LOCAL PATTERNS OF RESPONDING MAINTAINED BY CONCURRENT AND MULTIPLE SCHEDULES¹

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Local patterns of responding were studied when pigeons pecked for food in concurrent variable-interval schedules (Experiment I) and in multiple variable-interval schedules (Experiment II). In Experiment I, similarities in the distribution of interresponse times on the two keys provided further evidence that responding on concurrent schedules is determined more by allocation of time than by changes in local pattern of responding. Relative responding in local intervals since a preceding reinforcement showed consistent deviations from matching between relative responding and relative reinforcement in various postreinforcement intervals. Response rates in local intervals since a preceding changeover showed that rate of responding is not the same on both keys in all postchangeover intervals. The relative amount of time consumed by interchangeover times of a given duration approximately matched relative frequency of reinforced interchangeover times of that duration. However, computer simulation showed that this matching was probably a necessary artifact of concurrent schedules. In Experiment II, when component durations were 180 sec, the relationship between distribution of interresponse times and rate of reinforcement in the component showed that responding was determined by local pattern of responding in the components. Since responding on concurrent schedules appears to be determined by time allocation, this result would establish a behavioral difference between multiple and concurrent schedules. However, when component durations were 5 sec, local pattern of responding in a component (defined by interresponse times) was less important in determining responding than was amount of time spent responding in a component (defined by latencies). In fact, with 5-sec component durations, the relative amount of time spent responding in a component approximately matched relative frequency of reinforcement in the component. Thus, as component durations in multiple schedules decrease, multiple schedules become more like concurrent schedules, in the sense that responding is affected by allocation of time rather than by local pattern of responding.

Relationships between responding and reinforcement in the components of concurrent variable-interval variable-interval (*conc VI VI*) and multiple variable-interval variable-interval (*mult VI VI*) schedules are well known (see Herrnstein, 1970, for a summary). However, each relationship describes measures of responding and reinforcement averaged over several sessions. Little is known about responding or reinforcement measured at a more local level. For example, measures of responding

and reinforcement at various times since a preceding response, a preceding component change, or a preceding reinforcement have rarely been reported in the *conc VI VI* or *mult VI VI* schedule literature. The present experiments provide some new data on local patterns of responding and local patterns of reinforcement in both *conc VI VI* and *mult VI VI* schedules; *conc VI VI* schedules were studied in Experiment I, and *mult VI VI* schedules in Experiment II.

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EXPERIMENT I

METHOD

Subjects

Six White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights; each had experience in a variety of operant schedules.

Apparatus

Three standard three-key Lehigh Valley Electronics experimental chambers were used. Only the side keys, which could be transilluminated by white light, were operative. A PDP-12 computer scheduled and recorded events. Experimental sessions were conducted simultaneously and independently in the three chambers.

Procedure

The reinforcement schedule was a two-key *conc VI VI*. The schedule consisted of two parts: a constant reinforcement-per-opportunity VI schedule and a Bernoulli-trials generator.

VI schedule. A single, constant reinforcement-per-opportunity VI schedule (Catania and Reynolds, 1968; Farmer, 1963) arranged intervals between reinforcements. The constant probability of assigning a reinforcement was 0.017 every 1.0 sec, producing an average interreinforcement interval of approximately 60 sec. When the VI programmer assigned a reinforcement, the programmer was stopped until that reinforcement was delivered.

Bernoulli-trials generator. A reinforcement was available once it had been assigned by the VI schedule, but each reinforcement was available only for a peck on a particular key. The position assignment of reinforcements was made by a Bernoulli-trials generator. A sequence of Bernoulli trials is one in which there are two possible outcomes on each trial, exactly one of which occurs on each trial, and in which the probability of an outcome is constant and independent of the outcome on the preceding trial. In the present experiment, the possible outcomes of a Bernoulli trial were the assignment of the next reinforcement to the left or right key. A trial occurred at the beginning of the session and at the end of each reinforcement.

This method of programming a *conc VI VI* schedule ensures that (a) the probability that the obtained relative frequency of reinforcement on a key will deviate from the scheduled probability by any given amount is given by the binomial distribution, and (b) the probability of a reinforcement on a given key is independent of where the preceding reinforcement was assigned (Moffitt and Shimp, 1971). An important feature of this schedule is that

the relative frequency of reinforcement on a key does not depend on the time since the preceding reinforcement. The differences between the present method of programming a *conc VI VI* schedule and the more traditional method may produce differences in behavior. However, in terms of the relationships between the relative frequency of responding and the parameters of reinforcement studied, the present method is behaviorally equivalent to the more traditional method (see Menlove, Moffitt, and Shimp, 1973 and Pliskoff and Stubbs, 1969). It remains for future research to determine whether this equivalence also extends to the local patterns of behavior described here.

Other contingencies. Changeovers from one key to another were never reinforced. Each changeover initiated a 1-sec changeover delay (COD), during which reinforcements were not available. Changeovers that occurred during the COD restarted the delay interval. A 100-msec blackout of all lights provided feedback for each response. During reinforcement, the keylights and houselight were turned off and the food hopper was illuminated. Each session lasted 60 min, and sessions were conducted seven days a week.

Experimental conditions. Table 1 shows the probability of assigning a reinforcement on the left key for each subject in each condition. Besides the conditions shown in Table 1, each subject was exposed to brief periods of training that provided experience with relative frequencies of reinforcement different from the relative frequencies in the experimental conditions. Performance in certain operant tasks apparently becomes more reliable after experience with several values of the independent variable (Bloomfield, 1967; Moffitt and Shimp, 1971; Staddon, 1965). Before Condition 1, Birds 1, 2, and 3 were exposed to three days of training in which the probability of assigning a reinforcement on the left key was 0.1, followed by three days of training in which the probability of reinforcement on the left key was 0.9. In addition, between Conditions 3 and 4, Birds 1, 2, and 3 were exposed to seven days of training in which the probability of reinforcement on the left key was 0.0; Birds 4, 5, and 6 were exposed to five days of training in which probability of reinforcement on the left key was 0.0. An experimental condition was terminated only if the relative frequency

Table 1
Experimental Conditions for Experiment I

Conditions	Subjects	Probability of Reinforcement on the Left Key	Average Interreinforcement Intervals for Equivalent VI Schedule		Number of Sessions
			Left Key (sec)	Right Key (sec)	
1	1, 2, 3	0.50	120	120	12
	4, 5, 6	0.25	240	80	10
2	1, 2, 3	0.75	80	240	14
	4, 5, 6	0.75	80	240	11
3	1, 2, 3	0.25	240	80	30
	4, 5, 6	0.50	120	120	6
4	1, 2, 3	0.25	240	80	18
	4, 5, 6	0.50	120	120	8
5	1, 2, 3	0.50	120	120	10
	4, 5, 6	0.75	80	240	16
6	1, 2, 3	0.25	240	80	12
	4, 5, 6	0.25	240	80	12
7	1, 2, 3	0.75	80	240	19

of response on a key, plotted against days, looked stable for at least three or four days.

RESULTS

Average Relative Frequency of Response and Reinforcement

Table 2 shows relative frequency of responding and relative frequency of reinforcement for each subject. Relative frequency of responding was calculated for each session by dividing the number of responses on the left key by the to-

tal number of responses on both keys. Relative frequency of reinforcement was calculated for each session by dividing the number of reinforcements for responses on the left key by the number of reinforcements for responses on both keys. The relative frequencies shown in Table 2 were then calculated by averaging the relative frequencies for single sessions over the last six days of a condition. The probability of reinforcement was 0.5 for Birds 1, 2, and 3 in Conditions 1 and 5. The relative frequencies

Table 2
Relative Frequencies of Responding and Reinforcement

Condition Number		Relative Frequencies					
		Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	Bird 6
1	Resp.	0.528	0.417	0.407	0.275	0.240	0.278
	Rft.	0.492	0.475	0.505	0.247	0.260	0.237
2	Resp.	0.703	0.623	0.738	0.720	0.527	0.733
	Rft.	0.775	0.758	0.723	0.777	0.748	0.788
3	Resp.	0.472	0.367	0.415	0.578	0.463	0.467
	Rft.	0.232	0.270	0.330	0.547	0.510	0.438
4	Resp.	0.387	0.343	0.373	0.455	0.443	0.430
	Rft.	0.265	0.263	0.285	0.457	0.493	0.472
5	Resp.	0.515	0.518	0.450	0.717	0.475	0.598
	Rft.	0.525	0.457	0.493	0.793	0.750	0.697
6	Resp.	0.395	0.330	0.393	0.437	0.312	0.370
	Rft.	0.295	0.245	0.250	0.282	0.292	0.295
7	Resp.	0.647	0.572	0.702			
	Rft.	0.758	0.770	0.745			

of responding averaged over these conditions were 0.5216, 0.4674, and 0.4283 for Birds 1, 2, and 3 respectively. The probability of reinforcement was 0.5 for Birds 4, 5, and 6 in Conditions 3 and 4. The relative frequencies of responding averaged over these conditions were 0.5166, 0.4533, and 0.4483 for Birds 4, 5, and 6 respectively. Thus, the average relative frequency of responding in these conditions was never more than 0.1 from 0.5, and none of the six subjects exhibited any extreme position preference.

