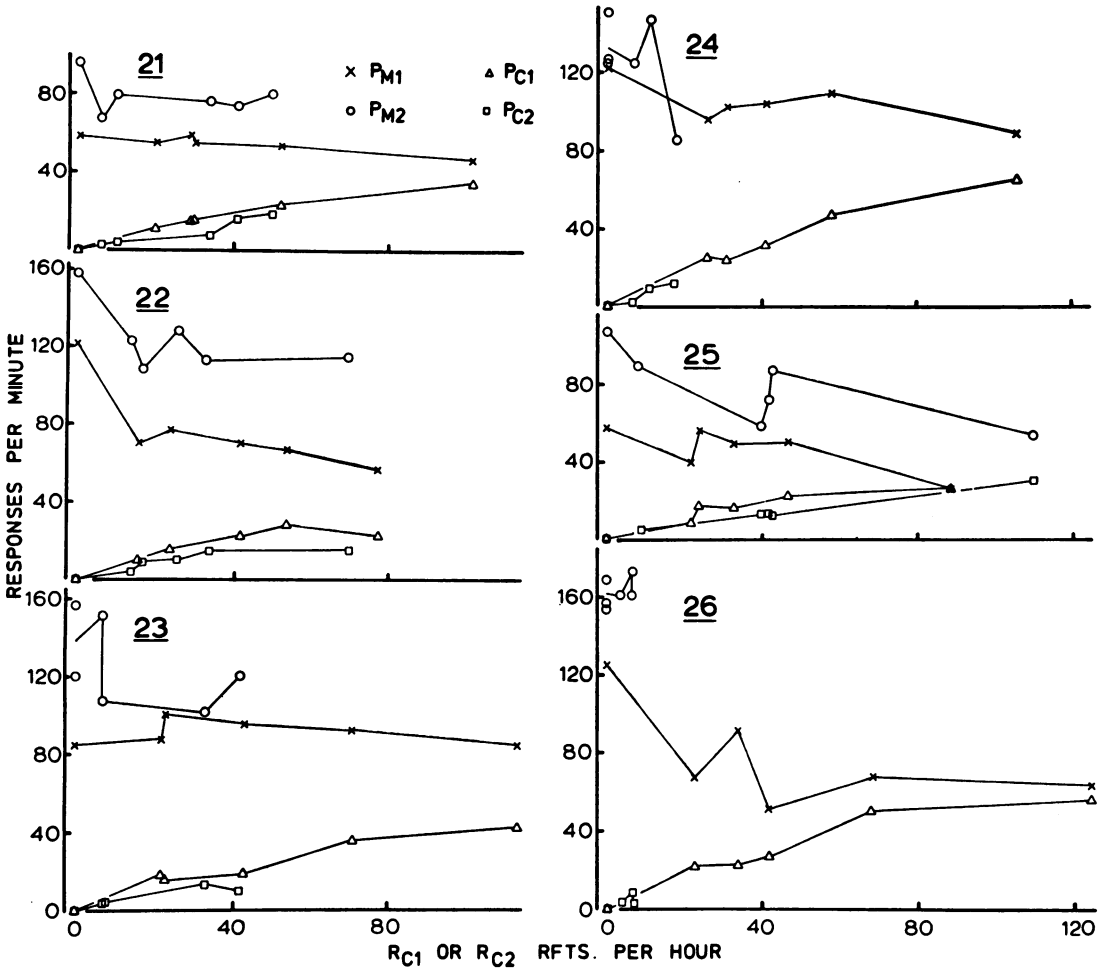


Fig. 1. Responses per minute in the four components of the multiple concurrent schedules as a function of the obtained reinforcement rate in the common schedule components.  $P_{m1}$  and  $P_{c1}$  are shown as a function of  $R_{c1}$ , and  $P_{m2}$  and  $P_{c2}$  as a function of  $R_{c2}$ .

that component was in effect. This follows Herrnstein's (1961) calculation of rates in that the time base used is that during which the response or reinforcement may occur.

#### Part 1

With the multiple schedule components set at VI 45-sec and VI 15-sec, the common schedule was varied. Figure 1 shows the number of responses per minute in each component of the multiple concurrent schedule as a function of the reinforcement rate obtained on the common schedule. With some reversals, response rates in the common schedule components increased, and, less clearly, those in the multiple schedule components decreased, as the common schedule reinforcement rate was

increased. As would be expected, the response rate in the second multiple schedule component (VI 15-sec) was greater than that in the first component (VI 45-sec). For most animals,  $P_{c1}$ , the response rate in the common schedule concurrent with the first multiple schedule component (VI 45-sec) was higher than  $P_{c2}$ , the rate in the common component concurrent with the second multiple schedule component (VI 15-sec). Finally, the response rates in the multiple schedule components were always higher than those in the common schedule components, even when the common schedule provided a higher reinforcement rate than one of the multiple schedule components (Condition 8), indicating a bias toward responding on the multiple schedule.

Varying the common schedule reinforcement rates allows an assessment of Equation 1 as it applies to the two concurrent schedules

comprising the multiple concurrent schedule. This analysis requires that  $\log P_{m1}/P_{c1}$  and  $\log P_{m2}/P_{c2}$  are plotted as a function of  $\log R_{m1}/R_{c1}$  and  $\log R_{m2}/R_{c2}$  respectively (Figure 2). In this figure, straight lines have been fitted by the method of least squares to the logarithmic data. The data from both concurrent schedules were taken together, as they appeared to fall on the same straight lines. The data from conditions in which no responses were emitted or reinforcements obtained cannot be shown on these graphs. The slopes of the fitted lines are a measure of  $a$ , and the intercepts are measures of  $\log c$ , in Equation 1. All performances showed undermatching ( $a$  less than 1.0) and all showed positive intercepts or biases toward the multiple schedule.

