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CHOICE: EFFECTS OF CHANGEOVER SCHEDULES ON CONCURRENT PERFORMANCE

R. D. TUSTIN AND MIKE DAVISON

UNIVERSITY OF AUCKLAND, NEW ZEALAND

The components of concurrent schedules were separated temporally by placing interval schedules on the changeover key. The rates of responding on both the main and changeover keys were examined as a function of the reinforcement rates. In the first experiment, the sensitivity of main-key performance to changing reinforcement rates was inversely related to the temporal separation of components, and changeover performance was monotonically related to the ratio of the reinforcement rates. In the second experiment, when the ratio of the reinforcement rates was scheduled to remain constant while the frequency of reinforcement was varied, changeover performance did not remain constant. A "sampling" interpretation of changeover responding was proposed and subsequently tested in a third experiment where extinction was always scheduled in one component and the frequency of reinforcement was varied in the second component. It was concluded that changeover performance can be interpreted using molar measures of reinforcement and that animals sample activities available to them at rates which are controlled by relative reinforcement rates.

Key words: choice, changeover schedules, sensitivity to reinforcement, changeover responding, sampling, generalized matching law, pecking, pigeons

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Animals responding on concurrent schedules of reinforcement always have two alternatives available to them: They can continue responding on a main key for food, or they can alternate between components. The distinction between the responses is especially clear in changeover-key concurrent schedules (Findley, 1958), as a changeover response is made on a separate key. Quantitative accounts of main key response rates have been suggested (Catania, 1969; Herrnstein, 1970), but there is little agreement on how changeover responding is controlled.

Two levels of analysis have previously been used to explain changeover responding. The first level of analysis explains changeover responding in terms of the moment-by-moment variations in the probabilities of reinforcement in the two components (Catania, 1966; Shimp, 1966). Shimp described this approach as a "momentary maximizing" approach, and showed that matching of main-key response rates to the reinforcement rates (Herrnstein, 1961) can be interpreted in terms of this approach. A second level of analysis of changeover responding uses molar measures, such as the overall rate of reinforcement in a component. Early explanations at the molar level suggested that animals responded either to attain the reinforcement rates in the alternate component as occurs in chained schedules (Findley, 1958) or to escape from the aversive low reinforcement rates in the present component (Rilling, Askew, Ahlskog, & Kramer, 1969; Thompson, 1964). But there is no way of determining whether animals are avoiding one component or attaining another, and, moreover, recent accounts of reinforcement emphasize the relative values of the components rather than absolute values. For example, both Baum (1973) and Premack (1971) argue that reinforcement involves a transition between activities of different values. The experiments reported here examined changeover responding using a molar level of analysis.

It is difficult to examine changeover performance experimentally under the usual concurrent schedules because changeover responding is quite unrestrained, and it is impossible to determine just what controls the respond-

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ing. Effective changeovers were constrained in the present experiments by placing interval schedules on the changeover key of concurrent schedules (Findley, 1958), so that changeover responses were effective only when the changeover schedule was completed. The rates of responding on the changeover key were free to vary and could differ between components. In Experiment 1, the changeover performance was examined as a function of the ratio of the reinforcement rates.

When an interval schedule is placed on the changeover key, the duration of each component must be at least the duration of the changeover schedule. Consequently, Experiment 1 also allows an assessment of how main-key performance changes as a function of the minimum component duration.

Herrnstein (1970) suggested that the rate of main-key responding (P_1) is controlled by the reinforcement rates for all responding according to the equation:

$$P_1 = k\left(\frac{R_1}{R_1 + mR_2 + R_0}\right), \qquad (1)$$

where R_1 is the reinforcement rate contingent on P_1, R_2 is the reinforcement rate contingent on responding in a second component, R_0 is the rate of unscheduled reinforcement, m measures the degree of interaction between components and k is the maximum value of P_1.

Herrnstein suggested that Equation 1 could account for responding in both concurrent and multiple schedules, and that responding becomes less sensitive to the changing reinforcement rates as the duration of the multiple schedule components increase. Presumably the performance in concurrent schedules should also become less sensitive to the changing reinforcement rates when component durations are increased by lengthening the changeover schedule. This prediction was tested in Experiment 1.

EXPERIMENT 1

METHOD

Subjects

Six experimentally naive homing pigeons were used, numbered 21 to 26. All birds were maintained at 80% ±15 g of their free-feeding weights by providing supplementary feed after experimental sessions.

Apparatus

The experimental chamber contained two response keys spaced 13 cm apart. Pecks exceeding .1 N on illuminated keys operated microswitches connected to solid state equipment situated remote from the chamber. During reinforcement, a grain hopper containing wheat situated midway between the response keys was raised and illuminated for 3 sec and all keylights were extinguished. Data were recorded on impulse counters.

Procedure

Concurrent schedules of reinforcement were arranged according to the changover-key method (Findley, 1958). Reinforcement was scheduled for pecks on the right-hand (main) key, which was transilluminated with either red or green light. Main-key components were alternated by the first response on the left-hand or changeover key after the completion of the changeover schedule. The changeover key was transilluminated with white light except during reinforcement.

Reinforcement was scheduled using variable-interval (VI) schedules composed of 12 intervals in random order from the arithmetic series a, $a + d$, $a + 2d$, etc., where $a = d/2$. The two reinforcement schedules operated independently and ran continuously until reinforcement was arranged, so the schedule ran even when subjects were in the alternate component. No reinforcement was available during a changeover delay of 1.5 sec following each response on the changeover key. The changeover delay was instituted to reduce the likelihood that changeover responses would be closely followed by reinforcement in either component (Herrnstein, 1961).

Fixed-interval schedules were placed on the changeover key so that responses on that key did not alternate components until the schedule requirement was complete. The changeover schedules operated independently of the reinforcement schedules. Both changeover and main key responses could be made at any time within sessions. Once animals did change components, the changeover schedule was restarted and animals could not change back until the schedule requirement was complete.

The numbers of reinforcements per session were set so that sessions would not exceed 45 min, with no more than 40 reinforcements