Table 2 shows that few subjects matched relative frequency of responding to relative frequency of reinforcement in all conditions. The majority of deviations were in the direction of 50-50 responding, or undermatching with respect to the key with the higher density of reinforcement. A recent review of a large body of the concurrent schedule literature by D. L. Myers (personal communication) has shown this type of undermatching to be typical. However, the deviations toward undermatching, while consistent, have been of a relatively small magnitude. In the present experiment, large deviations in the direction of undermatching were occasionally observed (approximate 50-50 responding was observed in three cases). The reasons for these large deviations in the present experiment are unknown. However, the data of three subjects (Birds 3, 4, and 6) showed the appropriate magnitude of undermatching when probability of reinforcement on the left key was both 0.25 and 0.75. The relative frequency of responding for Bird 3 was less than 0.1 from the relative frequency of reinforcement in Conditions 4 and 7, and for Birds 4 and 6 was less than 0.1 in Conditions 1 and 2. The major purpose of the present experiment was to observe local patterns of responding that were representative of those maintained by *conc VI VI* schedules. Since the literature on *conc VI VI* schedules shows slight undermatching to be the typical result, the results are presented here in detail only for those conditions in which slight undermatching was observed. Thus, data are presented here for Bird 3 in Conditions 4 and 7, and for Birds 4 and 6 in Conditions 1 and 2. These data are from conditions in which the relative frequency of responding was representative of values previously obtained in the concurrent schedule literature, but the relative frequencies of responding in those conditions

were not representative of the value observed in the present experiment. A more appropriate description of the present data would be large deviations from matching in the direction of undermatching.

Relative Frequency of Responding in Local Intervals Since Reinforcement

Figure 1 shows the relative frequency of responding on the key with the higher density of reinforcement plotted against time since a preceding reinforcement. The relative frequencies shown in Figure 1 were calculated by first

Fig. 1. Relative frequency of responding on the key with the higher density of reinforcement as a function of time since a preceding reinforcement on a logarithmic scale. Open circles show the relative frequency of responding following a reinforcement on the key with the higher density of reinforcement; dots show the relative frequency of responding following a reinforcement on the key with the lower density of reinforcement. The solid horizontal line shows the probability of reinforcement on the key with the higher density of reinforcement. The dashed horizontal line shows the overall relative frequency of responding on the key with the higher density of reinforcement.

assigning the intervals following reinforcement to one of two categories: intervals following a reinforcement on the key with the higher density of reinforcement, and intervals following a reinforcement on the key with the lower density of reinforcement. For example, the data for Bird 3 were categorized by combining intervals following a reinforcement on the right key in Condition 4 with intervals following a reinforcement on the left key in Condition 7 (the probabilities of a reinforcement on the right key in Condition 4 and on the left key in Condition 7 were both 0.75), and by combining the intervals following a reinforcement on the left key in Condition 4 with intervals following a reinforcement on the right key in Condition 7 (the probabilities of a reinforcement on the left key in Condition 4 and on the right key in Condition 7 were both 0.25). Then, the intervals following a reinforcement on both the key with the higher density of reinforcement and the key with the lower density of reinforcement were further subdivided into local intervals since a preceding reinforcement. These subintervals were 0-5, 5-10, 10-30, 30-60, and 60-180 sec since a preceding reinforcement. Finally, within each local interval since reinforcement, the numbers of responses on each key were summed over the last six days of a condition, and the number of responses in a local interval on the key with the higher density of reinforcement was divided by the total number of responses on both keys in that local interval. Time since a preceding reinforcement is plotted in Figure 1 on a logarithmic scale.

Figure 1 shows that the relative frequency of responding on the key with the higher density of reinforcement was highest in the first 5 sec following a reinforcement on that key. The relative frequency of responding in the first 5 sec following a reinforcement on the key with the lower density of reinforcement was less than or equal to its overall average value. After the first 5 sec following a reinforcement, the difference between the relative frequency of responding following a reinforcement on the key with the higher density of reinforcement and on the key with the lower density of reinforcement was no more than 0.05. These data show a positive recency effect of reinforcement on subsequent responding (Estes, 1964; Nevin, 1969; Shimp, 1966). While the magnitude of this effect was largest in the first 5 sec

following reinforcement, responding appeared to be influenced by the preceding reinforcement even after 1 min or more.

Interresponse-time Distributions

Figure 2 shows the relative frequencies of interresponse times (IRTs) in the neighborhood of the modal IRT plotted against 0.25-sec bins. Interresponse times in the neighborhood of the modal IRT define a local pattern of responding (Blough, 1963; Crites, Harris, Rosenquist, and Thomas, 1967; Sewell and Kendall, 1965). Interresponse times longer than 4 sec are not plotted in Figure 2, as these longer IRTs presumably are not descriptive of the local pattern of responding. Instead, they may be said to describe amounts of time spent not responding. The relative frequency of an IRT was computed by dividing the number of IRTs in a particular bin by the number of IRTs shorter than 4 sec. Thus, the sum of the plotted relative frequencies equals 1.0. Figure 2 shows that there were differences between the IRT distributions on the two keys within any condition. However, these differences were associated more with the position of a key than with the rate of reinforcement on a key. When the probabilities of reinforcement on the two keys were reversed between conditions, the shape of the IRT distribution on a particular key remained approximately the same. Thus, there was greater similarity between IRT distributions associated with the same key than between those associated with the same rate of reinforcement.

Response Rates in Local Intervals Since Changeovers

Figure 3 shows rate of responding and rate of reinforcement plotted against successive intervals since a preceding changeover. The top half of each panel in Figure 3 shows responses per minute in successive 0.5-sec intervals since a preceding changeover. The amount of time spent in a local interval was calculated by multiplying the local interval size, 0.5 sec, by the number of times the subject was exposed to that interval. The number of times a subject was exposed to a local interval was found by counting the number of changeovers and the number of reinforcements in that interval or in longer intervals. Then, the numbers and amounts of time were summed over the last six days of a condition, and the rate of re-

sponse in an interval was calculated by dividing the number of responses in the interval by the amount of time spent in the interval. The response rate in an interval was plotted in Figure 3 only if more than 25 sec was spent in that interval. The figure shows that the rate of response immediately following a changeover was higher than the rate at any other postchangeover time. This higher rate of response occurred on both keys in each condition. The response rate declined to a lower asymptotic level with increases in time since a preceding changeover. In each case, the asymptotic response rate on the key with the lower density of reinforcement was less than or equal to the asymptotic response rate on

the key with the higher density of reinforcement.

The bottom half of each panel in Figure 3 shows reinforcements per hour in successive intervals since a preceding changeover. The number of reinforcements on a key was small relative to the number of responses, and in order to reduce the variability in the reinforcement distributions, reinforcement rates were averaged over several intervals. Lines drawn between the points indicate continuity between the intervals. To compute the average rate of reinforcement in an interval, individual reinforcement rates in 0.5-sec intervals were calculated by dividing the number of reinforcements in an interval by the amount of

Fig. 2. Relative frequencies of interresponse times (IRTs) as a function of successive 0.25-sec bins. Each panel shows the distribution for a different subject. The distributions in the top half of each panel show IRTs when probability of reinforcement on the left key was 0.25. The distributions in the bottom half of each panel show IRTs when probability of reinforcement on the left key was 0.75. The distributions on the left of each panel show IRTs that occurred within a COD. The distributions on the right of each panel show IRTs that occurred after the COD. Open circles show IRTs on the left key, dots show IRTs on the right key.

Fig. 3. Response and reinforcement rates as a function of time since a preceding changeover. The top half of each panel shows responses per minute, the bottom half reinforcements per hour. The left half of each panel shows rates during conditions when probability of reinforcement on the left key was 0.25; the right half shows rates when probability of reinforcement on the left key was 0.75. Open circles show rates on the left key, dots show rates on the right key.

time spent in the interval. Then, these local reinforcement rates were averaged over several local intervals. The intervals over which the reinforcement rates were averaged were: 1-2, 2-3, 3-4, 4-6, 6-8, 8-10, 10-14, and 14-18 sec. The reinforcement rate was zero in the 0-1 sec interval; that is, during the COD. When less than 25 sec was spent in a 0.5-sec interval, a reinforcement rate was not computed for that interval, and averages taken over such intervals were not plotted. Figure 3 shows that the rate of reinforcement immediately following the COD was higher than at any other post-changeover time. The rate of reinforcement declined on each key to a lower asymptotic level with increases in the amount of time since a preceding changeover. In each case, the asymptotic reinforcement rate was lower on the key associated with the lower average density of reinforcement.