The allocation of responses to the multiple schedule components, measured as in Figure 2 as  $\log P_{m1}/P_{m2}$ , is shown as a function of the arranged common schedule reinforcement rate in Figure 3. The value of the performance

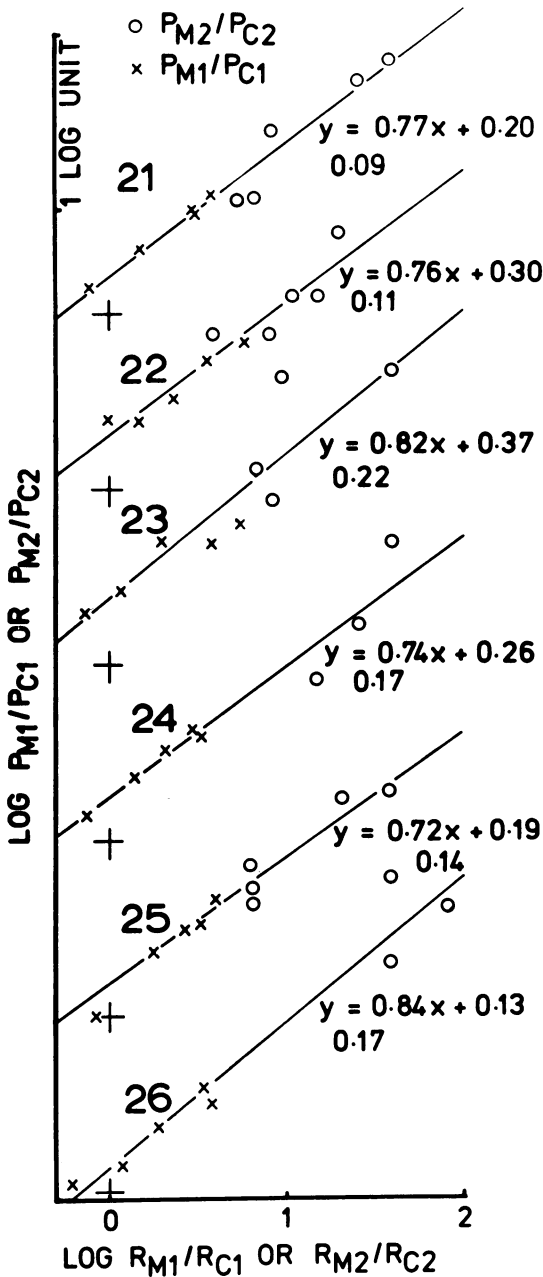


Fig. 2. The logarithm of the response-rate ratios  $P_{m1}/P_{c1}$  and  $P_{m2}/P_{c2}$  as a function of the logarithm of the ratios of obtained reinforcement rates  $R_{m1}/R_{c1}$  and  $R_{m2}/R_{c2}$  respectively. Each bird's data have been displaced one log unit down the abscissa. Least-squares lines have been fitted to each bird's data and the logarithmic equation and the standard error of the estimate are shown by each line.

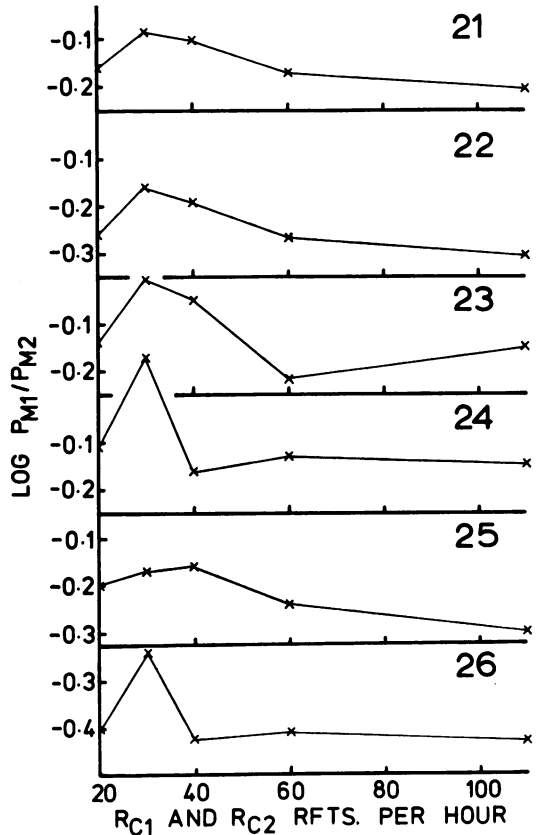


Fig. 3. The logarithm of the response-rate ratio  $P_{m1}/P_{m2}$  as a function of the number of reinforcements per hour arranged on the common schedule.

measure was always negative, since the ratio taken was of the lower divided by the higher reinforcement rate components. There appeared to be a downward trend on this graph for each bird, but in none did the trend reach the 5% level of statistical significance (Theil test, Hollander and Wolfe, 1973).

