CHOICE WITH A FIXED REQUIREMENT FOR FOOD, AND THE GENERALITY OF THE MATCHING RELATION

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Pigeons were trained on choice procedures in which responses on each of two keys were reinforced probabilistically, but only after a schedule requirement had been met. Under one arrangement, a fixed-interval choice procedure was used in which responses were not reinforced until the interval was over; then a response on one key would be reinforced, with the effective key changing irregularly from interval to interval. Under a second, fixed-ratio choice procedure, responses on either key counted towards completion of the ratio and then, once the ratio had been completed, a response on the probabilistically selected key would produce food. In one experiment, the schedule requirements were varied for both fixed-interval and fixed-ratio schedules. In the second experiment, relative reinforcement rate was varied. And in a third experiment, the duration of an intertrial interval separating choices was varied. The results for 11 pigeons across all three experiments indicate that there were often large deviations between relative response rates and relative reinforcement rates. Overall performance measures were characterized by a great deal of variability across conditions. More detailed measures of choice across the schedule requirement were also quite variable across conditions. In spite of this variability, performance was consistent across conditions in its efficiency of producing food. The absence of matching of behavior allocation to reinforcement rate indicates an important difference between the present procedures and other choice procedures; that difference raises questions about the specific conditions that lead to matching as an outcome.

Key words: choice, concurrent schedules, fixed ratio, fixed interval, matching, maximizing, key peck, pigeons

Choice is one of the most persistently studied topics in the experimental analysis of behavior. Early research in this area was diverse in both method and orientation, but Herrnstein's (1961) now classic finding—that relative response outputs of pigeons on concurrent variable-interval variable-interval (VI VI) schedules match relative reinforcement rates on those schedules—began a trend of convergence on a limited range of procedures for studying choice. To a great extent, concurrent VI VI schedules became the reference procedure, and the matching relation became the frame of reference for discussion. The matching relation has provided a framework for considering choice and has proven quite general in its applications, but in recent years questions have been raised about many aspects of this phenomenon. The most basic of these questions have attempted to determine

whether the matching relation is fundamental or whether it is the result of some more fundamental process. Many subsequent alterations of, additions to, and explanations of the matching relation have been proposed (e.g., for recent discussions of different views of choice, see Allison, 1981; Baum, 1981; Herrnstein & Vaughan, 1980; Heyman, 1979; Hinson & Staddon, 1983; Houston & McNamara, 1981; Nevin, 1982; Rachlin, 1978; Rachlin, Battalio, Kagel, & Green, 1981; Shimp, 1979).

Perhaps the use of concurrent VI VI schedules has contributed to this proliferation of different views; the seeming elegant simplicity of the concurrent VI VI procedure may have been deceptive. This procedure is far from simple, providing many different relations between behavior and reinforcement. As a result, the data can be used to support a number of different theoretical positions, suggesting that we need to change our strategy and develop new procedures for studying choice. The results from a wide variety of different procedures can provide a more extensive data base from which the different theoretical positions

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can be evaluated and the limits of the matching relation, as a general account of choice, can be explored. The present series of experiments provided data from one such procedure.

The basic procedure was a choice procedure in which responses on two keys were reinforced probabilistically, but only after a nonprobabilistic schedule requirement had been met. A fixed-ratio (FR) requirement was used in some conditions, and a fixed-interval was used in others. For the FR choice procedure, pecks on either key counted towards completion of the ratio; once the ratio had been completed, only a right-key or a left-key response would produce food, with specification of the reinforced response changing irregularly from ratio to ratio. For the FI choice procedure, the animals could respond on either key, but choices were not reinforced until the interval had elapsed. This procedure is like other concurrent procedures in that reinforcers are scheduled irregularly for left and right responses and in that relative reinforcement rates can be specified and varied. However, the procedure differs from the usual concurrent VI VI procedure in that reinforcers become available only at the end of a specified schedule requirement. With concurrent VI VI schedules, patterns of choices may be influenced by the availability of reinforcers at any time and by the changing probabilities of reinforcement that interact with behavior (e.g., an increasing probability of reinforcement on the alternate schedule as the animal continues to respond on a schedule). Many of these contingencies were altered by the present procedures. Because reinforcers were available only at the completion of a schedule requirement, patterns of choice prior to schedule completion would have no effect on food delivery. In addition, under the usual concurrent schedules, food is potentially available at any time, but here food was available only at specific, predictable times. This raises the question of whether matching results only when food is potentially available or at other times.

In a similar experiment, Nevin (1969) used a modified FI choice procedure in which lights behind two choice keys were lit briefly once in each sixth of the fixed interval. A response on either key turned off the lights until the next sixth or, if no response was made, the lights went off after a specified time. Follow-

ing completion of the interval, a response on one key produced food, with one response producing 75% of the reinforcers. Nevin was thus able to assess relative response rates on the two keys during different portions of the fixed interval; he observed matching in the different portions. Our experiments provided a more detailed examination by observing choice with both FR and FI requirements when (1) different schedule values were used, (2) relative reinforcement rates were varied, and (3) different intertrial intervals separated one choice from the next. The purpose was to assess the effects of these changes on the relation between response output and relative reinforcement of choices and, in addition, to provide information about maximizing tendencies and response sequences that would be relevant to different theories of choice.

