SYNTHETIC VARIABLE-INTERVAL SCHEDULES OF REINFORCEMENT¹

CHARLES P. SHIMP

UNIVERSITY OF UTAH

Three pigeons pecked for food on a synthetic variable-interval schedule of reinforcement that had two independent parts: a variable-interval schedule that arranged a distribution of interreinforcement intervals, and a device that randomly assigned each reinforcement to one of 10 classes of interresponse times. The frequencies of reinforcement for the 10 classes of interresponse times were systematically varied, while the overall frequency of reinforcement was held within a comparatively narrow range. The 10 classes extended either from 0.1 to 0.6 sec in 0.05-sec intervals, or from 1.0 to 6.0 sec in 0.5-sec intervals. In the former case, some control by reinforcement was obtained, but it was weak and no simple relationships were discernible. In the latter case, the relative frequency of an interresponse time was a generally increasing function of its relative frequency of reinforcement, and two simple controlling relationships were found. First, the function relating interresponse times per opportunity to reinforcements per opportunity was, over a restricted range, approximately linear with a slope of unity. Second, when all 10 classes of interresponse times were reinforced equally often, the relative frequency of an interresponse time approximately equalled the relative reciprocal of its length.

A long-range goal of the experimental analysis of behavior is the development of methods that precisely control the probability with which a response occurs at a specific moment in time. The attempt to reach this goal has led to the use of response rate and interresponse-time distributions as measures of the probability of occurrence of that response. Unfortunately, classical schedules of reinforcement do not control all of the contingencies that are believed to determine response rate and interresponse-time distributions (Anger, 1956; Blough and Blough, 1968; Jenkins, 1970; Morse, 1966). For example, it is well known that an interaction exists in, say, a variable-interval schedule, between the relative-frequency distribution of interresponse times and the relative-frequency distribution of reinforcements for those interresponse times:

which interresponse times are emitted depends on which interresponse times are reinforced, and at the same time, which interresponse times are reinforced depends on which interresponse times are emitted, *i.e.*, they depend on the organism. This interaction vastly complicates the search for functional relationships between response rate and frequencies of occurrence of interresponse times on the one hand, and reinforcement parameters on the other hand, in variable-interval schedules.

Anger (1954) circumvented this interaction by devising a schedule of reinforcement, which he called a synthetic variable-interval schedule, that duplicated many of the features of a variable-interval schedule, but which experimentally controlled the distribution of reinforcements for various interresponse times. That is, changes in the distribution of interresponse times did not change the distribution of reinforcements for the various interresponse times. With a synthetic variable-interval schedule, one can devise any distribution of reinforced interresponse times one chooses, and then look for the emergence of empirical relationships between steady-state interresponse-time distributions and corresponding reinforcement distributions.

Anger constructed a dependent variable, which he called the interresponse times per opportunity, by dividing the number of inter-

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response times in a particular class by the sum of the number of interresponse times in that class and the number of those in all classes of longer interresponse times. Anger's results suggested that the interresponse times per opportunity for a particular class of interresponse times depended on the number of reinforcements per hour for that class. More specifically, he arranged separate schedules of reinforcement (either fixed-interval or variable-interval schedules) for interresponse times belonging to the classes extending from 0 to 28 sec in 4-sec intervals. He then observed that the interresponse times per opportunity in the 0- to 4-sec class decreased when he decreased the relative frequency of reinforcement for that class, for all three rat subjects. He simultaneously increased the relative frequency of reinforcement for interresponse times in the 12- to 16-sec class and found that the interresponse times per opportunity in that class increased for two subjects. No effect was observed for the third subject, for which the increase in the relative frequency of reinforcement was for the 8- to 12-sec class, instead of for the 12- to 16-sec class. When the distribution of reinforcements was changed back to its initial form, behavior that was at least qualitatively similar to the original behavior was obtained for all three subjects. In short, Anger generally found that he could increase or decrease the frequency of occurrence of an interresponse time by increasing or decreasing the frequency of reinforcement for that interresponse time, but neither he nor Millenson (1964), who performed a similar experiment, systematically mapped out any quantitative, functional relationships.