Interchangeover-time Distributions

The local amount of time spent on a key may be specified by the time spent between a changeover to that key and the next changeover from that key, *i.e.*, the interchangeover time (ICT). While changeovers were not immediately reinforced, the probability of reinforcement on a key increased with increases in the amount of time spent on the other key,

and a large number of reinforcements were delivered for the first response following a COD. When the first response following a COD was reinforced, the preceding ICT was called a reinforced ICT. It was possible to observe reinforced ICTs shorter than the COD duration, because the animal could respond on a key for an amount of time shorter than the COD duration and then change to the other key. Only the time spent on the first key would count toward the ICT duration: the first response on the second key would terminate the ICT and start the COD on the second key. When the COD on the second key had terminated, the subject could receive reinforcement. This would be referred to as a reinforced ICT on the first key. Reinforcement did not occur during the COD, and the duration of the reinforced ICT was less than the COD. Notice also that there is a delay of reinforcement for ICTs, and this delay has a minimum value equal to the COD duration.

Figure 4 shows the relative-frequency distribution of ICTs and the relative-frequency distribution of reinforced ICTs. The top of each panel in Figure 4 shows the relative frequencies of ICTs in 0.5-sec bins. The relative frequency of ICTs in a particular bin was calculated by first summing the number of ICTs in each bin over the last six days of a condi-

Fig. 4. Relative frequencies of interchangeover times (ICTs) and reinforced ICTs as a function of time since a preceding changeover. The top of each panel shows relative frequencies of ICTs in 0.5-sec intervals; the bottom shows relative frequencies of reinforced ICTs in 1-sec intervals. The left half of each panel shows relative frequencies from conditions when probability of reinforcement on the left key was 0.25, right half when probability of reinforcement on the left key was 0.75. Open circles show relative frequencies from the left key, dots show relative frequencies from the right key.

tion and then dividing the number of ICTs in the particular bin by the total number of ICTs.

Figure 4 shows that the modes of the ICT distributions for the key with the lower density of reinforcement were more pronounced and occurred at shorter ICTs than the modes of the ICT distributions for the key with the higher density of reinforcement. These ICT distributions describe a pattern of responding on *conc VI VI* schedules in which a relatively long but variable amount of time was spent on the key with the higher density of reinforcement. Changes to the key with the lower density of reinforcement were followed by a short and relatively constant amount of time spent on that key.

The bottom half of each panel in Figure 4 shows the relative frequencies of reinforced ICTs in 1.0-sec bins. The relative frequency of reinforced ICTs in a particular bin was calculated by first summing the number of reinforced ICTs in each bin over the last six days of a condition and then dividing the number of reinforced ICTs in the particular bin by the total number of reinforced ICTs. Even though the relative frequencies of reinforced ICTs were taken over larger bin sizes than the relative-frequency distributions of ICTs, the number of reinforced ICTs in a bin was small relative to the number of ICTs, and the relative-frequency distributions of reinforced ICTs were variable. Lines drawn between the

points indicate continuity between bins. Except for the amount of variability in the distributions, the reinforced ICT distributions had approximately the same shapes as the ICT distributions. The modes of the reinforced ICT distributions for the key with the lower density of reinforcement were more pronounced and occurred at shorter ICTs than the modes of the reinforced ICT distributions for the key with the higher density of reinforcement. The modal reinforced ICT on a particular key occurred in approximately the same interval as the modal ICT on that key.

A comparison between ICTs and reinforced ICTs is facilitated when the relative frequency of ICTs in a bin is plotted against the relative frequency of reinforced ICTs in that bin. However, arguments analogous to those advanced by Shimp (1967) for IRTs suggest that in certain cases, other transformations of the data might be more informative. The likelihood that a reinforcement will be assigned during an ICT should be equal to the proportion of the session time consumed by ICTs in that bin. That is, except for sampling fluctuation, the relative frequency of a reinforced ICT would be expected to equal the relative amount of session time consumed by ICTs of that duration. Figure 5 shows the relative amount of time consumed by ICTs in an interval plotted against the relative frequency of reinforced ICTs in that interval. The number of reinforcements on a key was small rela-

Fig. 5. The relative amount of time consumed by an ICT of a particular duration as a function of the relative frequency of reinforced ICTs of that duration. The different panels show data for different subjects. The left half of each panel shows data from conditions when probability of reinforcement on the left key was 0.25; right half when probability of reinforcement on the left key was 0.75. Open circles show data from the left key; dots show data from the right key.

tive to the number of responses, so to reduce the variability in the functions, both the relative amount of time consumed by ICTs and the relative frequency of reinforced ICTs were summed over several bins. To compute the sums, individual relative amounts of time consumed by ICTs and individual relative frequencies of reinforced ICTs were computed in 0.5-sec bins. When less than 25 sec was spent in one of these bins, the ICTs in that bin were not included in the sums, and sums taken over those bins were not plotted. The amount of time consumed by an ICT was calculated by multiplying the duration of an ICT by the frequency of the ICT. The relative amount of time consumed by a particular ICT was calculated by first summing the amounts of time consumed by each ICT over the last six days of a condition and then dividing the amount of time consumed by ICTs of the particular duration by the total session time. The relative frequency of reinforced ICTs in a bin was calculated by dividing the number of reinforced ICTs in that bin by the total number of reinforced ICTs. Then, the individual statistics were summed over the intervals 0-1, 1-2, 2-3, 3-4, 4-6, 6-8, 8-10, 10-14, and 14-18 sec. Figure 5 shows that the relative amount of time consumed by an ICT of a particular duration was approximately equal to the relative frequency of reinforced ICTs of that duration.

DISCUSSION

A positive recency effect of reinforcement was observed on immediately subsequent responding: the relative frequency of responding on a key was highest immediately following a reinforcement on that key. Responding in local periods following reinforcement, differentiated with respect to which choice was reinforced, has been reported in two related operant experiments (Nevin, 1969; Shimp, 1966). In Shimp's study, a single reinforcement-selection mechanism assigned reinforcements to the two keys (using basically the same method as in the present experiment), and the probability of reinforcement on a key was independent of where the preceding reinforcement was assigned. In this experiment, positive recency was observed (Shimp, 1966, Experiment I). In Nevin's study, a separate VI schedule assigned reinforcements to each key, and probability of reinforcement on

a key depended on where the preceding reinforcement was assigned. In particular, it was lowest immediately following a reinforcement on that same key. However, the relative frequency of responding in the first postreinforcement trial was independent of which choice was reinforced on the preceding trial (Nevin, 1969). That is, positive recency was not observed. This observation was cited by Nevin as an instance in which local probability of reinforcement failed to control behavior. However, there is an alternative interpretation. Suppose that there was partial control by the local probability of reinforcement in Nevin's experiment. Then, the local probability of reinforcement would have directed responding away from the choice most recently reinforced. Suppose also that the tendency to respond to the local probability of reinforcement was in competition with a tendency to respond on the alternative most recently reinforced. The presence or absence of an observable positive recency effect would then depend on the relative magnitude of these competing tendencies. Thus, in Nevin's experiment, a positive recency effect may have been obscured by the local probability of reinforcement. In Shimp's experiment, and in the present Experiment I, the probability of reinforcement on a key was independent of where the preceding reinforcement was assigned, and changes in the local probability of reinforcement were minimized. In both of these experiments, positive recency was observed. These observations support the view that a subject tends to respond on the alternative most recently reinforced in a two-key *conc VI VI* schedule.

In previous experiments with *conc VI VI* schedules, both the overall frequency of responding on a key and the amount of time spent responding on a key have been measured. A local rate of responding on each key has been calculated by dividing the frequency of responding on a key by the amount of time spent on that key. As noted in a previous section, the relative frequency of responding on a key approximately matches the relative frequency of reinforcement on that key (Herrnstein, 1970). In addition, the relative amount of time spent responding on a key approximately matches relative frequency of reinforcement on that key, and the local rate of responding is invariant between keys (Baum and Rachlin, 1969; Brownstein and Pliskoff,

1968; Stubbs and Pliskoff, 1969). These observations have been cited to suggest that responding is distributed between the alternatives of *conc VI VI* schedules by the allocation of time spent responding, rather than by changes in the local pattern of responding. However, these data are not sufficient to prove that responding is distributed primarily by time allocation. For example, consider a *conc VI VI* schedule in which the relative frequency of reinforcement on one key is 0.8. A hypothetical subject might distribute responding by changing the local pattern of responding between the two keys. On the key with the higher density of reinforcement, the average time between responses (represented by both the mean and the mode of the distribution of IRTs) is 0.25 sec. On the key with the lower density of reinforcement, the average time between responses is 1 sec. If this subject allocated approximately 1 sec responding on the average to each key, the relative frequency of responding on the key with the higher density of reinforcement would be approximately 0.8. Thus, matching would be observed between relative frequency of responding and relative frequency of reinforcement. Now, suppose that this subject spends an average of 3 sec not responding after each period of responding on the key with the higher density of reinforcement. This time spent not responding would count as time spent on the key with the higher density of reinforcement, and would not change the overall relative frequency of responding. If there were no periods of time spent not responding on the key with the lower density of reinforcement, the relative amount of time spent on the key with the higher density of reinforcement would be approximately 0.8. Thus, matching would be observed between the relative amount of time spent on a key and the relative frequency of reinforcement on that key. In addition, the local rate of responding would be invariant on the two keys. The data for this hypothetical subject would be the same as that obtained in previous experiments, yet this subject could not be said to distribute responding primarily by the allocation of time. A direct measure of the local pattern of responding on each key is required to determine how responding is distributed in *conc VI VI* schedules.