EXPERIMENT 1: CHANGES IN SCHEDULE VALUE

Experiment 1 was designed to examine the effects of different schedule values on choice. An FR requirement was used for some pigeons and an FI requirement was used for others. The schedules were varied to assess the effects of different requirements both on overall relative response rates and on the pattern of choices across the schedule requirement.

METHOD

Apparatus

Two homemade ice-chest pigeon chambers were used. The work panel of each contained three response keys that could be lit by different colors, a houselight, and a feeder. Details of the chambers are described by Fetterman and Stubbs (1982). The chambers were located in a room with white noise present. The relay equipment that controlled sessions and recorded the data was located in an adjacent room.

Subjects

Subjects were 5 adult pigeons, which were maintained at 80% of their free-feeding weights. All had prior experimental histories.

Procedure

For the FR choice procedure, the houselight and the two side keys of the three-key

chamber were lit by yellow light; the center key was always dark and inoperative. A peck on either side key turned off all lights and made the key inoperative for 50 ms. More important, a peck on either side key counted toward completion of an FR requirement. Food was available only after completion of the ratio. When, for example, an FR 20 was used, the first 20 pecks completed the ratio but could not produce food; the 21st produced food only if it was on the appropriate key. Food was scheduled either for a peck on the left key or a peck on the right. The designation of which response would be reinforced alternated irregularly from reinforcer to reinforcer, with the sequence arranged by a stepping switch. If the ratio had been completed but a response was emitted on the wrong key, that response simply produced the 50-ms blackout after which the pigeon could peck again. This procedure fixed both the relative number of reinforcers that could be produced by each response and the order in which reinforcers were delivered (Stubbs & Pliskoff, 1969). The reinforcer was 3-s access to mixed grain during which the key lights were off and the white magazine light turned on. Each session lasted until a pigeon received 50 reinforcers.

For the FI choice procedure, the two side keys were lit by yellow light, the houselight was on, and the center keylight was off. A peck on either side key darkened the chamber for 50 ms. An FI requirement was in effect such that responses occurring before the interval was over did not produce food; however, once the interval had elapsed, a peck on one of the two keys produced food, with the side producing food varied irregularly from interval to interval. The procedure for food delivery was the same as in the ratio procedure. Each session lasted until a pigeon obtained 50 reinforcers.

Schedule value. FR requirements of 5, 20, and 50 responses were used with 3 pigeons; FI requirements of 18 s, 60 s, and 180 s were studied with 2 pigeons. Under all conditions, 75% of the reinforcers were allocated to one response and the remaining 25% were allocated to the other response. The designation of which response produced 75% of the reinforcers changed from condition to condition. Table 1 shows the order of schedule values for each pigeon, the response that was given

Table 1

Summary of conditions for the pigeons in Experiment 1. (L) and (R), left and right, refer to the response reinforced 75% of the time.

Con- di- tion	Pigeons			Ses- sions
	25	35	22	
1	FR 20 (L)	FR 20 (L)	FR 20 (L)	50
2	FR 50 (R)	FR 5 (R)	FR 50 (R)	30
3	FR 5 (L)	FR 5 (L)	FR 50 (L)	30
4	FR 20 (R)	FR 50 (R)	FR 5 (R)	20

Con- di- tion	Pigeon 54	Sessions	Pigeon 73	Ses- sions
1	FI 60 s (L)	36	FI 180 s (L)	40
2	FI 18 s (R)	52	FI 60 s (R)	51
3	FI 180 s (L)	35	FI 18 s (L)	35

the 75% allocation, and the number of sessions under each condition. Each condition was in effect until performance appeared stable for at least five sessions.

RESULTS

Left and right responses were recorded each session, as were reinforcers produced by each of the two categories of responses. Responses occurring before the schedule requirement had been met were recorded separately from those occurring after it had been met. The number of responses emitted after completion of the schedule requirement was limited by food delivery; if, for example, the first response was on the designated key, food was given and no further responses could occur. The number of reinforcers was fixed so that obtained relative reinforcement rates were virtually identical to scheduled rates. Relative response rates were obtained by dividing the total number of responses on a key by the total number of responses on both keys. Data were also recorded on counters and an event recorder so that more detailed relative response-rate measures could be calculated (e.g., for each sixth of a fixed interval).