Work on complex synthetic variable-interval schedules has not progressed much beyond the point reached by Anger in 1954. However, work with highly simplified synthetic schedules has revealed the utility of schedules in which the distribution of interresponse times does not affect the corresponding reinforcement distribution. Highly simplified schedules have allowed the discovery of a number of simple, quantitative relationships. Shimp (1968) devised a schedule in which there were two classes of reinforced interresponse times that were isolated from each other by an intervening class of non-reinforced interresponse times. Reinforcements were arranged by a single variable-interval schedule and a device that randomly allocated a reinforcement to

one or the other of the two classes of reinforced interresponse times. This schedule may be called a concurrent variable-interval variable-interval schedule of reinforcement for two classes of interresponse times. Staddon (1968) developed a similar schedule. Both Shimp and Staddon found that the relative frequency of occurrence of the shorter interresponse time was a monotonically increasing, negatively accelerated function of its relative frequency of reinforcement. Subsequently, it has been found that in such a schedule, the relative frequency of an interresponse time approximately equals the relative reciprocal of its length, when both interresponse times are reinforced equally often and the overall density of reinforcement is maintained at a sufficiently high level (Shimp, 1969b, 1970). It has also been found that the way in which the relative frequency of an interresponse time depends on the relative frequency of reinforcement for that interresponse time is the same, regardless of whether the two classes of reinforced interresponse times are arranged on the same key or on different keys (Moffitt and Shimp, 1971).

The schedule used in the present experiment was a straightforward extension of a concurrent variable-interval variable-interval schedule of reinforcement for two interresponse times. A principal methodological difference was that here there were 10 instead of two variable-interval components. Thus, the schedule was a 10-component concurrent schedule of reinforcement for 10 classes of interresponse times. A second principal difference between the present schedule and previous concurrent variable-interval variable-interval schedules of reinforcement for two interresponse times was that here there was no interval of non-reinforced interresponse times between two adjacent classes of reinforced interresponse times.

The objective of this experiment was to map out quantitative, functional relationships between responding and reinforcement in a complex synthetic variable-interval schedule.

METHOD

Subjects

Three White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. Each pigeon previously had responded in the presence of red and green

keylights in experiments using multiple variable-interval variable-interval schedules of reinforcement.

Apparatus

Only the center keys in three, three-key Lehigh Valley Electronics pigeon chambers were used. A Digital Equipment Corporation PDP-12A ("LINC" system) laboratory computer arranged the stimuli and reinforcements, and recorded the data.

Procedure

Variable-interval schedule. A distribution of interreinforcement intervals was arranged by a constant-probability variable-interval schedule. That is, every t sec, a random device scheduled reinforcement with some constant probability. In Conditions 1 to 6, the schedule was nearly a continuous reinforcement schedule, as t was 1.5 sec, and the constant probability was 0.8 (Condition 1) or 0.6 (Conditions 2 to 6). These combinations of parameters produce average interreinforcement intervals of only 1.9 sec and 2.5 sec, respectively. In Conditions 7 to 11, t was 1.0 sec and p was 0.05. These values produce an average interreinforcement interval of 20 sec. Throughout Conditions 1 to 11, the overall number of reinforcements per hour ranged from approximately 30 to 60. A previous experiment (Shimp, 1970), showed that in a concurrent variable-interval variable-interval schedule of reinforcement for two interresponse times, variations of this magnitude in the absolute rate of reinforcement do not affect the relative frequency of an interresponse time.

When reinforcement was arranged, it remained so until collected. No subsequent reinforcement could be arranged until a previously arranged one was collected. That is, once a reinforcement was arranged, a subject had to terminate an interresponse time in a particular class (selected in a way described below) and be rewarded before another reinforcement could be arranged.

It was possible for the first response after a reinforcement to be reinforced, if the variable-interval schedule had arranged a reinforcement, and if the time between the end of reinforcement and the response was in the appropriate class of 10 time intervals, which were randomly selected in the way described below.