In Experiment I, the distribution of IRTs on each key was recorded as a direct measure of

the local pattern of responding on the keys. These IRT distributions were relatively independent of the density of reinforcement on a key. The characteristic pattern of responding on a key depended more on key position than on density of reinforcement on the key. Since the differences in the local patterns of responding on the two keys did not change from condition to condition, the differences were apparently produced by an artifact that remained the same from condition to condition, *i.e.*, the fact that the two keys were in different positions, the bird's posture when pecking the two keys, *etc.* These results suggest that the local pattern of responding on a key is not a major determinant of the distribution of responses in *conc VI VI* schedules. This observation, combined with previous observations of the way in which time is allocated, provides strong support for the suggestion that responding in *conc VI VI* schedules is determined primarily by the allocation of time to the keys, rather than by changes in the local pattern of responding on those keys.

The rate of responding during the COD was higher than in any other postchangeover interval. The high rate of responding during the COD was accompanied by a zero rate of reinforcement during that interval. However, the rate of reinforcement was highest immediately following the COD, and it is possible that the high rate of responding during the COD was controlled by reinforcement after the COD. A number of studies have shown that when reinforcement contingencies are defined by fixed temporal intervals, a large portion of the total number of responses occurs before that interval terminates. In fixed-interval (FI) schedules for example, large numbers of responses occur before the end of the FI, even when the end of the interval is signalled by an external stimulus (Ferster and Skinner, 1957). In addition, when IRTs are differentially reinforced, the modal IRT is usually in an interval shorter than the reinforced IRT (see Shimp, 1967). Thus, it would seem plausible that the high rate of reinforcement following the COD determined the high rate of responding during the COD. However, it is also possible that the high rate of responding during the COD was a sampling artifact. Pliskoff (1971) and Silberberg and Fantino (1970) also found that response rate during the COD was higher than response rate after the COD. In each of

these experiments, and in the present Experiment I, the first response on a key started the COD timer. Thus, the COD was always started when the subject was responding. Suppose that a subject, when spending time on a key, alternates between periods of responding and not responding. Since the beginning of the COD marks a time when the subject is always responding, response rate would tend to be higher at that time. Since there would then be some possibility that the subject was in a period of not responding at any time after the start of the COD, response rate would tend to be lower at those times. In Experiment I, response rate was highest at the beginning of the COD, declining rapidly to a lower asymptotic level with increases in the amount of time since the preceding changeover. An increase in response rate was not observed near the end of the COD, where response rate might be expected to increase if the COD functioned as a discriminative cue for reinforcement. Therefore, the data from Experiment I suggest that the higher rate of responding during the COD was a sampling artifact.

The results of Experiment I show that the relative amount of time consumed by ICTs in an interval was approximately equal to the relative frequency of reinforced ICTs in the interval. This relationship between ICTs and reinforcement might be taken to imply that reinforcement of ICTs shaped the distribution of ICTs. While it is probably true that the differential reinforcement of ICTs affects the distribution of ICTs, the following considerations suggest that the data from Experiment I, or for that matter from any two-key *conc VI VI* schedule, cannot directly support this conclusion. Consider an extreme case in which all of the ICTs on a key are from the same class of ICTs. No reinforced ICTs could then fall outside of that class. This result would be true no matter how the schedule assigned reinforcements to ICTs. In general then, which ICTs occur determines to some extent which ICTs are reinforced.

A general nonanalytic method can be used to evaluate the extent to which responding in local intervals determines reinforcement in those intervals. A computer can be programmed to distribute responses in a schedule without regard to when reinforcements are likely to be assigned. If the functions relating responding to reinforcement for such

a simulated subject, called a "stat bird", are similar to the functions observed in real subjects, then the observed functions may not portray a shaping effect of reinforcement on responding. That is, correspondence between functions for stat birds and for real subjects implies a necessary relationship between responding and reinforcement. The observed relationship between responding and reinforcement would be obtained no matter how responses were distributed.

Accordingly, behavior maintained by a *conc VI VI* schedule was simulated on a computer. The *conc VI VI* schedule used in the simulation was the same as the schedule used in Experiment I. The probability of reinforcement on the left key was always 0.75. The computer simulation was conducted in "real time", and each simulated session lasted 60 min. The results of six simulated sessions were averaged. The stat bird responded according to the following rules:

1. A Bernoulli-trial occurred every 0.1 sec. The possible outcomes of a trial were the occurrence of a response or no response. The overall rate of responding by the stat bird could be varied by changing the probability of assigning a response in each 0.1-sec interval.

2. Whenever the stat bird responded, a test was made to see if the COD was in effect. If the COD was operating, the response was assigned to the key chosen on the previous response. That is, no changeovers occurred during the COD. If the COD was not operating, another Bernoulli-trial occurred. The possible outcome of this trial was assignment of the response to the left or right key. The relative frequency of response on the left key could be varied by changing the probability of assigning a response to the left key.

The consequences of assigning responses according to these rules were: (a) IRTs per opportunity (Anger, 1956) were approximately constant, (b) the probability of assigning a response to the left or right key after the COD was independent of where the preceding response was assigned, and (c) the assignment of a response was made without regard to when reinforcements were likely to be assigned. Two different sets of simulations were conducted. In the first set, the probability of assigning a response was 0.1 every 0.1 sec. These parameters resulted in an average response rate of approximately 60 responses

per minute. In this simulation, the probability of assigning a response to the left key was set equal to 0.74. This resulted in a relative frequency of responding on the left key of approximately 0.70, the actual mean of the relative frequencies of responding observed for the three subjects. The difference between the probability of assigning a response to the left key and the obtained relative frequency of responding on the left key was a result of the fact that changeovers in the simulation never occurred during the COD. In the second set of simulations, the probability of assigning a response was 0.05 every 0.1 sec. These parameters resulted in an average response rate of approximately 30 responses per minute. In this simulation, the probability of assigning a response to the left key was set equal to 0.73, which resulted in a relative frequency of responding on the left key of approximately 0.70. The simulation that produced an average response rate of 60 responses per minute had a shorter average ICT on both keys than the simulation that produced an average response rate of 30 responses per minute.

The results of the computer simulations are plotted in Figure 6. The top half of Figure 6 shows data generated by the simulation that produced an average response rate of 60 responses per minute. The bottom half of Figure 6 shows data generated by the simulation that produced an average response rate of 30 responses per minute. Both segments of Figure 6 show the relative amount of time consumed by ICTs plotted against the relative frequency of reinforced ICTs. The relative amount of time consumed by ICTs and the relative frequency of reinforced ICTs statistics were calculated as described for Figure 5. In both simulations, the relative amounts of time consumed by ICTs were approximately equal to the relative frequencies of reinforced ICTs. In that sense, the functions for the simulations were similar to the functions relating relative amount of time consumed by ICTs to relative frequency of reinforced ICTs obtained from real subjects.

The function relating ICTs to reinforcement obtained for real subjects was, in the sense described above, replicated by the computer simulations. These results suggest that the obtained ICT functions cannot be pre-

Fig. 6. The relative amount of time consumed by ICTs of a given duration from two stat birds as a function of the relative frequency of reinforced ICTs of that duration. Open circles show stat data from the left key, dots show stat data from the right key.

sented as evidence for a shaping effect of reinforcement on ICTs. There is a necessary interaction between ICTs and reinforced ICTs: which ICTs are reinforced may determine which ICTs occur, however, which ICTs occur determines which ICTs are reinforced. Therefore, the obtained functions presumably depend on this interaction. Stated differently, the functions may describe necessary relationships between responding and reinforcement in *conc VI VI* schedules. This necessary relationship may not reflect a controlling relationship of reinforcement on ICTs.

EXPERIMENT II

METHOD

Subjects

Three White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights. These were not the same subjects used in Experiment I. Each subject had experience in a variety of operant schedules.