Figure 1 shows relative response-rate measures for pigeons exposed to the FI choice (top) and the FR choice (bottom) across different schedule values. Relative response measures were calculated with respect to the response that was reinforced 75% of the time; some-

Fig. 1. Relative response rates as a function in schedule value under both FI and FR choice procedures. Relative response rates were calculated separately for responses emitted before completion of the schedule requirement and for those emitted after completion. Circles and triangles indicate whether 75% of the reinforcers were produced by left-key or right-key responses; the relative measure was always calculated with respect to the response that was reinforced 75% of the time. Thus, the dashed lines indicate the loci that correspond to matching. Each point represents mean performance over the last five sessions of a condition.

times this response was on the left key (circles) and sometimes on the right (triangles). Figure 1 shows only a very rough correspondence between relative response rates and relative reinforcement rates; in fact, the more salient feature is the variation in performance. For measures representing choice before the schedule requirement had been met, the average absolute deviations from matching were 0.14 for the FI conditions and 0.19 for the FR. The unfilled symbols, which represent performance after the schedule requirement had been met, fall somewhat closer to the matching lines. The unfilled symbols were closer to the matching lines in 15 of the 18 comparisons. Daily comparisons showed a similar effect, with 70 of the 90 comparisons showing a closer approximation to matching after completion of the schedule requirement. There are two other noteworthy features of Figure 1. First, there was no single pattern of

choices; relative responding often deviated from relative reinforcement rate, but the deviations were not systematic. In some cases, relative responding exceeded relative reinforcement, but there were also cases in which relative response rates were nearly equal on the two keys (e.g., Pigeon 54 under FI 180 s and Pigeon 25 under FR 20). Relative response output before the schedule requirement was completed (filled symbols) approximated matching (deviations less than 0.10) in 4 of 18 cases. Relative responding exceeded relative reinforcement by more than 0.10 in 10 of the remaining 14 cases. Although the points indicate a wide range of variability across birds and conditions, the means are representative of day-to-day performance. Standard deviations generally were less than 0.05 with an average of 0.04. Thus, there was a tendency for relative response rates to be higher than relative reinforcement rate, particularly for the

Fig. 2. Relative response rates across different portions of FI schedules when the schedule value was varied. Relative response rates were calculated for responses emitted during each sixth of the interval and for those emitted after the interval had elapsed. The data represent means of the last five sessions of a condition.

ratio birds, but this result was not consistent. Second, there were no consistent changes in performance that were related to changes in schedule value. There were no changes toward or from matching as the schedule value was increased.

Figure 2 provides a more detailed analysis of the FI conditions by showing relative response rates for each sixth of the interval and for the periods after the requirement had been met. Points are omitted from early portions of an interval in those cases where fewer than 10 responses per session were emitted. The results indicate that the patterns of performance varied for the different birds and across conditions. Typically, there was a closer approximation to matching as the interval neared completion.

Absolute response rates vary under simple FI schedules with an increasing rate as the interval neared completion. A similar finding was observed in the present situation with a higher rate of choice responses in later portions of the interval. Figure 3 shows response rates for left-key and right-key responses, confirming that rates on both keys increased over sixths of the interval. Stated generally, response rates were higher on one key than the

Fig. 3. Absolute rates of responding on the two keys during FI schedules when the schedule value was varied. Response rates were calculated for responses on each key during each sixth of the interval. The data represent means of the last five sessions.

other, with the response rate difference corresponding to the relative response rates of Figure 2.

Figure 4 provides details of performance under ratio conditions by presenting relative response-rate measures for each successive response comprising a ratio. The data were taken from event records, so the data in Figure 4 are samples, with each portion representing performance for one of the last five sessions under a condition. Event records from other sessions indicate that the data were comparable from session to session. Figure 4 shows that there was variability from condition to condition, as was the case with the interval procedures. In some cases, there was a tendency towards matching as the ratio neared completion (e.g., Pigeon 25 under FR 20 and Pigeons 25 and 22 under FR 50). In other cases, the data are characterized by almost exclusive responding on the key correlated with more food (e.g., Pigeon 35 under FR 20).

The individual event records are instructive by showing similar patterns of responding for

Fig. 4. Relative response rates in different portions of different FR schedules. The data were taken from event records; each set of data represents performance for one session.

the individual ratios. For example, Figure 4 shows a gradual decline in relative response rates for Pigeon 25 under FR 50. However, the individual records show a consistent pattern for each ratio run: The pigeon always began with a long series of left-key responses (average of 25 pecks); the pigeon then pecked once or twice on the right, then emitted another series of left-key responses (average of 11 pecks), pecked once or twice on the right, and then emitted a shorter series on the left, etc. Pigeon 25 under FR 20 always began with a series of responses on the key providing fewer reinforcers, and then changed to the other key, completing the ratio by responding almost exclusively on this key. Even where Figure 4

shows almost exclusive responding on one key, the individual records are revealing. Pigeon 35 under FR 20 simply responded on the right key. When a reinforcer was scheduled on the right, the 21st peck produced food; when, however, a reinforcer was scheduled on the left, the pigeon was fairly consistent in emitting 26 or 27 responses on the right, followed by one response on the left.