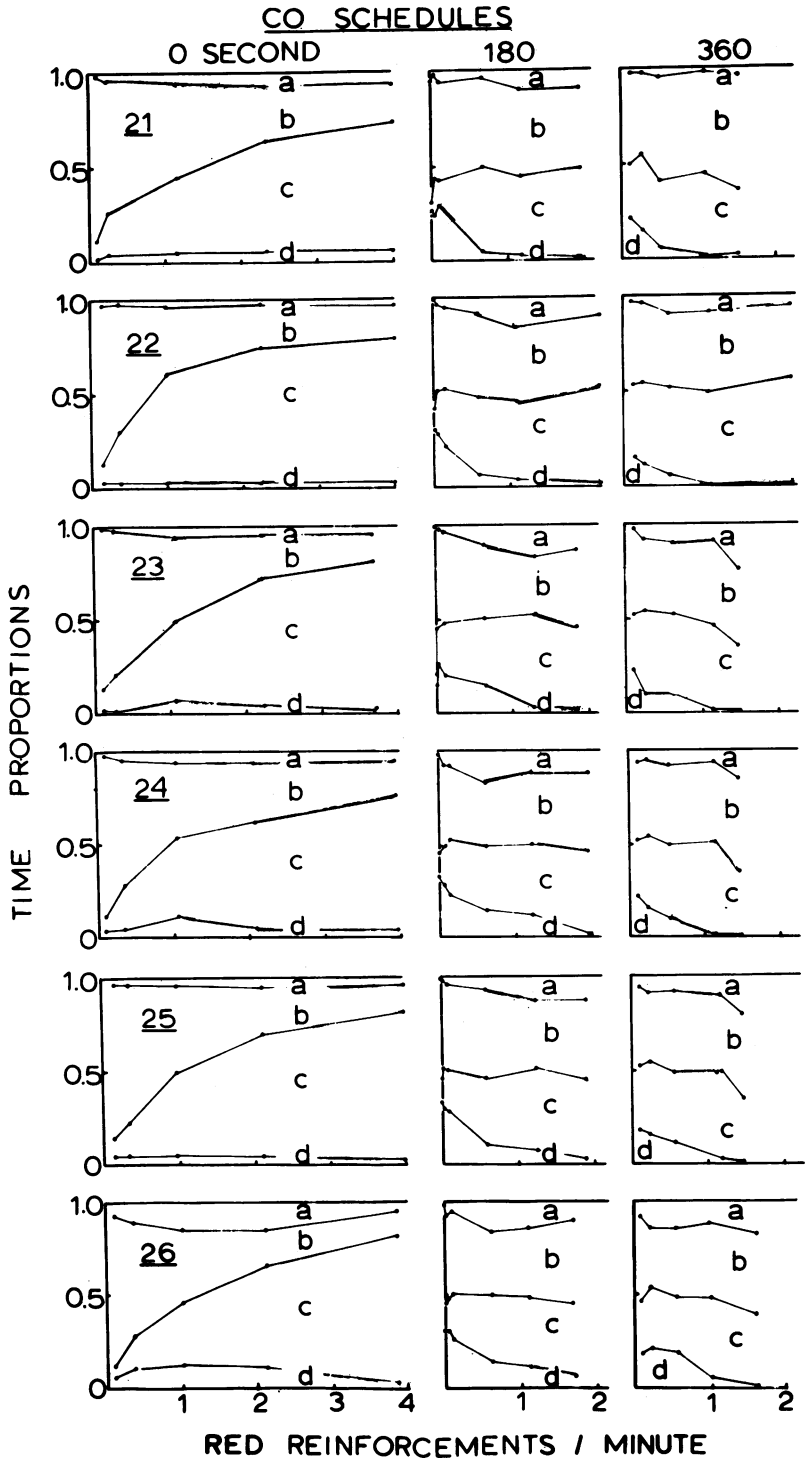


Fig. 1. The proportions of the total session time spent on (a) the green changeover key, (b) the green main key, (c) the red main key, and (d) the red changeover key are all shown plotted as a function of the reinforcement rate in the red component. Note that the letters refer to the areas enclosed by the lines. The scheduled reinforcement rates in the green components were constant within each panel.

Table 1

Sequence of conditions showing the variable-interval reinforcement schedules (sec) used in the red and green components, the fixed-interval changeover (CO) schedules (sec) that were used, and the numbers of sessions in training.

	Red	*Green*	*CO*	*Sessions*
1	60	60	180	20
2	480	60	180	21
3	480	60	0	22
4	60	60	360	20
5	480	60	360	19
6	30	60	360	21
7	180	60	360	22
8	15	60	360	26
9	15	60	0	22
10	180	60	0	26
11	30	60	0	23
12	60	60	0	17
13	30	60	180	20
14	1440	60	180	23
15	Ext	60	180	18
16	15	60	180	19

being obtained in any session. Experiments were run 7 days a week. Sessions started and ended in blackout. The data collected were (a) the numbers of responses and times spent on the main key and the changeover key in each component, (b) the numbers of reinforcements received in each component, and (c) the numbers of effective changeovers. Time spent on a key was counted from the first response on that key until the first response on another key. Time during reinforcement was not counted.

Experimental conditions were changed when all birds met a specified criterion of stability. The criterion required that the median of the relative main key response numbers from the last five sessions be within .05 of the median from the previous five sessions. This criterion had to be met five times, not necessarily consecutively. The numbers of training sessions are given in Table 1.

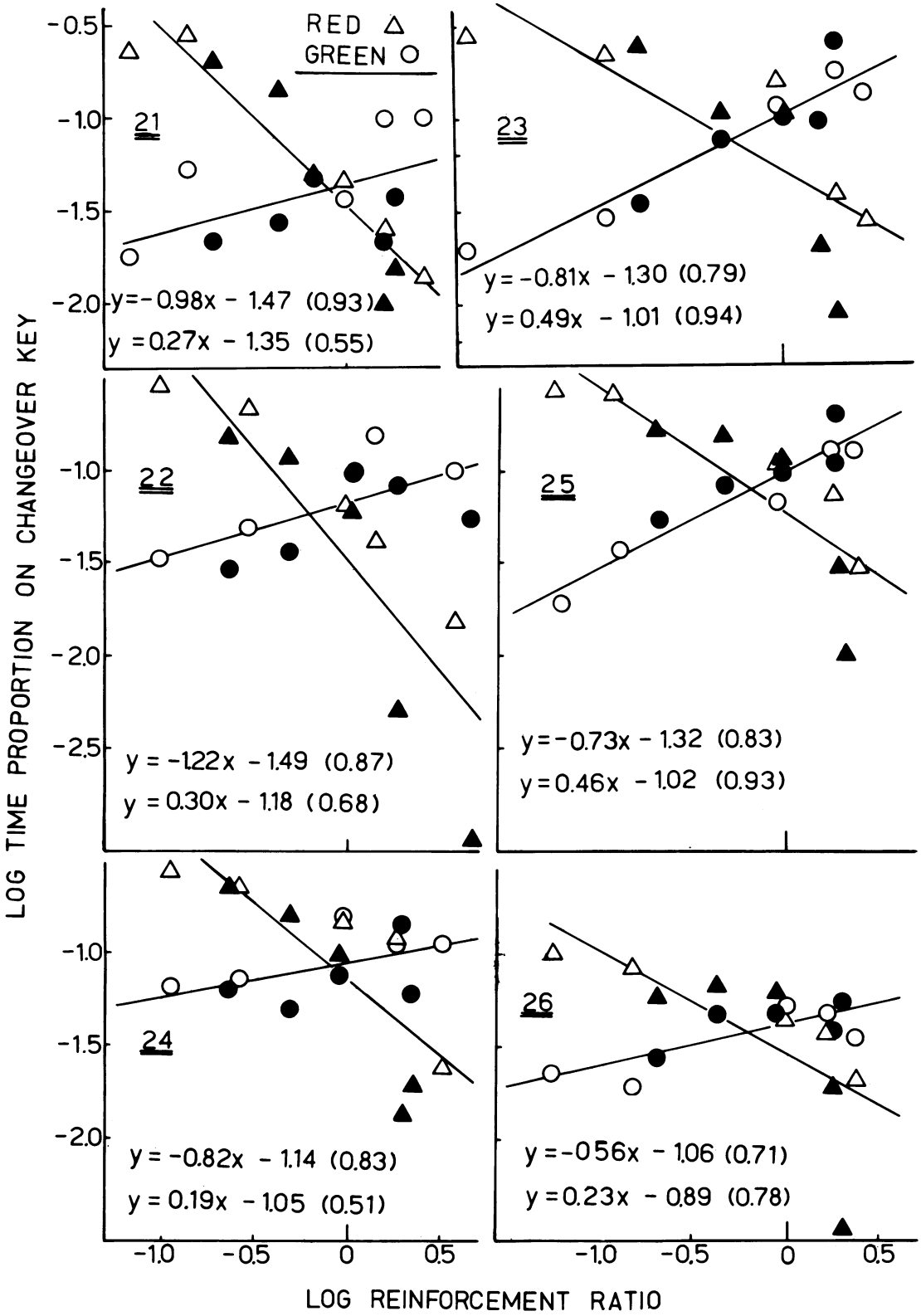
The schedule of reinforcement in the red component was varied. During preliminary training, the duration of the changeover schedule was increased progressively over successive conditions. The schedules of reinforcement and changeover schedules used in the experiment are shown in Table 1.