The reinforcement rates in the common schedule components  $R_{c1}$  and  $R_{c2}$  did not remain equal when these arranged reinforcement rates were increased, but became higher in the first component relative to the second (Figure 1 abscissa). However, the consequent changes in reinforcement-rate ratios in these

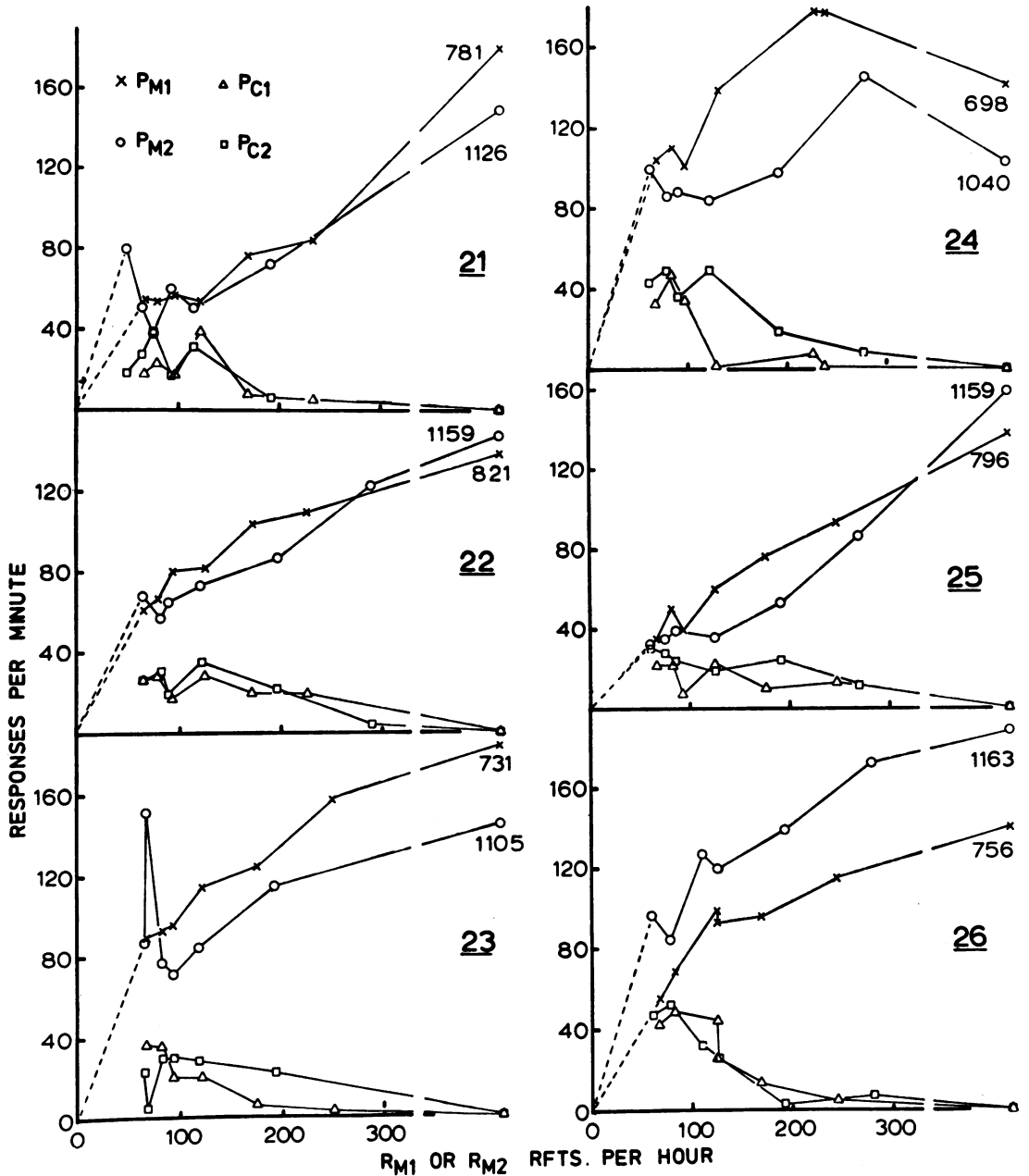


Fig. 4. Responses per minute in the four components of the multiple concurrent schedules as a function of the obtained reinforcement rates in the multiple schedule components.  $P_{m1}$  and  $P_{c1}$  are shown as a function of  $R_{m1}$ , and  $P_{m2}$  and  $P_{c2}$  as a function of  $R_{m2}$ . Broken lines connect the obtained data to assumed zero points. The abscissa values of extreme data points are shown by those data points.

components were not sufficiently large for their effects on response allocation to be clearly observed.

Part 2

Here, the common schedule was maintained at VI 60-sec while the multiple schedule components were changed under the restriction that the sum of the average intervals was 60 sec. Figure 4 shows the response rates in the multiple and common schedule components as a function of the obtained reinforcement rate on one of the multiple schedule components (that is,  $P_{m1}$  and  $P_{c1}$  are plotted against  $R_{m1}$ , and  $P_{m2}$  and  $P_{c2}$  are plotted against  $R_{m2}$ ). Increasing multiple schedule reinforcement rates increased response rates in that multiple schedule component and decreased the response rates in the concurrent common components.

The concurrent schedule data from Figure 4, excluding points with zero response or reinforcement rates, are shown as log ratios in Figure 5. Again, the data from the two components have been combined, as they appear to fall on the same least-squares fitted lines. On sign tests, the least-squares lines in Figure 5 are not discriminable from those shown in Figure 2: both sets have similar slopes, and both show a bias to the multiple schedule.

Performance in the multiple schedule composed of  $m1$  and  $m2$  components is shown in Figure 6 in the same manner as the concurrent schedule data were shown in Figures 2 and 5. By sign tests, the straight lines fitted to the data by the least-squares method had reliably smaller slopes (or values of  $a$  in Equation 1) than those from the concurrent performances (Figures 2 and 5). They showed no consistent positive or negative intercepts or biases ( $c$  in Equation 1) to either multiple schedule component.