EXPERIMENT 2: CHANGES IN RELATIVE REINFORCEMENT RATE

In the first experiment, behavior was quite variable both across pigeons and across conditions. Relative response rates generally did

Fig. 5. Relative response rates (L/R) plotted as a function of obtained relative reinforcement rates (log scales, base 10). Separate measures were calculated for responses emitted before and for those emitted after the fixed interval had elapsed. The points represent means for the last five sessions under each condition.

not match relative reinforcement rates. It is difficult to interpret these findings, because there are several sources of deviation from matching. The generalized matching law is

$$\frac{P_1}{P_2} = K \left(\frac{r_1}{r_2} \right)^a,$$

in which P_1 and P_2 represent responses, r_1 and r_2 represent reinforcers for the alternatives, and a and K represent constants. The parameter a represents the slope of the matching line and K its intercept. In the case of perfect matching, a and K are both equal to 1.0. Deviations of a above and below 1.0 are referred to as overmatching and undermatching, respectively. Deviations in K indicate changes in bias. It was not possible in the first experiment to determine whether the deviations from matching should be characterized as bias or as overmatching/undermatching. Relative reinforcement rates were varied in Experiment 2 in an attempt to identify the source of deviations.

METHOD

Apparatus and Subjects

The chamber and equipment were the same as in the first experiment. Subjects were 3 adult pigeons, maintained at 80% of their free-feeding weights. These pigeons had prior experimental histories but had not served in Experiment 1.

Procedure

The pigeons were trained under conditions that were similar to those of Experiment 1. An FI 60-s choice procedure was used: Responses could be emitted on either key, but they were not reinforced until the interval had elapsed; after completion of the interval, either a left-key or a right-key response produced food, with the designation of side producing food varying from interval to interval. Relative reinforcement rates were varied across conditions; computed with respect to left-key responses, they were 0.75 (in effect for 55–60 sessions), 0.10 (33–34 sessions), 0.50 (36–37 sessions), 0.25 (56–57 sessions), and a re-determination of the original 0.75 (43–44 sessions). Each condition was in effect until performance appeared stable for at least five sessions.

RESULTS

Figure 5 shows changes in log response ratios, both before and after the interval was completed, as a function of changes in log obtained reinforcement ratios. The diagonals show the locus of perfect matching. Although log response ratios increased as a function of log reinforcement ratios for all 3 pigeons, Pigeons 37 and 76 showed substantial deviations from matching. The points for Pigeon 71 fell much closer to the diagonal. The equations above each panel represent best fitting regres-

Fig. 6. Relative response rates across different portions within the FI schedule when the relative reinforcement rate was varied. Relative response rates were calculated for responses in each sixth of the interval and for those emitted after the interval had elapsed. The data represent means of the last five sessions.

sion lines for the five points before and those after the interval was completed. The slopes of these lines represent the degree of undermatching/overmatching and the intercepts show the amount of bias. For response ratios before completion of the schedule requirements, the results are mixed. Pigeon 37 shows approximate matching, Pigeon 76 shows undermatching, and Pigeon 71 shows overmatching. In addition, Pigeons 37 and 76 showed a bias to the left key and Pigeon 71 a slight bias to the right key. Visual inspection of the "before" points and examination of the coefficient of determination (in parentheses after each equation) show that the fitted lines failed to account for a substantial amount of variation for Pigeons 37 and 76. Unlike the "before" measures, response ratios after completion of the schedule requirement showed consistent overmatching for all 3 birds. Only Pigeon 76 showed an appreciable bias towards one key, and the coefficients of determination showed that for all 3 birds the fitted lines provided a reasonable description of the data.

The equations of Figure 5 were based on the five separate conditions (i.e., straight lines were fit to five data points). The calculations

thus give a double weight to the redetermined 0.75 condition, which may have influenced the results. Accordingly, we also averaged the two determinations of the one condition and performed calculations on the four resulting conditions. This new set of calculations did not change slopes and y intercepts markedly (the average absolute difference was only 0.03 for slopes and 0.02 for y intercepts). The calculations, however, did increase the amount of variance accounted for. The coefficients of determinations for before and after measures were 0.89 and 0.97 for Pigeon 37, 0.97 and 0.98 for Pigeon 76, and 0.98 and 0.99 for Pigeon 69. The two ways of calculating regression equations raise questions about the appropriateness of averaging. One way of calculating suggests that the regression equations do not account for an adequate amount of variance, whereas the other leads to results consistent with those of other concurrent schedules. Averaging eliminates differences in multiple determinations of a condition and gives support to the matching relation, yet averaging might give a false impression of regularity and quantitative order when variability across conditions is the rule.

Figure 6 provides detailed data on relative responding for each of the six 10-s portions of the interval. The findings are consistent with those of Experiment 1 in showing different patterns across pigeons and across conditions. There was no one general result that characterized performance. Instead, there are cases of approximate matching, cases of almost exclusive responding on one key, and cases of increasing or decreasing relative responding across the interval. In spite of the differences, there was some tendency for relative responding to approximate relative reinforcement rates more closely as the interval neared completion. Comparison of the first point with the sixth shows a closer approximation at the end of the interval in 12 of the 15 comparisons.