Apparatus

Only the center keys in the experimental chambers of Experiment I were used; each could be transilluminated by red or green light. The PDP-12 computer scheduled and recorded events. Experimental sessions were conducted simultaneously and independently in the three chambers.

Procedure

The reinforcement schedule was a two-component *mult* VI VI.

VI schedule. A separate VI schedule was associated with each component. The VI schedules were constant reinforcement-per-opportunity schedules with a constant probability of assigning a reinforcement every 1 sec. The rate of reinforcement could be varied independently for each component by varying the constant probability of assigning a reinforcement in the associated VI schedule. Each VI schedule could assign reinforcements only when its associated component was in effect. Once a VI schedule assigned a reinforcement, that reinforcement was held until collected. In particular, a reinforcement arranged but

not collected at the end of a component was not cancelled: the reinforcement was available the next time the component occurred.

Stimuli. During one component, the center key was transilluminated by red light; during the other component, the key was transilluminated by green light. During reinforcement, the keylight and houselight were turned off and the food hopper was illuminated. Each reinforcement consisted of 2.5-sec access to mixed grain. A 100-msec blackout of all lights provided feedback for each response.

Component alternation. The two components alternated and each of the two components was of the duration specified for that condition. However, if the feeder was operated at the time of a scheduled component change, the new component did not begin until the end of that reinforcement. A change-over delay prevented reinforcement in the first 2.5 sec of a component. Each session lasted for 15 presentations of each component, *i.e.*, slightly longer than 90 min.

Experimental conditions. Table 3 shows, for each condition, the component duration, the VI schedule in each component, and the scheduled relative frequency of reinforcement in the component associated with the red keylight. The scheduled relative frequencies of reinforcement were calculated by dividing the number of reinforcements per hour scheduled when the key was red by the sum of the number of reinforcements per hour scheduled when the key was red and the number of reinforcements per hour scheduled when the key was green. Conditions 1 through 6 were conducted to evaluate local patterns of respond-

Table 3
Experimental Conditions for Experiment II

Condition Number	VI Schedule		Scheduled Relative Frequency of Reinforcement when the Key was Red	Component Duration in Seconds	Number of Sessions
	Red	Green			
1	VI 1-min	VI 4-min	0.8	180 sec	15
2	VI 1-min	VI 1-min	0.5	180	8
3	VI 4-min	VI 1-min	0.2	180	19
4	VI 1-min	VI 4-min	0.8	180	17
5	VI 1-min	VI 1-min	0.5	180	12
6	VI 4-min	VI 1-min	0.2	180	12
7	VI 4-min	VI 1-min	0.2	5	10
8	VI 1-min	VI 4-min	0.8	5	22
9	VI 1-min	VI 4-min	0.8	180	30

ing at relative frequencies of reinforcement and component durations typical to the previous *mult VI VI* schedule literature. Conditions 7 through 9 were conducted to compare local patterns of responding maintained by 5-sec and 180-sec component durations. Besides the conditions shown in Table 3, each subject was exposed to four days of training when the scheduled relative frequency of reinforcement in the component associated with the red keylight was 0.1, followed by four days when it was 0.9. This brief training, between Conditions 2 and 3, was given for the same reason as the corresponding brief training in Experiment I. An experimental condition was terminated only if the relative frequency of response in a component, plotted against days, looked stable for at least three or four days.

RESULTS

Relative Frequency of Responding and Reinforcement

Figure 7 shows the relative frequency of responding from Conditions 1 through 6 plotted against the relative frequency of reinforcement in those conditions. The relative frequency of responding was computed by first summing the numbers of responses in each component over the last three days of a condition and then dividing the number of responses when the key was red by the total number of responses in both components. The relative frequency of reinforcement was computed by dividing the number of reinforcements when the key was red by the total number of reinforcements in both components. The average relative frequency of responding over Conditions 2 and 5, which had a scheduled relative frequency of reinforcement of 0.5, were 0.4858, 0.4953, and 0.5212 for Birds 7, 8, and 9 respectively. Thus, none of the three subjects exhibited any important color preference. The relative frequency of responding in Conditions 1, 3, 4, and 6, which had scheduled relative frequencies of reinforcement in the component associated with the red keylight of either 0.2 or 0.8, approximately equalled the values previously obtained in *mult VI VI* schedules by Lander and Irwin (1968) and by Reynolds (1963), although a slight deviation from these previous values toward equality between relative frequency of responding and relative frequency

of reinforcement was observed for Bird 9. The average relative frequency of responding for the three subjects was approximately at the midpoint of the range of values previously obtained in *mult VI VI* schedules. This range is indicated in Figure 7 by brackets. The diagonal lines show equality between relative frequency of responding and relative frequency of reinforcement.

Responding in Subintervals of Components

Figure 8 shows the rate of response in each component from Conditions 1 through 6 plotted against successive 5-sec subintervals of the 180-sec components. The amount of time spent in a subinterval in a single session was found by multiplying the number of component presentations by the width of the subinterval. The rate of response in a subinterval was computed by first summing the numbers of responses and amounts of time in each subinterval over the last three days of a condition and then dividing the number of responses in the subinterval by the amount of time spent in that subinterval. The time spent in a subinterval includes the time during reinforcement; however, the proportion of time during reinforcement was quite small, and reinforcements were distributed uniformly across the subintervals.

The local pattern of responding within components was different for each subject. In conditions in which the scheduled relative frequency of reinforcement was not 0.5 (Conditions 1, 3, 4, and 6), Bird 7 emitted a relatively high rate of response immediately after a change to the component associated with the higher density of reinforcement. Response rate decreased to a lower asymptotic level with increases in the amount of time in a component. This pattern of responding within the component associated with the higher density of reinforcement in *mult VI VI* schedules is known as positive transient contrast (Nevin and Shettleworth, 1966). In conditions in which the scheduled relative frequency of reinforcement was not 0.5, Bird 7 emitted a relatively low rate of response immediately after a change to the component associated with the lower density of reinforcement. The response rate increased to a higher asymptotic level with increases in the amount of time in the component. This pattern of responding within the component associated with the lower density

Fig. 7. Relative frequency of responding in a *mult* VI VI schedule as a function of the relative frequency of reinforcement. The triangles show replications. The brackets indicate the range of values previously obtained in *mult* VI VI schedules with relative frequencies of reinforcement of 0.2 and 0.8. The diagonal lines indicate matching between relative frequency of responding and relative frequency of reinforcement.

of reinforcement in *mult* VI VI schedules is known as negative transient contrast (Nevin and Shettleworth, 1966). The positive and negative transient contrast were approximately symmetrical for Bird 7, although the asymptotic response rates were achieved at different times within a component in different conditions. In each condition, the changes in response rate associated with transient contrast had ended by 60 sec into either component.

Positive transient contrast was also evident for Bird 8 in conditions in which the scheduled relative frequencies of reinforcement were not 0.5. However, the positive transient contrast was smaller in magnitude than that observed in Bird 7, and the effect lasted less than 15 sec. Except in Condition 1, negative transient contrast was not observed for Bird 8.

The pattern of responding within a component observed in Bird 9 was different from

Fig. 8. Responses per minute when the key was red (open circles) and when the key was green (dots) as a function of successive 5-sec subintervals of 180-sec components. The columns of panels show response rates from different conditions; the rows of panels show data from different subjects.

the pattern observed in either Bird 7 or Bird 8. In conditions in which the scheduled relative frequency of reinforcement was not 0.5, except Condition 1, Bird 9 emitted a moderately high response rate immediately after a change to the component with the higher density of reinforcement. However, this moderately high rate was followed by a gradual increase in response rate over the entire component. Bird 9 emitted a lower rate of response at the first of the component with the lower density of reinforcement. This low rate of response was followed by a gradual decrease in response rate over the entire component. The changes in response rate within components were approximately symmetrical.

Figure 9 shows responses per minute plotted against successive 0.25-sec subintervals of the entire 5-sec components in Conditions 7 and 8 and of the first 5 sec of the 180-sec components in Condition 9. Response rates were calculated by dividing the number of responses in a subinterval by the amount of time spent

in that subinterval. The amount of time spent in a subinterval in a single session was found by multiplying the number of component presentations by the width of the subinterval. The numbers and times were summed over the last three days of Conditions 7 and 8. However, the amount of time in the first 5 sec of the 180-sec component of Condition 9 was so small within a single session that sums of numbers and times were taken over the last 16 days of that condition. Times during reinforcement were not taken out of the total amount of time spent in a subinterval in computing response rates in any condition. This fact is not important for the distributions of Condition 9, since most of the reinforcements were delivered after the first 5 sec of the components in that condition. However, in Conditions 7 and 8, the inclusion of reinforcement time in the computation of response rates produced a systematic bias in response-rate distributions. Since no reinforcements were delivered in the first 2.5 sec of any component

Fig. 9. Responses per minute as a function of successive 0.25-sec subintervals of the first 5 sec of a component. The rows of panels show response rates for different subjects; columns of panels show response rates from different conditions. Open circles show response rates when the key was red; dots show response rates when the key was green.