Part 3

When the common schedule was absent and the reinforcement rates in the multiple schedule were varied as in Part 2, response rates in the multiple schedule components (Figure 7) varied in much the same manner as they did in the presence of the common schedule (Figure 4). When these data were plotted as log ratios (Figure 8), the least-squares lines were not different in slope (sign test) from those obtained in Part 2 (Figure 6), but were reliably smaller than those for concurrent schedule

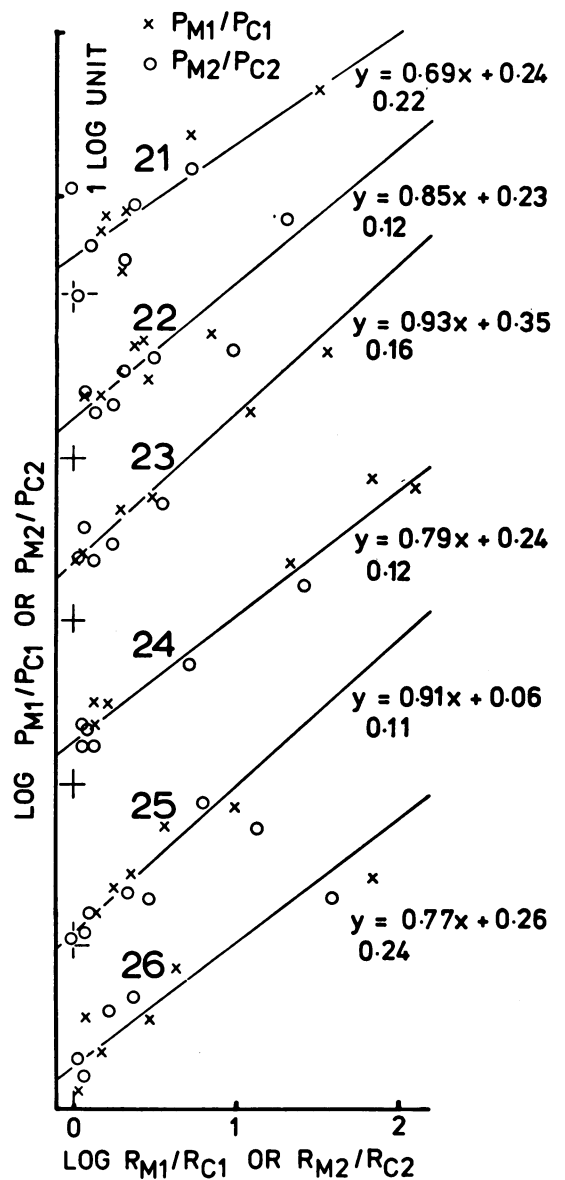


Fig. 5. The logarithm of the response-rate ratios  $P_{m1}/P_{c1}$  and  $P_{m2}/P_{c2}$  plotted as a function of the logarithm of the ratios of obtained reinforcement rates  $R_{m1}/R_{c1}$  and  $R_{m2}/R_{c2}$  respectively. Each bird's data have been displaced one log unit down the abscissa. Least-squares lines have been fitted to each bird's data, and the logarithmic equation and the standard error of the estimate are shown by each line.

performances in Part 1 (Figure 2) and Part 2 (Figure 5) again using sign tests.

Part 4

When the reinforcement rate in only one component ( $m2$ ) of the multiple schedule was

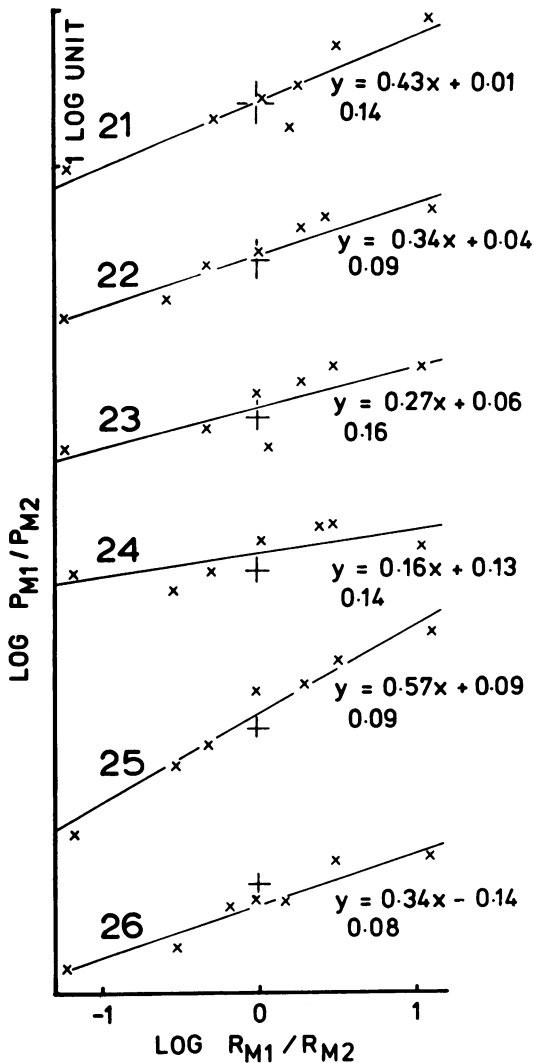


Fig. 6. The logarithm of the response-rate ratios  $P_{m1}/P_{m2}$  plotted as a function of the logarithm of the obtained reinforcement-rate ratios  $R_{m1}/R_{m2}$ . Each bird's data have been displaced one log unit down the abscissa. Least-squares lines have been fitted to each bird's data, and the logarithmic equation and the standard error of the estimate are shown by each line.

varied, the response rate in that component increased, and the response rate in the alternated multiple schedule component (m1) generally decreased (Figure 9). The rate of increase in the m2 response rate was much greater than the rate of decrease in the m1 response rate as the m2 reinforcement rate was increased. The response rate in the common schedule component (c2) concurrent with the varied multiple schedule component also decreased when the m2 reinforcement rate was

increased, and this decrease was often greater in percentage terms than the decrease in the m1 response rate. However, the response rate in c1, the common schedule component successive to the varied multiple schedule component, remained essentially constant when the m2 reinforcement rate was changed.