Event records were obtained under each condition, and, like the data of Figure 6, show different patterns for the different birds. A general comparison with the event records under FR conditions (Experiment 1) indicates that the pattern of responses was more variable from interval to interval. Whereas the ratio birds often demonstrated a characteristic pattern of choices from ratio to ratio, here there was no characteristic pattern that was similar

from interval to interval. This is not to say that the distribution of choices was completely nonsystematic. Figure 6 does indicate some patterning when the data were averaged across intervals. However, the relation of individual interval data and the average data was typically not obvious as it was in the case of ratio performance.

EXPERIMENT 3: CHANGES IN THE INTERTRIAL INTERVAL

In the first two experiments, the pigeons could respond at any time with only a brief (50-ms) feedback blackout separating pecks. Experiment 3 investigated the effects of an intertrial interval that separated one choice from the next. There were two reasons for changing intertrial intervals. First, ratio performance in Experiment 1 was often characterized by a rapid series of pecks on one key (typically the key providing more food). One function of the intertrial interval was to break up these rapid series of responses and to see whether the pigeons would then distribute responses to both keys. A second reason was that Nevin (1969) used an intertrial interval in his study with a similar procedure and obtained matching. Nevin's finding of matching with an intertrial interval and our failure to obtain matching without an intertrial interval suggest that this feature may be important.

METHOD

Apparatus and Subjects

The apparatus was the same as that used in the previous experiments. Subjects were 6 adult pigeons, maintained at 80% of their free-feeding weights. Three pigeons were new to the experiment; 3 had served in Experiment 2.

Procedure

The 3 new pigeons were trained on an FR choice procedure that was similar to that described in Experiment 1. For Experiment 3, an FR 10 requirement was used with pecks on either key counting towards completion of the ratio; once the ratio was complete, food was available for either a left-key or a right-key response. Relative reinforcement rate was 0.75 for left-key responses. During initial training (56 sessions) there was no intertrial interval; a 50-ms blackout was used as feed-

back. Then longer blackouts were introduced. Each response turned off the lights for a specified duration and responses during this blackout had no scheduled consequences. The intertrial intervals used were 1 s (48–56 sessions), 6 s (71–85 sessions), 18 s (32–38 sessions), and a redetermination at 1 s (24–26 sessions).

A less extensive study was conducted with the FI choice pigeons of Experiment 2. Following the last condition of that experiment (relative reinforcement rate of 0.75), a 6-s intertrial interval was introduced following each peck and this condition remained in effect for 62 sessions. The fixed interval continued to operate during the blackouts so that the use of a 6-s blackout reduced the number of responses that could be emitted in an interval. With FI 60-s and a 6-s blackout, an animal could respond no more than 10 times during a single interreinforcement interval. A last condition for these birds changed the procedure from a fixed-interval to a fixed-ratio choice by requiring that the animals peck 10 times (FR 10) with each choice followed by the 6-s intertrial interval. This last condition was in effect for 45 sessions.

RESULTS

Figure 7 shows the results for the pigeons exposed to FR choice. The top portions provide summary data and show the means computed over the last five sessions. The data show that relative response rates were high (above 0.90) in all cases. The lower portions of Figure 7 show data for each of the last five sessions of the first condition and each of the first and last five sessions of the subsequent conditions. The main finding is that introduction of the 1-s, 6-s, and 18-s intertrial intervals changed the pattern of responding from near-exclusive responding on one key to a pattern that approximated matching; with continued training, however, performance "recovered" and relative response rates increased to values near 1.0. The results indicate that increases in the intertrial interval produced only temporary changes in performance.

Figure 8 shows relative response rates within the fixed ratio and shows that with the occasional exception of the initial response, the measures approximated 1.0 throughout the ratios. There was no systematic change in performance as the ratio neared completion.

Fig. 7. Relative response rates under FR choice when the intertrial interval was varied. The top sections of the figure show summary data with relative response rates for responses emitted before and after the ratio had been completed. The bottom sections show relative measures for individual sessions, the first five sessions and the last five sessions.

Figure 9 shows data for the pigeons exposed to FI and then FR conditions. The top portions show average data before and after completions of the schedule requirement; the bottom portions show data across the schedule. Three sets of data are shown: (1) data taken from Experiment 2 when there was no intertrial interval under FI choice; (2) data when a 6-s intertrial interval was used; and

(3) data when the schedule was changed to an FR 10 with a 6-s intertrial interval. The top portions show similar changes for all 3 pigeons across conditions. Comparison of performance before the schedule requirement was met (filled symbols) shows that relative response rates decreased when the intertrial interval was increased, resulting in a closer approximation to matching (points for Pigeon

Fig. 8. Relative response rates across different portions of the FR schedule when the intertrial interval was varied. Points are means of the last five sessions under each condition.

71 lie close to matching in both cases). Relative measures then increased for all 3 pigeons when the procedure was changed from FI to FR choice. The bottom portions provide detailed data and show what has been observed before: The pattern of choices was variable from pigeon to pigeon and from condition to condition.