(i.e., during the COD) the times used to compute response rates were accurate during that interval. Since the duration of reinforcement was 2.5 sec, a reinforcement delivered immediately after the COD lasted until the end of the 5-sec interval. Reinforcements delivered at later times lasted beyond the 5-sec interval. Thus, the amount of time spent in reinforcement at the end of the 5-sec interval was larger than at any other time. Since there were about 30 reinforcements delivered in the component associated with the higher density of reinforcement, and the number of component presentations was 360, the amount of time in reinforcement at the end of a component was never more than about 10% of the total amount of time at the end of the component. The plotted points can be considered an upper bound on the actual rate of response at the end of the 5-sec intervals. A lower bound on the actual response rate could be computed by multiplying the plotted points by a factor of 0.9.

A single pattern describes the shape of the distributions of response rates over the first 5 sec of the component with the higher density of reinforcement. An initial low rate of response was followed by an increase to a higher maximum value. The rate of response then gradually decreased over the remainder of the 5-sec interval. For Birds 7 and 9, rate of response in the first subinterval of the component with the lower density of reinforcement was higher than rate of response in later subintervals. This relatively high rate of response was followed by a rapid decrease to a low minimum value. Response rate then increased over the remainder of the 5-sec interval. These descriptions fit the response patterns in the first 5 sec of both 5-sec and 180-sec components. For Bird 8, response rates in the first 5 sec of the component with the lower density of reinforcement did not show this same systematic pattern of variation.

The rate of response in the first 0.25-sec subinterval of the component associated with the lower density of reinforcement was always equal to, or greater than, rate of response in the first 0.25-sec subinterval of the component associated with the higher density of reinforcement. This relationship was reversed in all later subintervals. The negative correlation between response rates and reinforcement rates in the first subinterval of the compo-

nents may be an artifact of the procedure used in Experiment II. The change between components in Experiment II was instantaneous, and the components were associated with the same key. If a subject were emitting a burst of responses at the end of the component associated with the higher density of reinforcement, this burst could overlap the following component. Such an "overrun" would explain the relatively high rate of responding at the beginning of the component associated with the lower density of reinforcement. If a subject were responding at the low rate appropriate to the component associated with the lower density of reinforcement at the end of that component, this low rate could overlap the following component. Such an overrun of low rate would explain the relatively low rate of response at the beginning of the component associated with the higher density of reinforcement.

Figure 10 shows the relative frequency of responding plotted against the time since the onset of a component on a logarithmic scale, i.e., Figure 10 shows the relative frequency of responding in the first n sec of the 180-sec components. The relative frequency of responding was calculated by first summing the numbers of responses in each subinterval over the last three days of a condition and then dividing the number of responses in the first n sec of the component associated with the red key-light by the number of responses in the first n sec of both components. Only the data from conditions in which the scheduled relative frequency of reinforcement was 0.2 or 0.8 were plotted. In Conditions 7 and 8, when the component durations were 5 sec, the relative frequency of responding was computed over the full 5 sec, and only one value is plotted in Figure 10 for each of these conditions. In Conditions 1, 3, 4, 6, and 9, when the component durations were 180 sec, the relative frequency of responding was computed in the first n sec of the component. Figure 10 shows that as the amount of time since the onset of a 180-sec component decreased, the relative frequency of responding in a component changed in the direction of the scheduled relative frequency of reinforcement in the component. Except for Bird 8 in Conditions 1, 4, and 8, the relative frequency of responding approximately equalled the relative frequency of reinforcement in 5-sec components

and in the first 5 sec of 180-sec components. All deviations from equality between relative responding and relative reinforcement were in the direction of 50-50 responding, or undermatching, and the most extreme deviation was less than 0.2 from the scheduled relative frequency of reinforcement in the component.

Interresponse-time Distributions in Subintervals of Components

Interresponse-time distributions were recorded on the last three days of Conditions 4, 5, and 6. The IRT distributions were recorded separately in the first 5 sec, in the 5- to 30-sec subinterval, and in each subsequent 30-sec subinterval of each component. Only the IRT distributions for Bird 7, which were representative of the other two subjects, are presented.

Figure 11 shows the relative frequencies of IRTs in the neighborhood of the modal IRT plotted against 0.25-sec bins. As noted previously, interresponse times in the neighborhood of the modal IRT define a local pattern of responding in a component. The relative frequency of an IRT was calculated by first summing the numbers of IRTs in each bin over the last three days of a condition and then dividing the number of IRTs in a particular bin by the number of IRTs shorter than 4 sec. Thus, the sum of the plotted relative frequencies equals 1.0. The number to the left of the parentheses above each distribution in Figure 11 shows the number of IRTs shorter than 4 sec; the number within the parentheses shows the number of IRTs longer than 4 sec.

In Condition 4, a VI 1-min schedule assigned reinforcements when the key was red, a VI 4-min schedule assigned reinforcements when the key was green, and the scheduled relative frequency of reinforcement when the key was red was 0.8. In Condition 6, the VI schedules and relative frequencies of reinforcement in the components were reversed. In both conditions, the shapes of the distributions of IRTs emitted after the first 5 sec of the component associated with the red keylight were different from the shapes of distributions of IRTs emitted after the first 5 sec of the component associated with the green keylight. Differences between the IRT distributions in the first 5 sec of the components were not as large as differences between the

Fig. 10. Relative frequency of responding as a function of the first n sec of a component (on a logarithmic scale). The triangles show relative frequencies from 5-sec components; the circles show relative frequencies from the first n sec of 180-sec components. The brackets indicate the range of previously obtained results in 180-sec components with relative frequencies of reinforcement of 0.2 and 0.8. The flat horizontal lines indicate equality between relative frequency of responding and relative frequency of reinforcement. The slanted lines indicate the average relative frequencies from the first n sec of conditions with 180-sec component durations.

IRT distributions later in the components. The shapes of distributions of IRTs emitted when the keylight was red in Condition 4 were approximately the same as the shapes of distributions of IRTs emitted when the keylight was green in Condition 6, and the shapes of distributions of IRTs emitted when the keylight was green in Condition 4 were approximately the same as the shapes of distributions of IRTs emitted when the keylight

Fig. 11. Relative frequencies of interresponse times for Bird 7 when the key was red (open circles) and when it was green (dots). The interresponse time bins are 0.25-sec wide, and interresponse times longer than 4 sec are not plotted. The number not in parentheses above each distribution shows the number of interresponse times shorter than 4 sec; numbers in parentheses show the number of interresponse times longer than 4 sec. The columns of panels show data taken in different conditions; the rows of panels show data taken at different times in a component.

was red in Condition 6. That is to say, the shapes of IRT distributions were determined more by the VI schedule in a component than by the key color. Whenever there was a change in overall responses per minute, local response rate changed, *i.e.*, IRT distributions changed.

The numbers above each distribution in Figure 11 show that the number of IRTs longer than 4 sec in the components with the higher density of reinforcement was smaller than the number of IRTs longer than 4 sec in the components with the lower density of reinforcement. In Condition 5, when density of reinforcement in the two components was the same, the number of IRTs longer than 4 sec had a value between the values for the VI 1-min and the VI 4-min schedules of Conditions 4 and 6. Thus, when distributions of IRTs shorter than 4 sec are combined with

the total number of IRTs greater than 4 sec, it is clear that overall rate of responding in a component is controlled by both (a) local "pattern" of responding when the animal responds, and (b) amount of time spent responding defined by IRTs longer than those that reflect the local pattern of responding.

Interresponse-time distributions were also recorded over the entire component durations in Conditions 7, 8, and 9. Figure 12 shows the relative frequency of IRTs plotted in intervals 0.25-sec wide. The relative frequency of IRTs in a particular bin was calculated by first summing the number of IRTs in each bin over the last three days of a condition and then dividing the number of IRTs in that bin by the total number of IRTs. In Conditions 7 and 8, when the component durations were 5 sec, the first response in a component

Fig. 12. Relative frequencies of IRTs in bins 0.25-sec wide. Columns of panels show data from different conditions; rows of panels show data from different subjects. Circles show data when the key was red; dots show data when it was green.

constituted a large portion of the total number of responses. Since a separate analysis of the latencies of these first responses was made, the latencies were not included as IRTs. In Condition 9, when the component duration was 180 sec, the first response in a component constituted less than 0.1% of the total number of responses, and no attempt was made to eliminate the latencies of these responses from the IRT analysis. The IRT distribu-

tions shown in Figure 12 replicate the results for IRTs presented in Figure 11. The IRT distributions in the component with the higher density of reinforcement had different shapes than the IRT distributions in the component with the lower density of reinforcement.