Figure 10 shows both multiple (m1/m2) and concurrent (m2/c2) data for this part of the experiment on log ratio coordinates. Some data for Bird 21 are missing due to its death. In line with our previous findings, the slopes of the lines fitted to the concurrent schedule data were in each case greater than those fitted to the multiple schedule data, and the concurrent schedule data showed a consistent bias to the multiple schedule.

#### Reinforcement Rates

In many cases in the present experiment, the reinforcement rates obtained by the animals were very different from those that were arranged. For example, when a VI 5-sec schedule was one multiple schedule component, the animals typically obtained no reinforcements on the concurrently arranged common schedule. Similar effects of lesser magnitude occurred with other schedules. All absolute response-rate data (Figures 1, 4, 7, and 9) have been plotted against the obtained reinforcement rate in the component(s) in which the schedules were varied, but no method of plotting can do justice to the changes in reinforcement rate in components in which the schedules were held constant. On the other hand, response-ratio graphs do take into account changes in reinforcement rate in constant schedule components, except in Figure 3. Here, the nonsignificant downward trend could have resulted from variations from the arranged reinforcement rates in the two components of the multiple schedule, but in fact there was no significant trend in the ratio of reinforcement rates,  $R_{m1}/R_{m2}$ , in these components.

#### DISCUSSION

In the experimental analysis of behavior, an important question is the generality of a relation between two variables—that is, how far is a specified relation independent of contextual or other environmental modifications. The present experiment asked this question both