Results

The Experiment 1 had two aims: first, to examine behavior when a changeover schedule was used, and second, to compare behavior when changeover schedules were and were not used. The use of response rate as a dependent variable is complicated in the present experiment by the difficulty of selecting an appropriate time base. The number of responses might be divided by the total session time, as is conventional in concurrent schedules (Herrnstein, 1970), by the time spent in each component, or by the time spent responding on a particular key. To obviate these difficulties, the data are first considered in terms of time allocation.

Figure 1 shows how the animals allocated the total session time under the three changeover-schedule durations. The time was allocated to four keys (the main and changeover keys in both the red and green components). The proportions of the total time allocated to each key are shown by areas in Figure 1. Under most conditions, the major part of the time was allocated to the main keys (Areas b and c) rather than to the changeover keys (Areas a and d). Figure 1 shows that the proportions of time allocated to the main key in the red component (Area c) increased with the increasing reinforcement rate under the 0-sec and FI 180-sec changeover keys [the trends are significant for all subjects at the $p < .05$ level (Kendall, 1955)]. Under the FI 360-sec changeover schedule, there is a significant trend for the time allocated to the main key in the red component to increase with the increasing reinforcement rate in that component in only two subjects (22 and 26). The proportions of time allocated to the main key in the green component (Area b) were inversely related to the reinforcement rates in the red component, reaching significance at the .05 level as follows: The trends were significant under the 0-sec changeover schedule for all subjects; the trends were significant for the averaged data and for four individual subjects (21, 22, 23,

Fig. 2. The logarithms of the proportions of time spent on the changeover keys in the red and green components (respectively) under the FI 180-sec (open) and FI 360-sec (filled) changeover schedules are shown plotted as a function of the logarithm of the ratio of the overall reinforcement rates. The least-squares lines which are shown were fitted using Equation 2. The magnitudes of the correlation coefficients are shown in brackets.


RED △
GREEN ○
21
y=-0.98x - 1.47 (0.93)
y =0.27x - 1.35 (0.55)
23
y=-0.81x - 1.30 (0.79)
y=0.49x - 1.01 (0.94)
22
y = -1.22x - 1.49 (0.87)
y = 0.30x - 1.18 (0.68)
25
y=-0.73x - 1.32 (0.83)
y=0.46x - 1.02 (0.93)
24
y = -0.82x - 1.14 (0.83)
y = 0.19x - 1.05 (0.51)
26
y=-056x - 1.06 (0.71)
y=0.23x - 0.89 (0.78)
-0.5
-1.0
-1.5
-2.0
-2.5
-1.0
-0.5
0
0.5
LOG TIME PROPORTION ON CHANGEOVER KEY
LOG REINFORCEMENT RATIO

and 25) under the FI-180 sec changeover schedule; and the trends were significant for no subjects under the FI 360-sec changeover schedules (Kendall, 1955).

Changeover Performance

The proportions of total session time allocated to the changeover keys in the two components are shown in Figure 1 by the Areas a (green component) and d (red component). Under the 0-sec changeover schedule, the time allocated to the changeover key in the red component showed an inverted U-shape with a peak near the point where the two reinforcement rates were equal: The peaks occur at this point for Subjects 23, 24, and 26 and at an adjacent data point for the other subjects. Under both the FI 180-sec and FI 360-sec changeover schedules, the times allocated to the changeover key in the red component decreased as the reinforcement rate in that component increased ($p < .05$ level for each subject). The times allocated to the changeover key in the green component increased with increasing reinforcement rate in the red component ($p > .05$) for the averaged data and for subjects 22, 23, 24, and 25 under the FI 180-sec changeover schedule, and $p < .05$ for the averaged data and for subjects 23, 25, and 26 under the FI 360-sec changeover schedule (Kendall tests). As the times allocated to the changeover keys varied in both components when the changeover schedules were used but the scheduled reinforcement rate was varied in only one component, the time allocated to the changeover key must be affected by both reinforcement rates rather than by the absolute rate of reinforcement in just one component. The times allocated to the changeover key were inversely related to the relative rates of reinforcement.

The next question is whether the changeover performance can be described adequately in terms of a simple mathematical relation between the two reinforcement rates. Previous authors (e.g., Stubbs & Pliskoff, 1969) have related changeover performance to the ratio of the reinforcement rates, and the same measure is used here. Figure 2 shows the logarithms of the proportions of time spent on the changeover keys when FI 180-sec and FI 360-sec changeover schedules were used, plotted as a function of the logarithms of the ratios of the reinforcement rates. Least squares lines fitted to the data using Equation 2 are also shown in Figure 2. Equation 2 is:

$$CO_{t1} = c\left\{\frac{R_2}{R_1}\right\}^a \qquad (2)$$

where CO_t is the proportion of the total session time spent on the changeover key in one component. Logarithmic axes were used in Figure 2 as the data will be well described by straight lines when logarithmic data are used, if Equation 2 is an adequate description of changeover performance.

Figure 2 shows that the proportions of time allocated to the changeover keys were monotonically related to the ratios of the reinforcement rates under both the FI 180-sec and FI 360-sec changeover schedules. The slopes of the fitted lines are all negative for the times allocated to the changeover key in the red component and are all positive for the times allocated to the changeover key in the green component [$p < .05$, Sign tests (Siegel, 1956), when tests were applied to the signs of the slopes], showing that the times allocated to the changeover key are functionally related to the ratio of the reinforcement rates. However, the correlations between the time proportions and the reinforcement ratios were not always high, ranging from .94 to .51. Furthermore, the slopes were higher for the data from the red component than from the green component, and the intercepts of the fitted lines were lower for the data from the red component than from the green component in each of the six cases [$p < .05$, Sign test (Siegel, 1956)], suggesting that the changeover performance cannot be explained entirely in terms of the ratio of the reinforcement rates.

A third question concerns the effects of the changeover schedules on the changeover performance. Figures 1 and 2 showed monotonic relations between changeover performance and reinforcement rates under both the FI 180-sec and FI 360-sec changeover schedules, but an inverted U-shape was found under the 0-sec changeover schedule. However, the time allocation under a 0-sec changeover schedule can also be measured in terms of the mean interchangeover time (ICT, computed by dividing the total time spent in a component by the number of changeovers). The mean ICTs are shown in Figure 3.