The distribution of reinforced interresponse times. When reinforcement was arranged by the variable-interval schedule, it was allocated by an additional random device to one of 10 classes of reinforced interresponse times. For each reinforcement arranged by the variable-interval schedule, exactly one class of interresponse times was selected, and the probabilities with which the classes were selected were constant and independent of the previously selected interresponse time. The method is the natural extension of the method used in previous one-key and two-key schedules of reinforcement for two interresponse times (Shimp, 1968, 1969b, 1970, 1971; Moffitt and Shimp, 1971). Recall that, once a reinforcement was arranged, no subsequent ones were arranged until the first one was collected. Consequently, the sequence of reinforcements actually delivered was the same as the sequence of reinforcements arranged by the schedule. This feature of the schedule ensured that the probability of reinforcement for a response class was independent of the previously reinforced class. There is no such assurance with the conventional method of arranging a concurrent schedule, where each class of reinforced responses has a separate variable-interval tape (unless all the tapes stop whenever any one arranges a reinforcement, as in Stubbs and Pliskoff, 1969). This feature of the schedule also ensured that scheduled and obtained relative frequencies of reinforcement were equal. However, because of sampling fluctuation, the obtained relative frequencies of reinforcement differed from the theoretical probabilities computed from the linear functions in Table 1.

Experimental conditions varied in terms of the probability distribution of reinforcements over the 10 classes of interresponse times. The experimental literature gave no rationale for selecting any one reinforcement probability distribution over another, so linear functions were selected arbitrarily. Table 1 shows the linear functions selected to provide the probability distributions of reinforcements. In the table, and elsewhere in this paper, the 10 classes of reinforced interresponse times are indexed, for the sake of brevity, by the numbers 1, 2, 3, . . . , 10, with 1 referring to the shortest and 10 referring to the longest interresponse time. The top panel of Figure 1 graphically displays these linear functions for Conditions 1 to 9. The center panel of Figure 1 shows the

Table 1
Experimental Conditions

Condition Number	Lower and Upper Bounds of the Interval of Reinforced Interresponse Times (sec)	Probabilities of Reinforcement [P(X)] for the 10 Classes of Reinforced Interresponse Times ¹	Number of Days of Training
1	1.0, 6.0	$P(X) = 0.1000$	17
2	1.0, 6.0	$P(X) = 0.0091X + 0.0500$	26
3	1.0, 6.0	$P(X) = 0.0164X + 0.0100$	13
4	1.0, 6.0	$P(X) = 0.0222X - 0.0222$	14
5	1.0, 6.0	$P(X) = 0.1000$	13
6	1.0, 6.0	$P(X) = -0.0100X + 0.1550$	22
7	0.1, 0.6	$P(X) = 0.1000$	14
8	0.1, 0.6	$P(X) = 0.0222X - 0.0222$	26
9	0.1, 0.6	$P(X) = -0.0222X + 0.2222$	20
10	1.0, 6.0	$P(X) = 0.1000$	26
11	1.0, 6.0	(see text and Table 2)	27

¹The variable X in each function runs from 1 to 10, with 1 and 10 corresponding to the shortest and longest reinforced interresponse times, respectively.

corresponding obtained relative frequencies of reinforcement, averaged over the three subjects and the last six days of the various conditions. There is less sampling fluctuation, of course, in the curves that represent averages over a greater number of conditions. The bottom panel shows the corresponding reinforcements-per-opportunity (Catania and Reynolds, 1968; Reynolds and McLeod, 1970). The reinforcements-per-opportunity for a particular class of interresponse times equals the number of reinforcements for interresponse times in that class, divided by the total number of reinforcements for interresponse times in that class or in any class of longer interresponse times.

Table 2 shows the reinforcement distributions used in Conditions 10 and 11. Condi-

tion 10 was a replication of Conditions 1 and 5: *i.e.*, in Condition 10, the probabilities of reinforcement for the 10 classes of reinforced interresponse times all equalled 0.10. Condition 11 was designed to explore the importance of the reinforcements-per-opportunity variable. As the bottom panel in Figure 1 shows, the reinforcements-per-opportunity variable was an increasing function throughout Conditions 1 to 10. In Condition 11, it was set equal to a constant value of 0.2, except for the class of longest reinforced interresponse times. The reinforcements per opportunity for that class must equal 1.0.