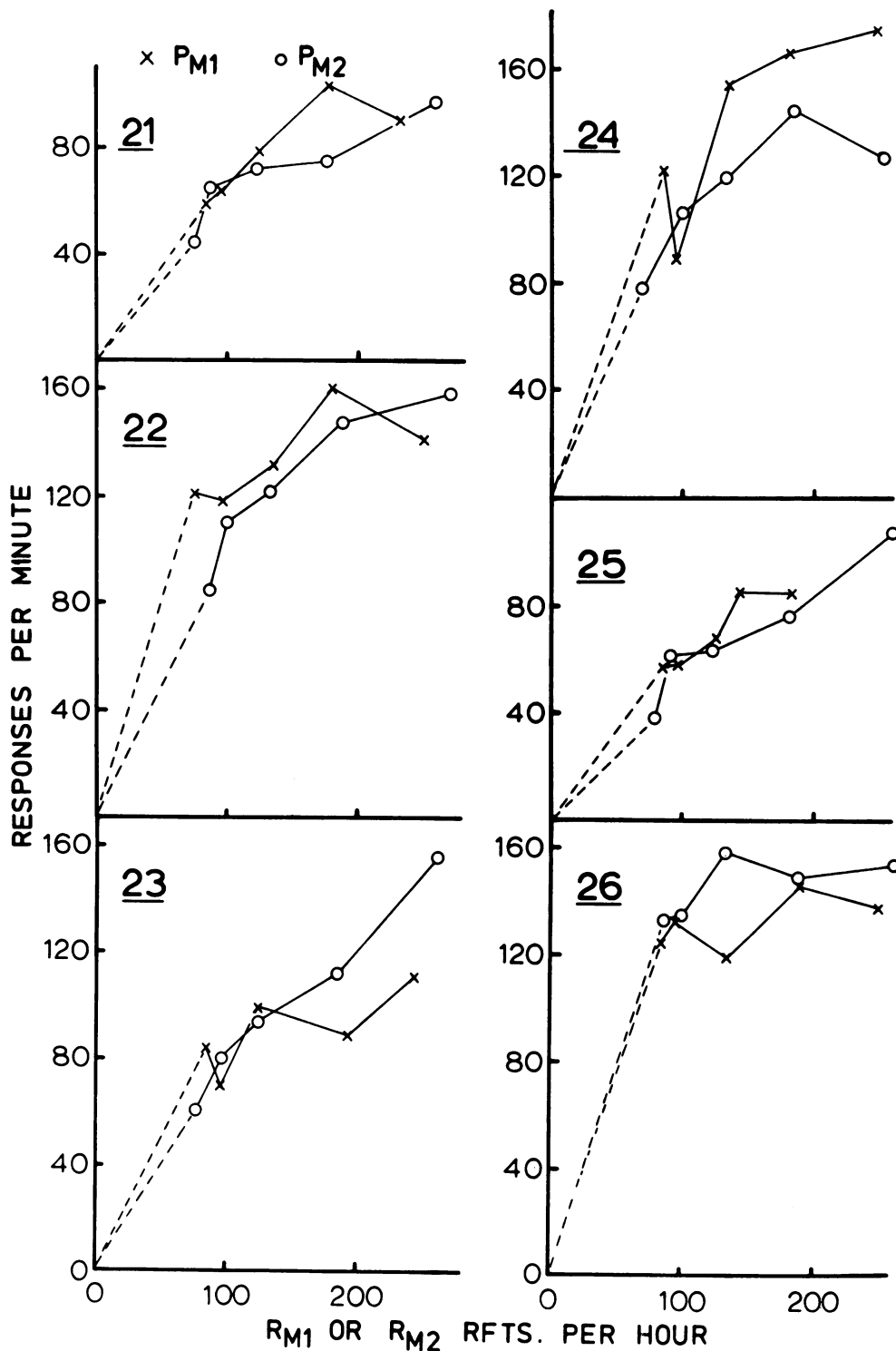


Fig. 7. Responses per minute in the two components of the multiple schedule as the obtained reinforcement rates in the components varied.  $P_{m1}$  is shown as a function of  $R_{m1}$ , and  $P_{m2}$  is shown as a function of  $R_{m2}$ . Broken lines connect the data to assumed zero points.

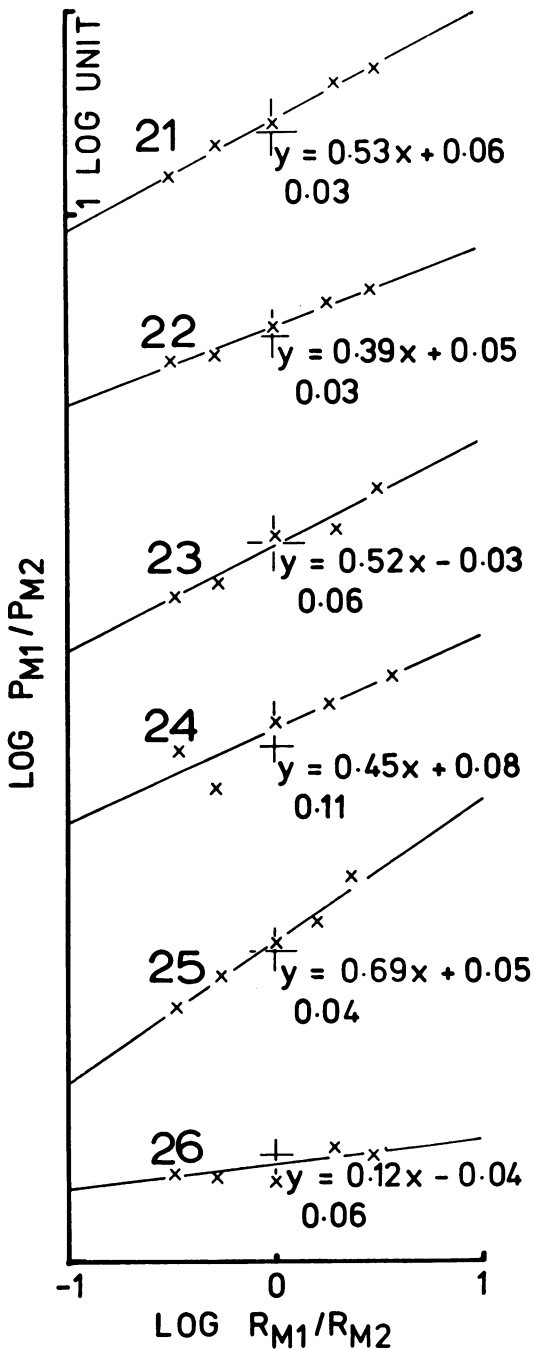


Fig. 8. The logarithm of the response-rate ratios  $P_{m1}/P_{m2}$  plotted as a function of the logarithm of the ratios of obtained reinforcement rates  $R_{m1}/R_{m2}$ . Each bird's data have been displaced one log unit down the abscissa. Least-squares lines have been fitted to each bird's data, and the logarithmic equation and the standard error of the estimate are shown by each line.

of response rates as a function of reinforcement rates, and of response-rate ratios as a function of reinforcement-rate ratios.

Response rates have generally been found to be a direct function of the reinforcement rate for that response, and an inverse function of reinforcement rates for other responses. The interactive effect of reinforcement at other times or other places is well known, the former (multiple schedule interaction) being a smaller effect than the latter (concurrent schedule interaction) (Herrnstein, 1970). Both multiple and concurrent interactions have been demonstrated here (Figures 1, 4, and 9). Figure 1 showed that increasing the common schedule rate of reinforcement decreased the multiple schedule response rates (concurrent interactions). A similar effect was shown in Figure 4, but it was noted that the response-rate decrease on the common schedule caused by concurrent interactions was less than the response-rate increase on the multiple schedule itself, a finding also reported by Davison and Hunter (1976). Figure 9 clearly showed both multiple and concurrent interactions occurring at the same time, and supports Herrnstein's (1970) contention that the concurrent interactive effect is the larger of the two. Figure 9 also demonstrated that the response rate in the component c1 concurrently arranged with the multiple schedule component m1 following or preceding a changed reinforcement-rate component m2 was unaffected by that reinforcement rate change. These results contrast with those of Catania (1961), who found that doubling the reinforcement rate in c2 reliably decreased the response rate in m1 without changing the response rate in c2 itself. Perhaps the differences between Catania's results and those reported here are related to the fact that Catania arranged extinction in m2 in both conditions, or to the different procedures for concurrent scheduling (two-key *versus* switching key).