Figure 3 shows the mean ICTs in the two components under the 0-sec changeover sched-

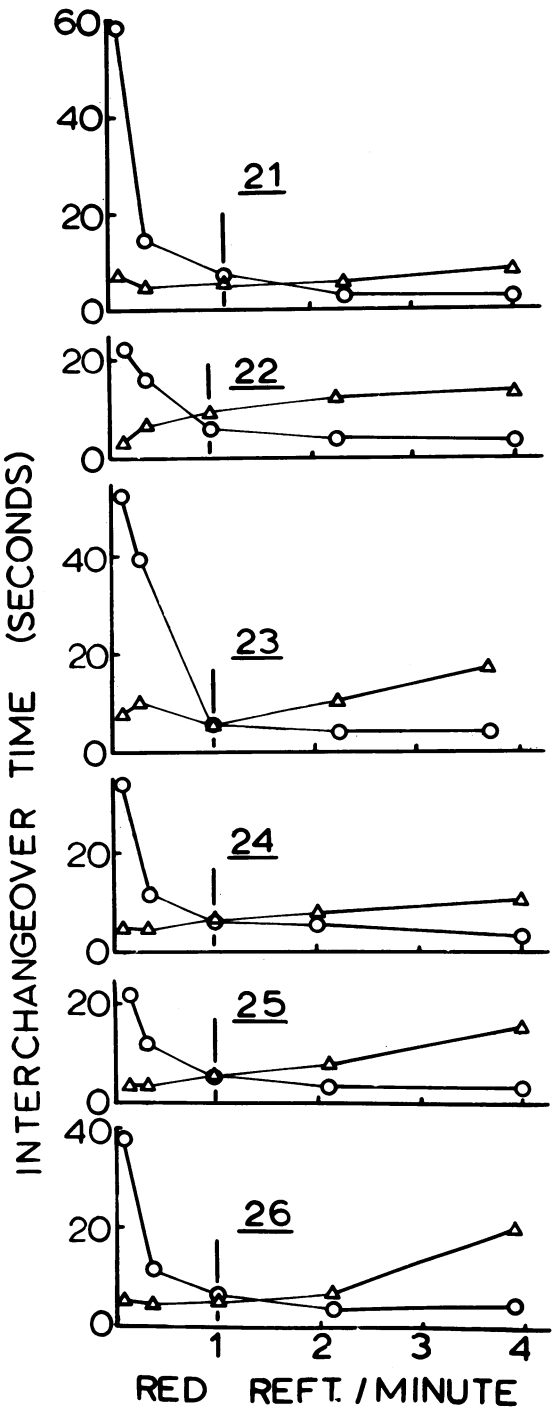


Fig. 3. The average times between changeovers in the red and green components under the FI 0-sec changeover schedules are shown plotted as a function of the reinforcement rate obtained in the red component. The mean interchangeover times (ICT) in the red component are marked by triangles and those in the green component are marked by circles. The red component has the lower reinforcement rate to the left of the vertical black line, and the green component has the lower reinforcement rate to the right of the vertical black line.

ule when the reinforcement rate in the red component was varied from being less than to being greater than the reinforcement rate in the green component. We now look at how the mean ICT changed as the reinforcement rates in the two components move from being equal to being unequal; that is, we look at the mean ICT while moving away from the vertical line in each panel of Figure 3. Moving to the left of the vertical line, the mean ICT in the green component (circles) increase as the relative reinforcement rate in that component increases; and moving to the right of the vertical line the mean ICT in the red components (triangles) increase as the relative reinforcement rate in that component increases. Both trends occur in the data of each subject. This shows that the mean ICT in the component with the higher reinforcement rate was controlled by the relative reinforcement rates. There were no regular trends for the mean ICT in the components with the lower reinforcement rates to change as the relative reinforcement rates decreased further; that is, there was no regular change in either the circles when moving to the right of the vertical lines, or in the triangles when moving to the left of the vertical lines.

To recapitulate on Figures 1 to 3: Changeover performance was affected by the reinforcement rates in both components. When changeover schedules were used, the times allocated to the changeover key were inversely related to the relative reinforcement rate in that component (Figure 1). When changeover schedules were not used, the mean ICT in the component with the higher reinforcement rate was directly related to the relative reinforcement rate. These results are related, as the mean ICT is directly related to the value of the component, while the time spent on the changeover key is inversely related to the value of that component. Finally, Figure 2 showed that changeover performance was monotonically related to the ratio of the reinforcement rates when changeover schedules were used.

Main-Key Performance

Figure 1 showed that the proportions of total session time allocated to the main key in

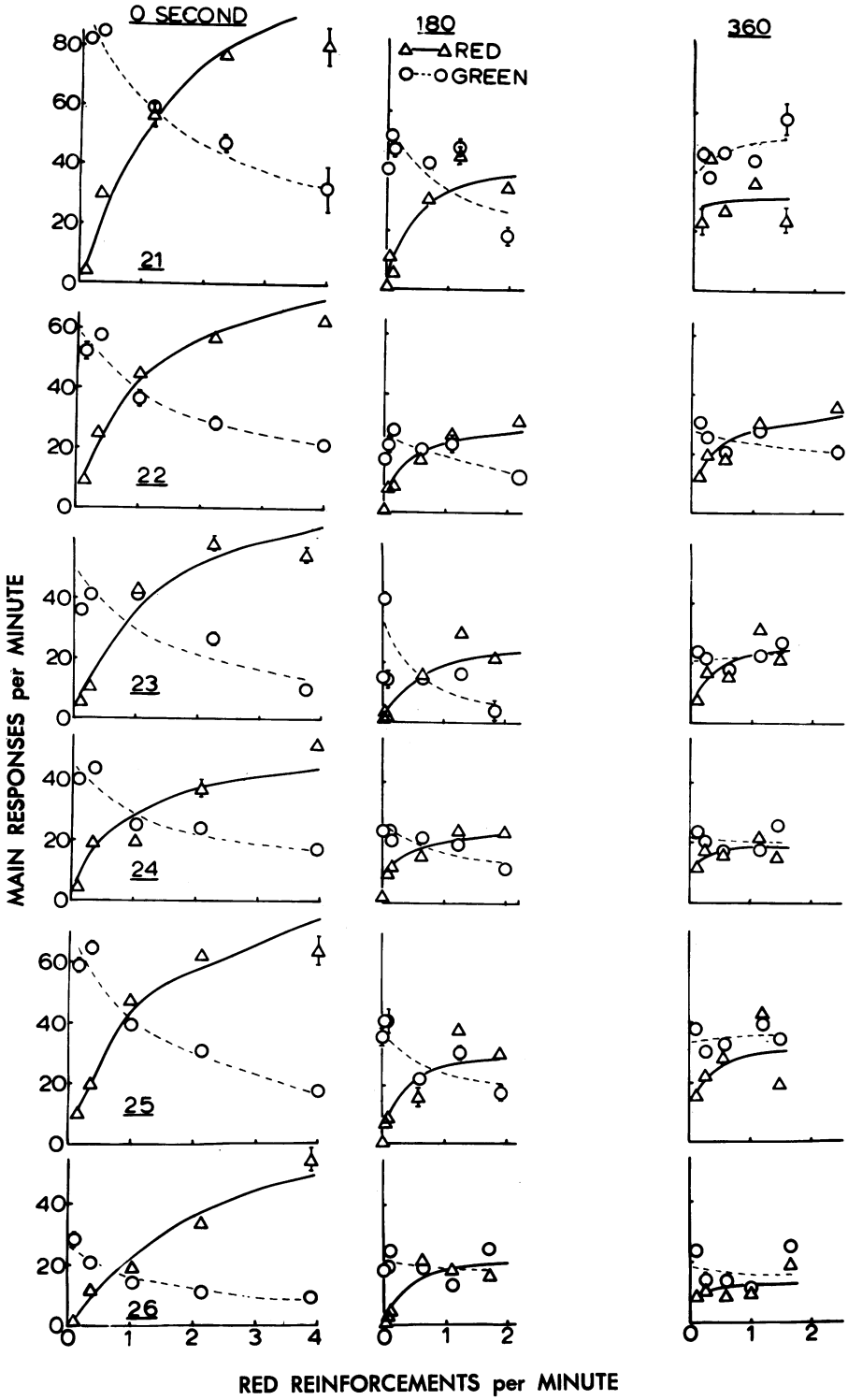


Fig. 4. The numbers of responses per min in the red and green components as a function of the numbers of reinforcements per min in the red (changed) component for the FI 0-sec, FI 180-sec, and FI 360-sec changeover schedule durations. Data points represent the means of the last five sessions, with one standard deviation of the within-session variability being shown by the length of the vertical line. Least-squares lines fitted using Equation 3 are shown.