GENERAL DISCUSSION

Choice was studied in schedules in which a requirement had to be completed before choice responses were reinforced. Procedural variations included fixed-ratio and fixed-interval schedules, changes in schedule value, changes in relative reinforcement rates, and changes in an intertrial interval imposed between individual responses. Figure 10 summarizes the data of the different experiments by showing deviations from matching under all conditions when relative reinforcement rates were greater for one response than for the alternate response. Figure 10 does not treat specific findings of the experiments (e.g., bias), but instead addresses three general conclusions. First,

Fig. 9. Relative response rates when the schedule requirement and the intertrial interval were varied. The top sections of the figure show summary measures for responses emitted before and after the schedule requirement was completed. The bottom sections show measures across the different portions of the FI and FR schedules. Points are means of the last five sessions.

performance was quite variable, with many points showing substantial differences between relative response rates and relative reinforcement rates. In this regard, both the median and mean for all fixed-interval conditions show correspondence between relative response and reinforcement measures, but the individual points indicate that the summary measures are not representative of the particular instances on which they are based. Second, there is a difference between fixed-ratio and fixed-interval conditions, with interval conditions leading to relative response rates above and below relative reinforcement rates, but ratio conditions typically producing relative response rates that were more extreme than relative reinforcement rates. The third main finding is that response and reinforcer measures were more nearly equal after the schedule requirement had been met. However, the "after" measures are less than ideal because food delivery terminated the opportunity for responses in this category. Accordingly, comparisons were made for early and late portions of a schedule before the requirement had been met. These comparisons showed a closer equivalence of response and

Fig. 10. Deviations from matching of relative response rates to relative reinforcement rates. The data are taken from the different conditions of all three experiments. Means and medians are given that combine performances from all cases involving fixed-ratio procedures and all cases involving fixed-interval procedures. The top section shows performance for data based on responses emitted before the schedule requirement was completed. The bottom section shows performance for responses emitted after the schedule requirement was completed.

reinforcer measures in three-fourths of the interval cases as the interval neared completion; there was no clear corresponding trend near the ends of the ratio schedules for relative response rates to more closely approximate relative reinforcement rates.

Previous experiments on concurrent schedules have usually produced consistent patterns of results from subject to subject, with matching (or some variant of matching) as a general finding. In contrast, matching was not a general result in the present experiment and performances were characterized by a large degree of variability. We need to consider three basic questions in relating present results with past. Why was there an absence of matching? Why was performance so variable? And why did interval and ratio procedures yield different results?

Deviations from Matching and Variability in Performance

With regard to the questions of matching and variability, a large part of the answer has to do with the ways reinforcers interact with

behavior in the different situations. The present procedures are similar to concurrent VI VI schedules in specifying different relative reinforcement rates for different responses. However, the present procedures differ in many other ways. Under concurrent VI VI schedules, reinforcers are potentially available at any time and are obtained as the animals alternate between the two schedules. Several features of the procedure favor alternation and even specific patterns of alternation: an increasing probability of reinforcement on one schedule the longer the animal works on the alternate schedule (Catania, 1966); the often large proportion of reinforcers that follow a changeover (Dreyfus, Dorman, Fetterman, & Stubbs, 1982); and the effects of changeover contingencies (Hunter & Davison, 1978; Stubbs, Pliskoff, & Reid, 1977). In a more general sense, the various explanations of concurrent VI VI performance that emphasize response strength, maximizing, or molecular processes all predict matching by pointing to different aspects of the situation to which animals could be sensitive. It would seem that in the interaction of behavior and reinforcement, a variety of factors all afford matching as the outcome. In contrast, the present procedures lack many of the contingencies—or perhaps constraints—that operate in other situations. Reinforcers were available only at the end of an interval or a ratio, and prior patterns of responding did not alter the delivery of food. Many of the patterns of choice that interact with reinforcement under typical concurrent schedules would have little or no effect in the present situations. This lack of constraint does not favor the formation of any one pattern of responding. If many patterns can be equally effective, even those producing substantial deviations from matching might result with variability becoming the rule.

The term “effective” might seem vague, but it can be specified and quantified so that different patterns of choice can be compared. Prior to completion of the schedule, responses would have no effect on food (other than to complete the requirement); but, once the requirement had been completed, the number of responses made to produce food provides a measure of effectiveness. A minimum of one response would be required if every response was on the key for which food was assigned; however, two or more responses could occur