Davison and Hunter (1976) found that the rules for response allocation ( $a$  and  $c$  in Equation 1) were unaffected by the presence or absence of a third concurrent schedule. Parts 1, 2, and 4 (Figures 2, 5, and 10) show that the same rules apply when other schedules occur successively to, rather than simultaneously with, concurrent VI schedules. The slopes of the lines fitted to the concurrent schedule data ( $a$  in Equation 1) are close to those commonly

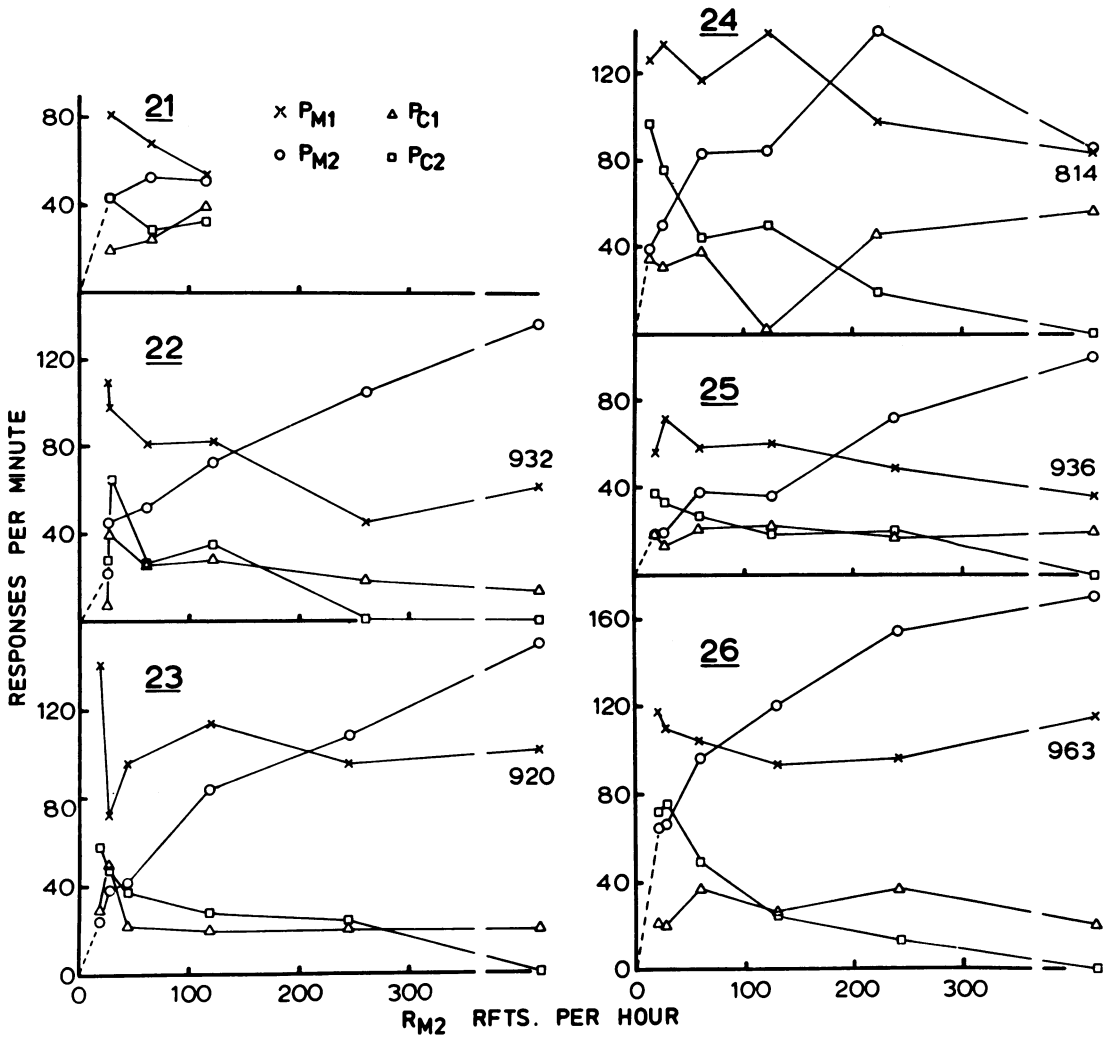


Fig. 9. Responses per minute in the four components of the multiple concurrent schedules as a function of the obtained reinforcement rate in the second multiple schedule component ( $R_{m2}$ ). Broken lines connect the data to assumed zero points. The abscissa values of extreme data points are shown by those data points.

reported for concurrent VI schedule performance (Baum, 1974; Lobb and Davison, 1975). The only difference from typical concurrent schedule performance occurs in the intercept or bias term,  $\log c$ , the bias being to the multiple schedule in all cases. This result is most probably due to the use of a switching-key concurrent schedule in conjunction with the procedure of providing discriminative stimuli only for the multiple schedule. Common schedule response rates did vary with multiple schedule reinforcement rates, and as the common schedule components were not separately signalled, the control of appropriate common schedule performance might require frequent

reference to the multiple schedule stimuli. Such an effect is similar to that reported by Catania (1975). We conclude that, apart from bias, concurrent schedule response allocation is unaffected by *both* the successive reinforcement context in which it occurs *and* the concurrent reinforcement context in which it occurs (Davison and Hunter, 1976).