the red component were directly related to the reinforcement rate in that component, and that the times allocated to the main key in the green component were inversely related to the reinforcement rates in the red component under both the 0-sec and FI 180-sec changeover schedules. Figure 4 shows the absolute response rates on the main key in both components, where the absolute response rate was computed by dividing the number of responses by the total session time. The absolute rates of responding in the red component increased monotonically with the increased reinforcement rate in that component under both the 0-sec and FI 180-sec changeover schedules [the trends were significant at the .05 level for each subject under each condition (Kendall, 1955)]. The absolute rates of responding on the main key in the green component decreased monotonically with increased reinforcement rate in the red component for all subjects under the 0-sec changeover schedule and for the averaged data, but for only two individual subjects (24 and 25) under the FI 180-sec changeover schedules [$p < .05$ in each case (Kendall, 1955)]. There were no regular trends in the absolute response rates under the FI 360-sec changeover schedules in either the red or green components.

The lines shown in Figure 4 were fitted using Davison and Hunter's (1976) equation which describes absolute response rate in terms of the relative reinforcement rate raised to a power:

$$P_1 = k\left\{\frac{R_1}{R_1 + R_2}\right\}^a. \qquad (3)$$

This equation was used rather than Equation 1 because Davison and Hunter found that the parameters of Equation 1 could take negative values which are difficult to interpret and because the values of the parameters could fluctuate widely. The parameter a of Equation 3 is equivalent in meaning to the parameter m of Equation 1. The values of the slopes, intercepts, and standard errors of estimate of the fitted lines are given in Table 2.

The exponents of Equation 3 measure the sensitivity of the change in absolute response rate to the changing relative reinforcement rates. The exponents of Equation 3 for both the response data (from Figure 4) and the time data (from Figure 1) are shown in Figure 5. The values of the exponents decrease as the changeover schedule duration increases for both the time and the response data. There is no exception to the trends for the time data, and only 3 data points out of 36 are out of the expected order for the response data. The trend for the exponents to decrease in value as the changeover-schedule duration increased indicates that performance becomes less sensitive to the changing relative reinforcement rates when the temporal separation of components increases.

Table 2

The slopes, intercepts, and standard errors of estimate (SE) of the least-squares lines fitted between the log main-key response rates and the log proportion of reinforcement using Equation 3 under the FI 0-sec, FI 180-sec, and FI 360-sec changeover schedules.

	Slopes			*Intercepts*			*S.E.*		
	0	*180*	*360*	*0*	*180*	*360*	*0*	*180*	*360*
				Red					
21	1.37	.69	.66	2.14	1.68	1.50	.11	.21	.14
22	1.01	.58	.65	1.91	1.50	1.57	.08	.11	.08
23	1.11	.79	.72	1.89	1.45	1.51	.08	.15	.12
24	.98	.44	.29	1.72	1.40	1.32	.13	.06	.07
25	1.03	.58	.45	1.99	1.54	1.56	.12	.14	.14
26	1.36	.69	.30	1.84	1.41	1.15	.21	.11	.14
				Green					
21	.73	.56	.23	1.98	1.74	1.60	.04	.13	.06
22	.67	.55	.17	1.78	1.50	1.45	.06	.09	.08
23	.80	1.24	.11	1.71	1.53	1.31	.13	.25	.08
24	.67	.49	.07	1.66	1.43	1.34	.05	.07	.09
25	.83	.47	.06	1.85	1.57	1.52	.04	.12	.05
26	.80	.14	.16	1.43	1.34	1.27	.09	.11	.18

Discussion

Changeover Performance

When fixed-interval schedules were placed on the changeover key of concurrent schedules, the proportions of time allocated to the changeover key were inversely related to the relative reinforcement rate in that component (Figure 1). As the changeover performance varied regularly in both components although the scheduled reinforcement rate was varied in only one component, it is clear that changeover performance is controlled by the relative reinforcement rates and not simply by one reinforcement rate taken in isolation (Thompson, 1964). Baum (1973) and Premack (1971) have argued that reinforcement involves a change between activities having different relative values. The results of Experiment 1 support the view that relative rather than abso-