if the pigeon engaged the alternate key. The fewer the number of responses required to produce food, the more effective would be the pattern of responding. Figure 11 provides the relevant data for comparing all conditions. The top portion is a histogram showing the frequency with which different numbers of responses were required to produce a reinforcer once available. The data are very consistent, with the pigeons requiring only 1.6 to 2.5 responses to produce a reinforcer in most cases. Similar numbers occurred whether the interval or ratio procedure was used and when schedule value, relative reinforcement rates, or intertrial interval were changed. The data reveal that the pigeons were very effective in producing food across a variety of conditions. Although performance was consistent across conditions, the question can be raised whether the number of responses needed to produce food was influenced by deviations between relative response and reinforcement measures. The bottom portions of Figure 11 provide the answer by showing the correlation between deviations and number of responses needed to produce food. The middle portion shows no relation between response number and deviations from matching before the schedule requirement was met; performance was equally effective across changes in relative response measures. The bottom portion shows that response number was not affected by deviations in relative response rates unless the degree of responding on one key was extreme. These results make sense, because variation in relative response rates should have no effect on the producing of food prior to completion of the schedule. Afterwards, different response patterns would have little effect on the number of responses needed to produce food provided both keys were sampled often; however, exclusive or near-exclusive responding on one key could produce an excessive number of responses on one key prior to the alternate response being emitted and reinforced. The increase in response number that accompanied persistent responding on one key was small, and the increase may not have been discriminable because these responses came at the end of the schedule.

The data of Figure 11 demonstrate that effectiveness, as measured by responses emitted after completion of the schedule requirement, varied little across changes in relative response

Fig. 11. The top section shows the frequency with which different numbers of responses occurred prior to food delivery once the schedule requirement was completed. Data come from the different conditions of the three experiments. The bottom sections plot these response measures against deviations from matching—both for deviations from matching of responses emitted before the schedule requirement was met and those emitted after.

allocation. However, relative response measures do not provide information about specific patterns of behavior that might affect the delivery of food. Some patterns might be more effective than others, but yield the same relative response measure. In the case of the FI choice procedure, patterns favoring response alternation as the end of the interval approached would serve to minimize the delay

of food and result in fewer responses needed after completion of the schedule requirement. The different patterns we observed had the common feature that alternations were prevalent especially at the end of the interval requirement. In contrast, changeovers should occur only near the end of the schedule requirement under ratio choice procedures; changeovers that occur before this time are inefficient because they increase the time taken to complete the schedule requirement, and hence increase the delay to food. In other words, the animals should show exclusive responding on one key (presumably on the key with the higher relative reinforcement rate) until the schedule requirement is completed and then, if food is not produced, alternate between the two keys. The relative response measures for the FR choice procedure were generally consistent with this pattern (cf. Figures 4 and 9).

Fixed-Ratio and Fixed-Interval Choice

Regarding the difference between ratio and interval procedures, the difference is probably related to the general characteristics of FR and FI schedules (Ferster & Skinner, 1957). Ratio schedules are response-based and require a specific number of responses before food delivery, but interval schedules are time-based and do not require a specific number of responses. The different characteristics of these two schedules may have led to patterns of responding that contributed to the overall differences between the two tasks. Event records for the ratio subjects were more consistent from ratio to ratio, not only in the number of responses emitted, but also with respect to the specific patterns of choices; there were also regularities under interval conditions, but here the patterns were more variable from interval to interval with responding beginning at different times in an interval, with different numbers of choices in each interval, and, most important, with variable patterns of choices from interval to interval. It appears that the ratio task is more likely to establish a dominant sequence of choices. Supporting evidence for this view comes from other experiments on response variability. For example, Boren, Moerschbaecher, and Whyte (1978) allowed monkeys to respond on any of six levers to obtain food according to both FR and FI

schedules. They found that FR schedules produced less variability than FI schedules, with fewer switches from lever to lever under ratio conditions (see also Moerschbaecher, Thompson, & Thomas, 1979). Schwartz (1980, 1981a, 1981b, 1982) used a stimulus-correlated task that arranged for pigeons to peck two keys eight times; any of the variety of stimulus-peck combinations that included four left and four right pecks were reinforced. Although 70 different combinations could produce food, Schwartz found that one sequence came to predominate for each pigeon. Attempts to produce greater response variability met with only limited success (Schwartz, 1982). The results suggest that stereotypy results even when it is not reinforced directly. Although Schwartz's task differed from ours in a number of ways, it is similar to our ratio task in that different sequences could produce food and in that the requirement was response based. Just as he found that one sequence tended to dominate for each bird, so our event records showed a consistent pattern of choices from ratio to ratio.

If ratio schedules produce a greater stereotypy of behavior, the question is how this stereotypy leads to extreme responding on one key. Again, the data of Schwartz are useful. He observed that different sequences predominated for the different pigeons, but found that in 9 of 12 pigeons, the dominant sequences consisted of four pecks on one key followed by four on the other key. Thus, the dominant sequence is not arbitrary; rather, the sequences that were emitted were the ones that probably involved less effort and time to complete rather than those that involved intricate series of alternations. Our findings seem similar in that the birds often produced long series of responses on the key correlated with more food. Of the many possible sequences of pecks that would complete the requirement, the easier, quicker-to-complete sequences dominated (i.e., an FR 20 could be completed faster with pecks on one key than with many alternations between two keys). Figure 11 shows that the deviations from matching were correlated with a slight increase in the number of responses needed to produce food. There is, however, a tradeoff: Sequences of choices with many alternations might reduce the total number of responses per reinforcer, but these

sequences take longer to complete; long series of responses on one key could increase the number of responses, but the sequence could be completed more quickly. These contingencies are absent in an FI procedure because it is a time-based schedule. Different sequences do not hasten the delivery of food, and patterns with few or many responses and with few or many alternations are similarly effective in producing food. Stereotypy may develop in reinforcement situations, as Schwartz has pointed out, but it is more likely in schedules such as an FR in which some patterns produce food more quickly or more easily than others.