A quantitative analysis of IRT distributions from Conditions 7, 8, and 9 was conducted to assess the contribution of IRTs to

relative responding in both 5-sec and 180-sec components. First, the arithmetic means of IRT distributions in each component were calculated. Then, the reciprocals of the mean IRTs were multiplied by 60 sec/min. The resulting number is a response rate predicted from the IRT distribution. In Conditions 7 and 8, the only other factor that might contribute to response rate was the latency of the first response in a component. In Condition 9, the latencies of the first responses in the components constituted such a small proportion of total responses that the means of the IRT distribution were not affected by their inclusion. Finally, a relative rate of responding was calculated by dividing the response rate predicted from the distributions of IRTs emitted in the component associated with the red keylight by the sum of the response rates predicted from the IRT distributions in both components. The predicted relative rates of responding are shown in column 2 of Table 4, and the actual relative rates of responding obtained in each condition are shown in column 1. Table 4 shows that relative rates of responding predicted from the IRT distributions in Condition 9 were approximately equal to actual relative rates of responding obtained in Condition 9. Thus, the IRT distributions adequately account for relative responding in *mult VI VI* schedules with 180-sec components. The relative rates of responding predicted from the IRT distributions in Conditions 7 and 8 were never as close to the relative frequencies of reinforcement in those conditions as were the actual relative rates of responding obtained. Thus, the relative re-

sponding in 5-sec components must have been determined by something in addition to the interresponse-time distributions in those components.

Latencies of the First Responses in a Component

Figure 13 shows the relative frequencies of occurrence of the latencies of the first responses in a component from Conditions 7, 8, and 9 plotted against the duration of these latencies, *i.e.*, the times between the onset of a component and the first response in the component. The latencies from Conditions 7 and 8 are plotted against 0.25-sec bins. Due to the large possible number of values of latencies in 180-sec components, the latencies from Condition 9 are plotted against 1.0-sec bins. The relative frequency of latencies in a particular bin was calculated by dividing the number of latencies in that bin by the total number of latencies. The number of latencies were summed over the last three days of Conditions 7 and 8. The number of latencies in a single session with 180-sec components was small, and the numbers of latencies were summed over the last eight days of Condition 9. If a subject failed to respond during a component presentation, no latency was recorded, and a latency was not recorded for the first component presented in a daily session. The numbers in parentheses in each panel of Figure 13 show the percentages of times a subject failed to respond in the first 5 sec of a component. Since the component durations in Conditions 7 and 8 were 5 sec, the numbers in parentheses in the panels for those conditions show the per-

Table 4
Relative Rate of Response and Relative Amount of Time Spent Responding

Condition	Subject	Relative Rate of Response		Relative Amount of Time Spent Responding	
		Obtained	Predicted from IRTs	Obtained	Adjusted
7	1	0.222	0.343	0.402	0.213
	2	0.178	0.203	0.437	0.188
	3	0.200	0.407	0.287	0.200
8	1	0.830	0.698	0.631	0.798
	2	0.608	0.583	0.520	0.764
	3	0.793	0.628	0.675	0.771
9	1	0.629	0.632	0.503	
	2	0.665	0.681	0.502	
	3	0.718	0.721	0.504

Fig. 13. Latencies of the first responses in a component. Columns of panels show latencies from different conditions; rows of panels show latencies from different subjects. Open circles show latencies from the component associated with the red keylight, dots from the component associated with the green keylight. The numbers in parentheses show the percentages of times a subject failed to respond in the first 5 sec of a component. The number to the left of the comma indicates percentages from the component associated with the red keylight; the number to the right indicates percentages from the component associated with the green keylight.

centages of component presentations in which a subject failed to respond.

The latency distributions in the component with the lower density of reinforcement had an initial mode at latencies shorter than 0.5 sec. In each case, these short latencies were below a second mode at longer latencies in the same component. The short latencies may have been terminated by responses in bursts that "overran" the component change. If the modes at latencies shorter than 0.5 sec from the component with the lower density of reinforcement are ignored, the latency distributions from the component with the higher density of reinforcement had modes at shorter latencies than the distributions from the component with the lower density of reinforcement. In addition, there was a greater percentage of times when no response was emitted in the first 5 sec of the component with the lower density of reinforcement. This description fits the latency distributions for both 5-sec and 180-sec components. It is difficult to compare the latencies in 5-sec components with the latencies in 180-sec components from Figure 13: the latency distributions in Condition 9 were more variable due to the smaller total number of latencies in that condition, and the class width was 1.0 sec in Condition 9 but was 0.25 sec in Conditions 7 and 8. In order to compare the latencies from 5-sec components with the latencies from 180-sec components, means of the latencies shorter than 5 sec in each of the two component durations were calculated. The means of the latencies from 5-sec components with the higher density of reinforcement were 0.83, 0.68, and 1.34 sec for Birds 7, 8, and 9, respectively; means from 180-sec components were 1.20, 0.78, and 2.05 sec. Thus, the average latencies from 180-sec components with the higher density of reinforcement were slightly longer than the average latencies from 5-sec components with the higher density of reinforcement. The means of the latencies from 5-sec components with the lower density of reinforcement were 1.85, 1.20, and 2.61 sec for Birds 7, 8, and 9, respectively; means from 180-sec components were 1.58, 1.19, and 2.05 sec. Thus, the average latencies from 5-sec components with the lower density of reinforcement were slightly longer than the average latencies from 180-sec components with the lower density of reinforcement. Thus, for each bird the difference between average latencies

in 5-sec components was larger than the differences between average latencies in 180-sec components.

It is possible to construct a measure of the contribution of the latency of the first response in a component to the determination of relative response rate. The amount of time spent responding in a component can be defined as the time from the first response in the component to the end of that component. That is, the amount of time spent responding in a component is the duration of the component minus the latency of the first response in the component. A relative amount of time spent responding was computed by dividing the amount of time spent responding in the component associated with the red keylight by the total amount of time spent responding in both components. These relative amounts of time spent responding are shown in column 3 of Table 4. The relative amount of time spent responding accounts for no difference in overall relative response rates between 180-sec components (see column 3, Condition 9). The relative amount of time spent responding in 5-sec components was closer to the relative frequency of reinforcement in the components than the relative amount of time spent responding in 180-sec components (see column 3, Conditions 7 and 8). The relative amount of time spent responding in 5-sec components is even closer to the relative frequency of reinforcement in the components if a consideration is made for latencies that may have been terminated by responses in bursts overlapping a component change. As noted previously, some latencies in the component associated with the lower density of reinforcement were shorter than 0.5 sec. In each case, these short latencies were well below a second mode of longer latencies in the same component (see Figure 13). If the latencies shorter than 0.5 sec are assumed to be an artifact of the change between components, the latency distribution should be adjusted accordingly. Such an adjustment was made by first counting the number of latencies shorter than 0.5 sec. The total number of latencies shorter than 0.5 sec was then multiplied by the relative frequency of latencies in each category longer than 0.5 sec; that is, each bin longer than 0.5 sec and the number of times a subject failed to respond in a component. The products from each of these multiplications were then added to the

observed number of latencies in the appropriate category. The resulting sums formed an adjusted latency distribution. The relative amount of time spent responding was then calculated from the adjusted latency distribution. The adjusted relative amounts of time spent responding in 5-sec components were approximately equal to the scheduled relative frequency of reinforcement in that component.

Time spent responding was also analyzed for the first 5 sec of the 180-sec components in Condition 9. The amount of time spent responding in the first 5 sec of 180-sec components was defined as the 5-sec interval minus the latency of the first response in the component. If the latency was longer than 5 sec, no time was spent responding in the first 5 sec of the component. Relative amounts of time spent responding were then calculated by dividing the amount of time spent responding in the first 5 sec of the component associated with the red keylight by the total amount of time spent responding in the first 5 sec of both components. The relative amounts of time spent responding in the first 5 sec of 180-sec components for Birds 7, 8, and 9 were 0.6532, 0.6505, and 0.7362 respectively. While latencies account for no difference in relative response rate between 180-sec components (see Table 4 column 3, Condition 9), latencies do account for some of the difference in the relative response rates in the first 5 sec of those same components.