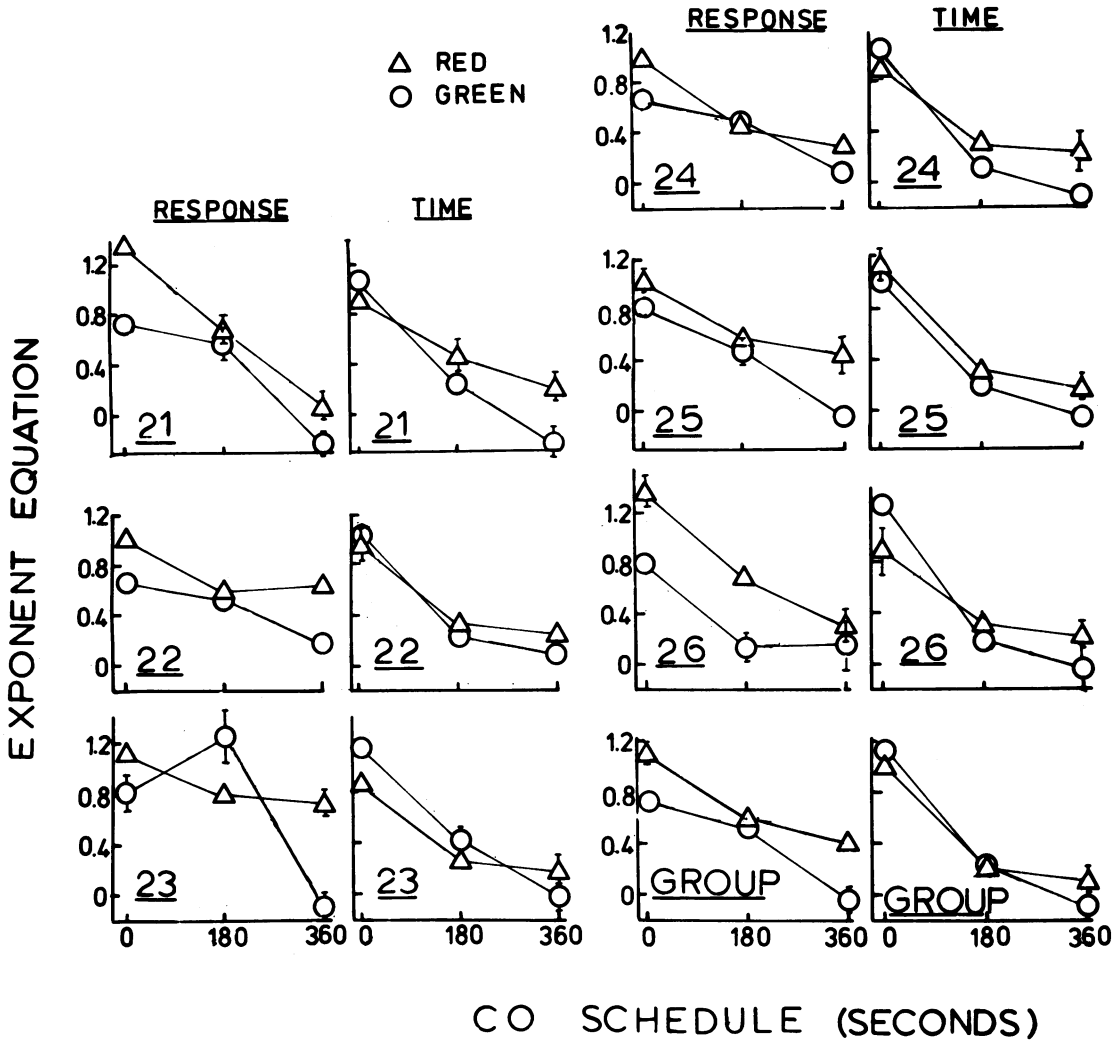


Fig. 5. The exponents for Equation 3 when fitted to response rates and times allocated to the main key in the red and green components for the FI 0-sec, FI 180-sec, and FI 360-sec changeover schedules. The vertical lines show the magnitudes of the standard deviation of each exponent.

lute values are important in the alternation between activities.

Experiment 1 also showed a functional similarity between measures of changeover performance when changeover schedules were and were not used. When changeover schedules were used, the proportions of time spent on the changeover key were inversely related to the relative reinforcement rate in that component (Figure 2). When no changeover schedule was used, the mean ICT in the component with the higher reinforcement rate was directly related to the relative reinforcement rate in that component (Figure 3). These results are functionally similar as the mean ICT is a direct measure of the value of a component while the time spent on a changeover key is a reciprocal measure of the value of a component.

Previous authors have plotted the rates of changeover responding as a function of the ratio of the reinforcement rates and have obtained an inverted U-shaped curve with a peak where the reinforcement ratio is unity (e.g., Stubbs & Pliskoff, 1969). The inverted U-shaped relation between changeover performance and the ratio of the reinforcement rates was also obtained in Experiment 1 when no changeover schedule was used (Figure 1). When changeover schedules were used, the

proportions of time spent on the changeover keys were monotonically related to the ratio of the reinforcement rates (Figure 2), further supporting the idea that changeover performance is controlled by the ratio of the reinforcement rates (Equation 2). But the different slopes and intercepts for the lines fitted to the data from the red and green components cannot be explained in terms of the ratio of the reinforcement rates.

Main-Key Performance

Previous experiments have shown that multiple-schedule performance approximates concurrent schedule performance when the component durations of the multiple schedules are reduced (Shimp & Wheatley, 1971; Todorov, 1972). Experiment 1 showed that concurrent-schedule performance approximated multiple-schedule performance when the reinforcement rates in the two components were separated temporally by increasing the duration of the changeover schedule (Figure 4), as the performances became less sensitive to the changing reinforcement rates as a function of the increased temporal separation of components. This result supports the prediction of Herrnstein (1970) that the temporal separation of components would decrease the sensitivity of performance. In Experiment 1, the sensitivity of performance was measured using the exponent of Equation 3, and the exponents for both time and response data were plotted in Figure 5. That figure showed that the sensitivity of performance varied quantitatively as a function of the temporal separation of components, and supports Herrnstein's suggestion that concurrent- and multiple-schedule performances differ in a quantitative way and that both can be described by the one equation, provided that the equation includes a term to measure the sensitivity of performance (such as m in Equation 1 and a in Equation 3). However, it must be noted that these equations describing main-key performance have been criticized for other predictions that they make (Edman, 1978; Spealman and Gollub, 1974).

EXPERIMENT 2

Experiment 1 showed that changeover performance was monotonically related to the ratio of the reinforcement rates when changeover schedules were used. However, the different slopes and intercepts obtained from the lines fitted to the data from the two components could not be explained in terms of the ratio of the reinforcement rates, suggesting that expressions such as Equation 2 may not be adequate descriptions of changeover performance. Experiment 2 was conducted to examine further the idea that changeover performance is controlled by the ratio of the reinforcement rates. In Experiment 2, the ratio of the reinforcement rates was scheduled to remain constant, but the absolute frequency of reinforcement was changed in both components. If changeover performance is a function solely of the ratio of the reinforcement rates, then the rates of responding on the changeover key should remain constant when the ratio of reinforcement rates is constant but the absolute rates of reinforcement are changing.

METHOD

Subjects

Six homing pigeons were used, numbered 141 to 146. These pigeons had previously participated in an experiment similar to Experiment 1 except that variable-interval changeover schedules were used. The birds were maintained at 80% ±15 g of their free-feeding weights.

Apparatus

The experimental chamber used (No. 14) is similar to that used in Experiment 1, except that the response keys were farther apart.

Procedure

Concurrent schedules of reinforcement were arranged according to the changeover-key method (Findley, 1958). Reinforcement was scheduled for pecks on the right-hand (main) key, which was transilluminated with either red or green light. Main-key components were alternated by the first response on the left-hand or changeover key after the completion of the changeover schedule. The changeover schedule was always a variable-interval schedule (VI 60-sec), composed of 13 intervals in random order taken from an arithmetic series.

The scheduled reinforcement ratio (red rate divided by the green rate) was always 2. The frequency of reinforcement was changed in both components between experimental con-