General Accounts of Choice

A final set of issues concerns the relation of the present findings to general accounts of choice. Many specific explanations have been given, so only general accounts will be considered—accounts that emphasize matching, accounts that emphasize a maximizing or an optimization process, and accounts that focus on a more molecular process.

The matching relation has been given the status of a general law, but the evidence comes mainly from the large body of experiments that have employed concurrent VI VI schedules. There are deviations from matching under some conditions (e.g., see Myers & Myers, 1977; Wearden & Burgess, 1982), and use of other schedules produces deviations (e.g., concurrent FI FI schedules; see White & Davison, 1973), but these deviations can be accounted for by a more generalized version of the matching law (e.g., Baum, 1974). Also, there is controversy about some choice arrangements (e.g., concurrent VR VR schedules), but it is possible to fit these results into a matching framework (e.g., Baum, 1981). The present results often showed deviations between relative response and reinforcement rates, so the question is how these deviations can be accounted for. There are two possibilities. The first suggests that the present procedures do not provide an adequate test of the matching law. In some of our experiments, the data do not permit a clear assessment of whether the deviations we observed should be described as a lack of matching or whether they were attributable to bias. Experiment 2 presented data of the sort typically used to

distinguish matching and bias, with results suggesting deviations from matching. But here, different ways of calculating regression equations suggested somewhat different accounts. Even if more experiments like Experiment 2 were performed and all indicated deviations from matching, the procedure still might not provide a fair test of the matching relation. Both ratio and interval choice procedures contained periods during which responses could not produce food, and insofar as these periods were discriminable, variability in performance might simply indicate that there is little control by relative reinforcement rate when reinforcement is discriminably not available. Only when food is potentially available might the pattern of responding change and become like that typically observed in choice experiments. The major problem with this possibility is that at the end of the schedule requirement there should have been a closer approximation to matching than we observed. The second possibility considers the implications of the procedures for matching and raises questions about the generality of findings that come from concurrent VI VI schedules. In any choice procedure, there are several aspects of the situation to which the animals may be sensitive. Both the present procedures and the more usual concurrent procedures arrange reinforcers irregularly for different responses. Perhaps this molar distribution of reinforcers by itself produces only a very rough approximation to matching, as was the case in the present experiments. Perhaps other aspects of concurrent VI VI procedures, such as changing local probabilities of reinforcement and a high probability of reinforcement following a changeover, are responsible for the fine tuning that leads to the remarkable degrees of matching that are often observed (cf. Stubbs, Fetterman, & Dreyfus, in press).

Regarding maximizing accounts, the present data are compatible. The efficient way in which the pigeon obtained food, once available, demonstrates that performance was nearly optimal in providing food with the fewest responses. Although the different patterns of performance were optimal in producing food at the end of a condition, the question can be asked whether the particular pattern developed as a result of some underlying optimization process. Perhaps the pattern of choices

was inefficient when a condition began and was replaced by a more efficient pattern as training on a condition progressed. Comparison of responses per reinforcement early and late in training indicates that the answer is no. Comparison of efficiency data for the first and last five sessions when relative reinforcement rates were varied (Experiment 2) shows that behavior was no more efficient in producing food at the end of a condition. So, although performances were quite efficient, variations and changes in the pattern of choices did not result from (nor were they correlated with) increases in efficiency. In this respect, behavior did not interact with the feedback properties of the schedules.

The results are generally compatible with molecular accounts, but suggest modification of these accounts. Molecular accounts such as those of Shimp (1966, 1979) and Silberberg, Hamilton, Ziriax, and Casey (1978) emphasize sequences of responses, stating that a response is under the control of prior responses or prior time elapsed. These accounts also hypothesize a momentary maximizing process, stating that responses are emitted depending on which response has the higher momentary probability of reinforcement. Our findings of response sequences, particularly under the fixed-ratio choice procedure, are compatible with this view, and the results argue against positions maintaining that successive choices are independent. However, it is difficult to see how the results fit with the momentary maximizing notion because there was no maximizing sequence before the schedule requirement was met. A particular sequence reinforced at the end of the schedule requirement could influence performance, but momentary maximizing accounts imply that reinforcement of a particular sequence should establish similar sequences in earlier portions of the schedule. However, our pigeons often did one thing at the beginning of a schedule requirement and another at the end. Our results suggest that the sequences were not formed on a response-to-response basis. Instead, the sequences appear to have been organized within the context of the entire schedule requirement. Insofar as there is momentary maximizing, the moment appears to last for the duration of the schedule requirement; and a response does not depend simply on a few

prior responses, but on the responses that fill this moment.

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