DISCUSSION

The present results, and previous comparisons of *mult* VI VI and *conc* VI VI schedules, have shown differences in the behavior maintained by *mult* VI VI and *conc* VI VI schedules when the component durations in the *mult* VI VI schedule were long. For example, in *conc* VI VI schedules the relative frequency of responding on an alternative is approximately equal to the relative frequency of reinforcement provided by that alternative (Herrnstein, 1961). In *mult* VI VI schedules, the relative frequency of responding in a component is approximated by a linear function of the relative frequency of reinforcement in the component with slope less than one and y-intercept greater than zero (Lander and Irwin, 1968; Reynolds, 1963). However, when component durations in the *mult* VI VI schedule are short, distinctions in the behavior main-

tained by *mult* VI VI and *conc* VI VI schedules are no longer observed. For example, when component durations in *mult* VI VI schedules are in the neighborhood of 5 sec, the relative frequency of responding in a component is approximately equal to the relative frequency of reinforcement in the component (Killeen, 1972; Shimp and Wheatley, 1971; Todorov, 1972), just as in *conc* VI VI schedules. The data from Experiment II extend this three-way comparison among *conc* VI VI schedules, *mult* VI VI schedules with short component durations, and *mult* VI VI schedules with long component durations. The specific questions asked in making this comparison were (a) what local changes in responding are associated with the overall changes in responding observed in *mult* VI VI schedules when component durations are changed, and (b) to what extent is responding in *mult* VI VI schedules with short component durations related to responding in *conc* VI VI schedules?

The maximum difference in response rate between the components of a *mult* VI VI schedule are observed when the component durations are short. This relationship is a consequence of the observation that the relative frequency of responding in a component is closer to 0.50 when component durations are long, and the observation that the relative frequency of responding in a component is closer to the relative frequency of reinforcement in the component when component durations are short. This relationship would seem to describe an active change in responding between *mult* VI VI schedules with short and with long component durations. However, it is possible to argue that there is no active change in responding in *mult* VI VI schedules when component durations are changed. The change that occurs when *mult* VI VI schedule components are changed may be in the manner in which the experimenter measures the subject's responding. For example, when there were differences in response rate between components of a *mult* VI VI schedule with long component durations, those differences were not constant over the entire duration of the components. With a single exception, the maximum difference in response rate occurred in the first 5 sec of a component. In addition, the relative frequency of responding in the first 5 sec of a 180-sec component was distributed over ap-

proximately the same range as the relative frequency of responding in 5-sec components. This set of observations suggests that a subject may respond in the same pattern at a fixed time since the onset of a component, that the pattern of responding at that moment is independent of the eventual duration of the component, and that differences observed in responding with different component durations are the result of differential sampling by the experimenter, rather than active changes in responding on the part of the subject. To evaluate these possible alternatives, several different measures of the local pattern of responding were taken within 5-sec components and within subintervals of 180-sec components.

Several individual results from Experiment II show that the local pattern of responding in the first 5 sec of a 180-sec component is approximately the same as the local pattern of responding in 5-sec components. First, relative frequency of responding in the first 5 sec of a 180-sec component is distributed over approximately the same range as relative frequency of responding in 5-sec components. Second, the shape of the distribution of response rates over the first 5 sec of a 180-sec component was qualitatively the same as the shape of the distribution of response rates over 5-sec components. Third, the distribution of IRTs in a component did not discriminate between the first 5 sec of 180-sec components and 5-sec components. The only local pattern of responding that consistently discriminated between 180-sec and 5-sec components was the latency of the first response in a component. These combined results provide a strong indication that when *mult VI VI* schedule component durations are changed, changes in responding on the part of the subject do not contribute in an important way to changes in overall responding. This conclusion is even more compelling when the IRT and latency distributions are considered in greater detail.

Differences in response rate in the two components of *mult VI VI* schedules with 180-sec components were associated with differences in the shapes of the distributions of IRTs shorter than 4 sec and with differences in the frequencies of IRTs longer than 4 sec. These data show that changes in response rate were associated both with changes in local patterns of responding in bursts and with changes in amounts of time spent responding. This fact

would seem to establish a major difference between *conc VI VI* and *mult VI VI* schedules. In *conc VI VI* schedules, the local rate of response is approximately the same on the two alternatives, the relative amount of time spent on an alternative is approximately equal to the relative frequency of reinforcement provided by that alternative, and therefore, the distribution of responding is determined primarily by the allocation of time to the alternatives. In *mult VI VI* schedules, the local pattern of responding in bursts and the allocation of time spent responding combine to determine responding. However, this distinction does not apply over the entire duration of 180-sec *mult VI VI* schedule components nor to 5-sec *mult VI VI* schedule components. The largest difference in response rate between components typically occurred in the first 5 sec of 180-sec components and in 5-sec components. This maximum difference in response rate between components was accompanied by the smallest difference in the IRT distributions between components. The similarity between IRT distributions in the first 5 sec of the components and the associated large difference in relative response rates in the same intervals hints at the possibility of a major contribution of time allocation during this period. A source of time allocation in this interval is obvious: the latency of the first response in a component.

While there were differences in mean latencies between the first 5 sec of 180-sec components and 5-sec components, the differences in the latency distributions were small, and these small differences could not account for the large differences in overall responding observed between 5-sec and 180-sec components. However, even if the latency distributions were the same in a 5-sec component and in a 180-sec component, the latencies in the 5-sec component would contribute more importantly to overall responding than the latencies in the 180-sec component. A 3-sec latency consumes over half of a 5-sec component, but the same 3-sec latency consumes less than 2% of a 180-sec component. The large changes in amounts of time spent responding with a 5-sec sample at the beginning of a 180-sec component (and with 5-sec components), as opposed to a sample over the entire 180-sec component, is illustrated by the fact that when the obtained latency distributions were adjusted for

overruns, the relative amount of time spent responding in a 5-sec component matched the relative frequency of reinforcement in that component.

These observations provide an answer to the first question posed at the beginning of this section. Any changes that occur in the local pattern of responding when component durations are changed are small enough to be considered trivial in determining observed differences in overall responding. The observed differences in overall responding are the result of differences in the behavior sampled with different component durations.

The second question requires a comparison of the behavior maintained by *conc VI VI* schedules and *mult VI VI* schedules with short component durations. In a previous comparison of those schedules, Killeen (1972) concluded that matching in *mult VI VI* schedules with short component durations was produced by a difference in the local response rate in the two components. This conclusion implies that subjects behave differently in the two components of a *mult VI VI* schedule with short component durations, in the sense that the local pattern of responding in the two components are different. Since the local patterns of responding are approximately the same on the alternatives of *conc VI VI* schedules, Killeen's analysis distinguishes between behavior maintained by *mult VI VI* schedules with short component durations and *conc VI VI* schedules. However, this distinction may be only superficial. Killeen defined local response rate as the number of responses in a component divided by the experimenter-controlled component duration. With this definition, any change in the number of responses in a component requires a change in local response rate, because the experimenter-controlled component duration remains the same. However, a change in the number of responses in a component could be produced by a change in either the local pattern of responding in a component or the amount of time spent not responding in a component. Killeen's distinction would be appropriate only if the change in his local response rate were associated with a change in the local pattern of responding in the components.

The results of Experiment II suggest that it is possible to construct a functional amount of time spent responding in a component defined

by an adjusted distribution of the first responses in a component. A local response rate, different from that described by Killeen, can then be constructed by dividing the number of responses in a component by the functional amount of time spent responding in a component. Such a measure was not constructed from the data of Experiment II. However, other results from the short component durations of Experiment II show that the new local response rate would be invariant between the two components, just as in *conc VI VI* schedules. First, the results of Experiment II show that the relative frequency of responding in a component was approximately equal to the relative frequency of reinforcement in that component, or

$$(1) \quad \frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2}.$$

Where R_i is the frequency of responding in component i , and r_i is the frequency of reinforcement in component i . Second, the results of Experiment II show that the relative functional amount of time spent responding in a component was approximately equal to the relative frequency of reinforcement in the component, or

$$(2) \quad \frac{T_1}{T_1 + T_2} = \frac{r_1}{r_1 + r_2}.$$

Where T_i is the functional amount of time spent responding in component i , and r_i is the frequency of reinforcement in component i . Since the right-hand side of Equation (1) is equal to the right-hand side of Equation (2), those equations can be combined to yield

$$(3) \quad \frac{R_1}{R_1 + R_2} = \frac{T_1}{T_1 + T_2}.$$

Simple algebraic manipulation shows that Equation (3) is equivalent to

$$(4) \quad \frac{R_1}{T_1} = \frac{R_2}{T_2}.$$

Thus, the results of Experiment II require invariance in the local rate of responding. When this observation is combined with the IRT results from Experiment II, which show only small differences in the IRT distributions between 5-sec components, it is clear that the local pattern of responding is subordinate to the amount of time spent responding, just as in *conc VI VI* schedules.

These conclusions are not meant to imply that responding in 5-sec components of *mult* VI VI schedules is exactly the same, in any sense, as responding in *conc* VI VI schedules. Rather, there is a continuum of choice experiments with *conc* VI VI schedules at one extreme and *mult* VI VI schedules with long component durations at the other extreme. As the component durations in the *mult* VI VI schedules are reduced to 5 sec, the sampled behavior resembles more and more the behavior maintained by *conc* VI VI schedules, in the sense that time allocation becomes the major determinant of responding.

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