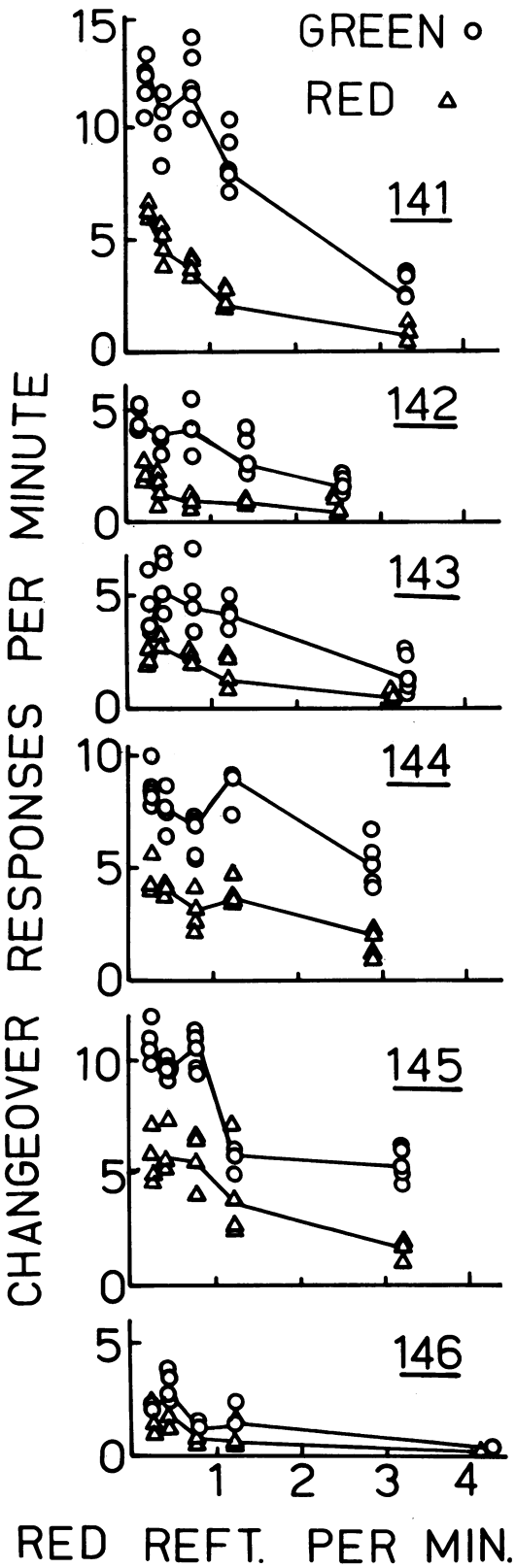


Table 3

The sequence of conditions showing the variable-interval reinforcement schedules used in the red and green components, the variable interval changeover (CO) schedules, and the numbers of sessions training that were given.

	Red	*Green*	*CO*	*Sessions*
		Experiment 2		
1	30	60	60	21
2	120	240	60	17
3	60	120	60	19
4	180	360	60	25
5	15	30	60	23
		Experiment 3		
1	30	Ext	0	18
2	480	Ext	0	20
3	180	Ext	0	19
4	15	Ext	0	19

ditions as shown in Table 3. All of the other experimental procedures were the same as those described for Experiment 1. The schedules of reinforcement were independent rather than dependent (Stubbs & Pliskoff, 1969), so it was possible for the obtained reinforcement ratio to depart from the scheduled ratio. Independent schedules were used so that there would be no compulsion on animals to alternate between components.

Results

The rates of responding on the changeover keys on both components are shown in Figure 6 as a function of the reinforcement rate in the red component. Each data point is shown from the last five sessions in each experimental condition. The response rates were computed by dividing the numbers of responses by the total session times.

The median rates of responding on the changeover key decreased as a function of the increased reinforcement rate for all subjects in the red components and for four of the six subjects in the green component. [The trends did not reach significance at the .05 level for Subjects 143 and 144 (Kendall, 1955).] The ratio of the reinforcement rates was scheduled to remain constant, and there was no trend for the reinforcement ratio to change

Fig. 6. The numbers of changeover responses per min in the red and green components as a function of the reinforcement rate in the red component when the scheduled reinforcement ratio was constant but the frequency of reinforcement changed. Each data point from the last five sessions is shown.

regularly between conditions. However, the reinforcement ratio was high for three subjects in the experimental condition providing the most frequent reinforcement as the birds took most the reinforcements from the component where a VI 15-sec schedule operated.

Discussion

The results of Experiment 1 showed that changeover performance was monotonically related to the ratio of the reinforcement rates. However, when the scheduled ratio of the reinforcement rates was maintained constant in Experiment 2 and the absolute frequency of the reinforcement was varied, changeover performance did not remain constant but showed an inverse relation with the absolute frequency of reinforcement. As the reinforcement rates increased, the response rates on the changeover keys decreased in both components.

The results of Experiment 2 are consistent with two effects that have previously been noted. Catania (1969) reported an inverse relation between a reinforcement rate and the rates of other responsess not earning that reinforcement. Fantino, Squires, Delbruck, and Peterson (1972) also conducted an experiment with concurrent schedules where the ratio of the reinforcement rates was maintained constant between conditions while the absolute frequency of reinforcement varied, and they also found that the rate of changeovers decreased as a function of the increased overall reinforcement rate.

The results of both Experiments 1 and 2 indicate that molar measures of changeover performance are useful, but neither experiment unequivocally supported at attempt to describe changeover performance as a function of the ratio of the reinforcement rates. In Experiment 1, the different slopes and intercepts of the fitted lines between components cannot be explained in terms of the ratio of the reinforcement rates. In Experiment 2, changeover performance varied independently of the ratio of the reinforcement rates. Possibly a different mathematical relation between changeover performance and the two reinforcement rates would be more satisfactory, but other types of explanation are possible. A different type of explanation is suggested below and is tested in Experiment 3.

Recent theoretical accounts of behavior emphasize that animals are always active and are frequently changing between activities (e.g., Schoenfeld & Farmer, 1970). Using this theoretical view as a base, researchers may ask questions such as, "On what activity will an animal spend most time?" and "How will an animal decide when to alternate between activities?" The first question covers the area which has been examined extensively in the literature on choice in concurrent schedules, but there is less consensus on the answer to the second question or even on how the question should be handled.

Animals in concurrent schedules of reinforcement are free to alternate between components. Several experiments have shown that animals spend most time in the component which provides the most frequent reinforcement, and that animals approximately match their allocation of time and responding between alternatives to the relative frequency of reinforcement obtained from the alternatives (See reviews by Lobb & Davison, 1975; Myers & Myers, 1977). So the first question can be answered: Animals spend most time on the activity providing the most frequent reinforcement.

While animals spend most time on the activities which provide the most frequent reinforcement, they also sample other activities. Different explanations have been offered on how this sampling is controlled. For example, Hunter and Davison (1978) used a Markov chain explanation which emphasizes the sequence of main key responses, and Catania (1966, p. 228) emphasized the moment-by-moment changes in the probabilities of reinforcement being available in the two components. An explanation is offered here which emphasizes the idea that animals sample for reinforcement. The explanation offers a framework for examining and discussing the data using molar measures, and while it has different emphases from other explanations, it is not necessarily incompatible with other explanations.

It is assumed that animals determine which activity or component has the higher reinforcement rate and that the animals spend most time on that activity. From the most favorable activity, the animals sample the other available activities. There are two fundamentally different ways that an animal might sample less attractive activities and still produce

matching: The animal might sample the less attractive activities for lengthy periods, but only occasionally sample, and vary the durations of samples, when the experimental conditions change; or the animal might make frequent samples of brief periods and vary the frequency of samples between experimental conditions. That is, animals might spend 60 sec on an activity either in 2 samples of 30 sec (high duration) or in 10 samples of 6 sec (high frequency). Which of these practices actually occurs? Or do animals vary both the frequency and duration of samples between experimental conditions?

The mean ICT under the FI 0-sec changeover schedules were plotted in Figure 3, where it was shown that the mean ICT in the components with the lower reinforcement rates were roughly constant when the relative reinforcement rates changed. Figure 3 showed that the near-matching of time allocation to relative reinforcement rates was achieved mainly through an adjustment in the ICT of the component with the higher reinforcement rate. Translating this effect into the terminology used above, the near-matching occurred because the animals adjusted the *frequency* of the samples into the components with the lower reinforcement rates, but there was little adjustment of the durations of those samples. Of course, the durations of the ICTs in the components with the richer reinforcement rates changed concomitantly. Menlove (1975, p. 316) has reported the same effect in concurrent schedules: The ICTs in the component with the higher density of reinforcement were long but variable whereas the ICTs in the component with the lower density of reinforcement were shorter and relatively constant.