The slopes of the lines fitted to response allocation in the multiple schedules (Figures 6, 8, and 10) were similar whether or not a common schedule was available, and were flatter than those fitted to the concurrent schedule data. The difference in the required value of  $a$  demonstrated here between multiple and con-

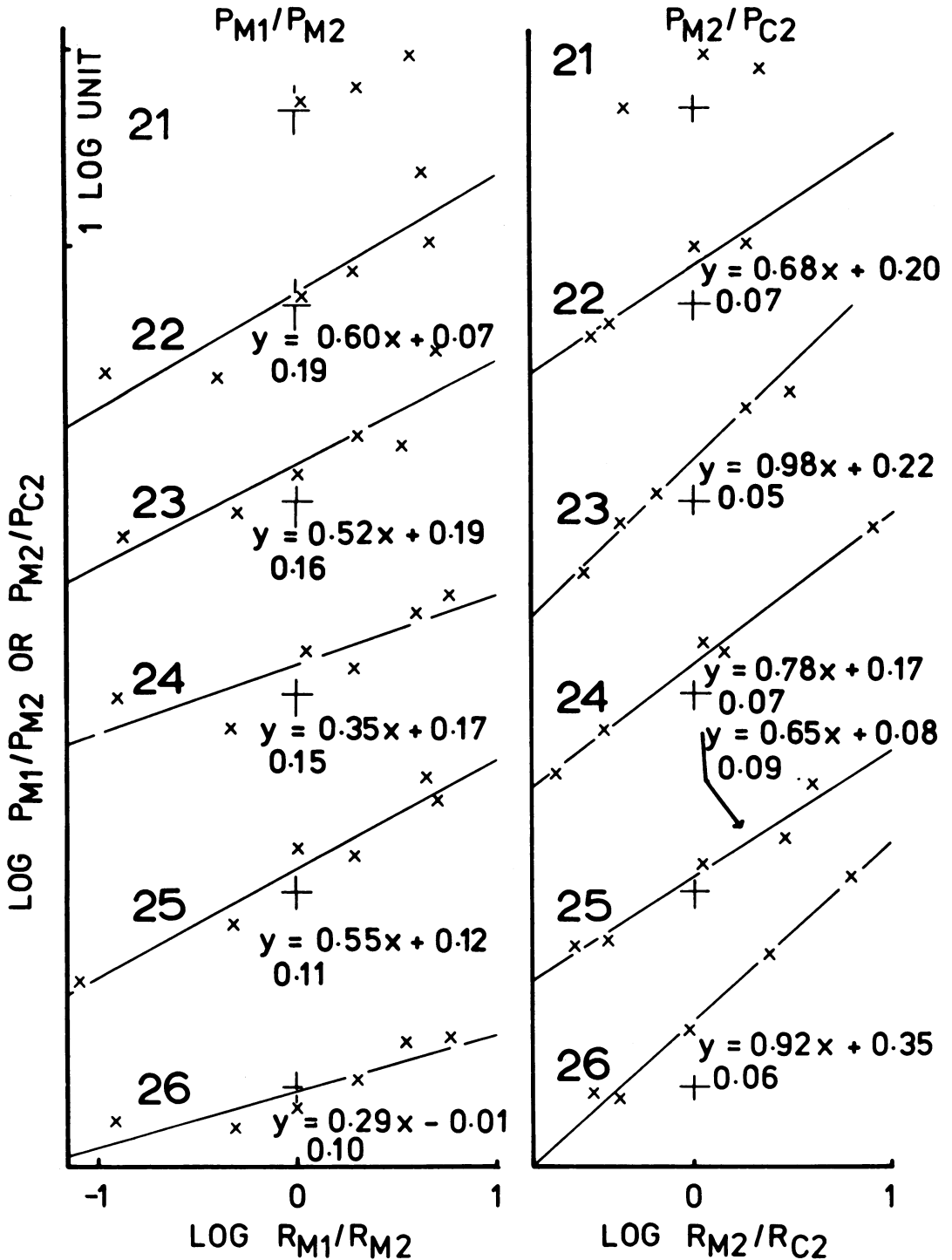


Fig. 10. The logarithm of the response-rate ratios  $P_{m1}/P_{m2}$  (left panel) and  $P_{m2}/P_{c2}$  (right panel) plotted as a function of the logarithm of the ratios of obtained reinforcement rates  $R_{m1}/R_{m2}$  and  $R_{m2}/R_{c2}$  respectively. Each bird's data have been displaced one log unit down the abscissa. Least-squares lines have been fitted to the data for Birds 22 to 26, and the logarithmic equation and the standard error of the estimate are shown by each line. Bird 21 died during this part of the experiment.

current schedule performance has been noted before, but has not been shown in the performance of the same animals within the same session. We conclude that multiple schedule response allocation is unaffected by the provision of a common reinforcement schedule, and conclude also that multiple schedule performance is indeed less sensitive to reinforcement-rate changes than is concurrent schedule performance.

Another way of assessing whether multiple schedule performance is independent of the context in which it occurs is whether or not the ratio of responses allocated to a pair of unchanging multiple schedule components changes when the context is varied (Figure 3). No significant change in this measure was shown, though some downward trend was noted. Such a trend might indicate that the multiple schedule performance moved toward matching ( $a = 1$  in Equation 1) with increases in the common schedule reinforcement rate. Pliskoff *et al.* (1968) reported similar but stronger changes in response ratios with changes in the common schedule reinforcement rate over the range 0 to 60 reinforcements per hour on the common schedule. We cannot at present explain the difference between their results and those reported here.

The results reported by Pliskoff *et al.* (1968) differ in other ways as well. They found no bias to the multiple schedule, and that the multiple schedule response ratios fell on the same line as the concurrent schedule response ratios when a common schedule was arranged. The present experiment found greater undermatching in the multiple schedule performance. As we have mentioned, the bias may have been due to the provision of discriminative stimuli in the multiple schedule alone and the use of the switching procedure. The other dif-

ferences in results could be due to the same procedural variations.

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