Using the sampling explanation, the changeover responding can be described as follows: Animals determine which component has the higher reinforcement rate and spend most time in that component while sampling other components. When the relative reinforcement rates provided by interval schedules of reinforcement change, the *rates* of sampling the leaner components change and the durations of the ICTs in the richer components change. The changes between conditions can be summed up: When the relative reinforcement rates from VI schedules change, the rates of sampling the leaner components change so that the rate of sampling is inversely related to the relative reinforcement rate in that component. The rate of sampling a lean component will decrease either when less reinforcement is scheduled for that component or when more reinforcement is scheduled for the richer component.

The sampling explanation of changeovers provides one way of organizing the data, and this approach is briefly compared to other approaches to bring out points of similarity and difference:

1. The sampling explanation relates changeovers explicitly to reinforcement and so differs from the explanation offered by Hunter and Davison (1978) as the Markov-chain idea emphasizes the sequence of main-key responses.

2. The sampling explanation allows that the ICT will be affected by any contingency applied directly to the changeover response which delays the availability of reinforcement. For example, lengthening the COD would be expected to increase the duration of the ICT as found by Stubbs, Pliskoff, and Reid (1977). If the COD were removed altogether, the ICT in the leaner schedule might be shortened, but this would lead to overmatching rather than to undermatching or indifference. Herrnstein (1961) suggested that changeovers can be accidentally reinforced. Herrnstein's suggestion can be tested as the likelihood of superstitions developing is related to the frequency of delivering the response-independent food.

3. Previous papers on the topic of changeovers have discussed the relationship between performances on concurrent and multiple schedules (Menlove, 1975; Shimp & Wheatley, 1971; Todorov, 1972). The sampling explanation indicates that the major difference between concurrent and multiple schedules lies in the number of options available for the animal to sample at any time. Animals in a multiple-schedule component have the options only of working or pausing, and experimenters typically can measure only the work (but see Bouzas & Baum, 1976). Possibly the major difference between concurrent and multiple schedule performances is on the part of the experimenter who is better able to measure changeovers between activities under concurrent schedules. Similar points have been made by Menlove. The sampling explanation indicates that animals will allocate time in multiple schedules between working and pausing according to the relative reinforcement

rates for working, and is consistent with the type of time allocation found by Bouzas and Baum.

4. Although the sampling explanation is essentially a way of organizing data, it does highlight particular points and can suggest theoretical hypotheses. One hypothesis is that animals are actually motivated to sample the alternatives in their environment, as is implied by a concept of curiosity. Experiment 3 was conducted to examine this hypothesis.

EXPERIMENT 3

It was hypothesized above that animals may be motivated to sample the activities available to them. One way of interpreting and testing this hypothesis is to arrange no reinforcement in one component of concurrent schedules and to vary the frequency of reinforcement in the other component. Any changeovers into the extinction component would need to be explained, and any variation in the changeover rate would also need to be explained. The present hypothesis predicts that changeovers would occur. The sampling explanation of changeovers predicts that the rate of changeovers into the extinction component will be inversely related to the frequency of reinforcement in the alternate component.

One common explanation of the continuation of behavior although it is unreinforced comes from the argument of accidental reinforcement or superstition. If food is presented after a response, then that response is more likely to occur in the future even though there is no contingency between the response and food. Herrnstein (1961) suggested that changeovers can be accidentally reinforced. The likelihood of superstitions developing is related to the frequency of delivering the response-independent food: The higher the rate of food presentations, the more likely it is that the accidental pairings will occur, and the more likely it is that superstitious behavior will develop. That is, a positive relation between the rate of superstitious behavior and the reinforcement rate is expected. Two experiments have found a positive relation between the rate of responding and the rate of food presentation under variable-time schedules (Lachter, 1971; Neuringer, 1970). An inverse relation between the changeover rate and the reinforcement rate appears inconsistent with the idea that changeovers were maintained by accidental reinforcement (Herrnstein, 1961).

METHOD

Subjects

The subjects and apparatus of Experiment 2 were used.

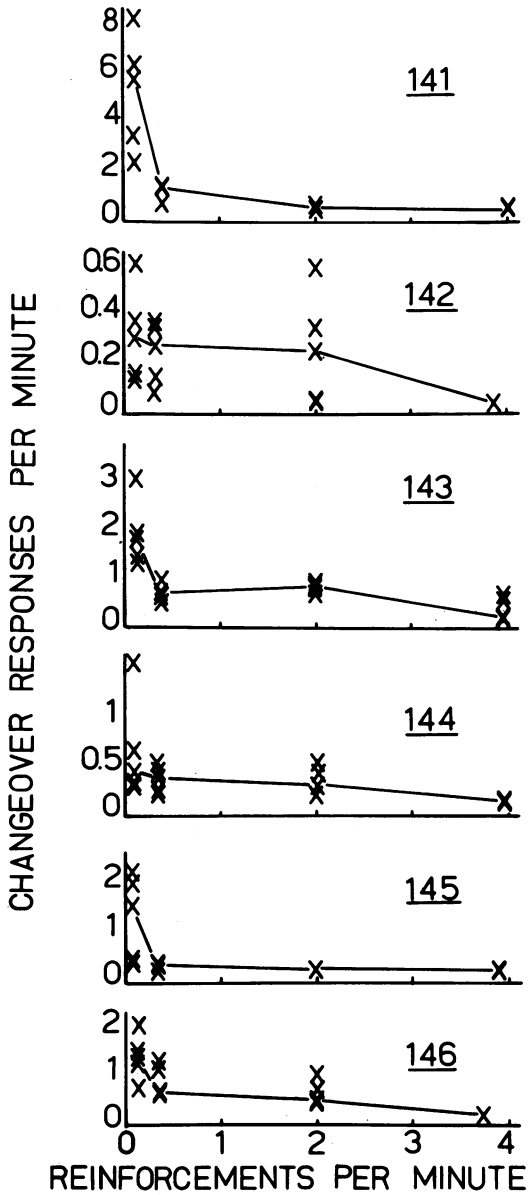


Fig. 7. The numbers of changeover responses per min as a function of the numbers of reinforcement per min in the red component when no reinforcement was provided in the green component. Each data point from the last five sessions is shown.

Procedure

The experimental procedure was the same as that used in Experiment 2 except that no changeover schedule was used and no reinforcement was available for responses made in the green component. A changeover delay of 1.5 sec was used, and the stability criterion described in Experiment 1 was used. The reinforcement in the red component was provided by the schedules given in Table 3. The numbers of training sessions are also given in Table 3.

Results

The rates of changeover responding out of the red component are shown in Figure 7 for each of the last five sessions in the four experimental conditions. The median response rates from each condition are joined. The median changeover response rates decrease as a function of the increased reinforcement rate in the red component [$p > .05$ for each subject except 143 (Kendall, 1955)].

Discussion

When no reinforcement was available in one component of concurrent schedules and the rate of reinforcement was varied in the other component, changeover responding still occurred at a rate that was inversely related to the main-key reinforcement rate. This result is consistent with the sampling explanation of changeover responding as that explanation postulates that the rate of sampling a lean component is inversely related to the reinforcement rate in the richer component. The inverse relation between the changeover rate and the reinforcement rate appears inconsistent with the idea that the changeovers were maintained by accidental reinforcement.

The fact that changeovers occurred into a component providing no reinforcement is consistent with the notion that animals are motivated to sample alternative activities. This idea is a simple extension of the suggestion by Schoenfeld and Farmer (1970) that animals are constantly active, as it is suggested that part of this activity involves sampling the options available to them. Of course, the present findings do not establish that animals are motivated to sample alternative activities, but are only suggestive.

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