In Conditions 1 to 6, 10, and 11, the classes of reinforced interresponse times extended from 1.0 to 6.0 sec, in 0.5-sec intervals. In Con-

Table 2
Reinforcement Distributions in Conditions 10 and 11

Classes of Reinforced Interresponse Times (sec)	Condition 10		Condition 11	
	Probability of Reinforcement	Reinforcements per Opportunity	Probability of Reinforcement	Reinforcements per Opportunity
1.0 to 1.5	0.100	0.100	0.200	0.200
1.5 to 2.0	0.100	0.111	0.160	0.200
2.0 to 2.5	0.100	0.125	0.128	0.200
2.5 to 3.0	0.100	0.143	0.102	0.200
3.0 to 3.5	0.100	0.167	0.082	0.200
3.5 to 4.0	0.100	0.200	0.066	0.200
4.0 to 4.5	0.100	0.250	0.052	0.200
4.5 to 5.0	0.100	0.333	0.042	0.200
5.0 to 5.5	0.100	0.500	0.034	0.200
5.5 to 6.0	0.100	1.000	0.134	1.000

Fig. 1. The functions relating the 10 classes of reinforced interresponse times to: the theoretical probabilities of reinforcement (top); the obtained relative frequencies of reinforcement (center); and the obtained reinforcements per opportunity (bottom). The obtained functions in the center and bottom panels are means over all three subjects and the last six days of all of the conditions for which a particular theoretical function applied.

ditions 7 to 9, the 10 classes extended from 0.1 to 0.6 sec, in 0.05-sec intervals. The relative length of an interresponse time is characterized in the present paper by the relative reciprocal of the length of that interresponse time (Killeen, 1968; Shimp, 1969*b*). The relative reciprocal of the k^{th} interresponse time in the present experiment is

$$\frac{1}{T_k} \div \sum_{i=1}^{10} \frac{1}{T_i}$$

where T_k is the lower bound of the k^{th} interresponse time, and the denominator is the sum of the reciprocals of the lower bounds of the 10 classes of reinforced interresponse times. The relative reciprocal of the k^{th} interresponse time in Conditions 1 to 6, 10, and 11 was the same as the relative reciprocal of the k^{th} interresponse time in Conditions 7 to 9. Therefore, these two sets of conditions provided a comparison between the effects of reinforcement of interresponse times having the same relative lengths but having different absolute lengths. In addition, the interresponse times reinforced in Conditions 7 to 9 were in the range of interresponse times often said to conform to different laws than do longer ones (Blough, 1963, 1966; Ray and Sidman, 1970).

Other procedural details. Visual response-feedback was provided by the white keylight and the houselight, both of which were darkened for 0.5 sec (Conditions 1 to 6, 10, and 11) or for 0.05 sec (Conditions 7 to 9) after every key peck. Thus, the duration of the blackout after a response was always one-half of the lower bound of the shortest reinforced interresponse time. Reinforcement consisted of 1.6-sec access to mixed grain. During reinforcement, the keylight and the houselight were darkened and a light over the food hopper was turned on. A session was terminated at the end of a subject's sixty-fourth reinforcement. All temporal intervals were determined by a crystal clock in the computer. This clock ran at 100 Hz during Conditions 1 to 6, 10, and 11, and at 1000 Hz during Conditions 7 to 9. The clock ran at a rate 10 times faster than the width of the intervals in which interresponse times were recorded.

Experimental conditions were changed at times more dependent on convenient access to

the computer for programming and data analysis purposes than on a rational criterion of behavioral stability. As shown in Table 1, in no case was a condition terminated after fewer than 13 or more than 27 days.

RESULTS

The results from the conditions in which the 10 classes of reinforced interresponse times ranged from 1 to 6 sec in 0.5-sec bins were very different from the results from Conditions 7 to 9, in which the 10 classes ranged from 0.1 to 0.6 sec in 0.05-sec bins. Accordingly, the results are presented in two different parts, corresponding to the two different intervals of reinforced interresponse times. All of the results presented here are averages over the last six days of an experimental condition.

Reinforced interresponse times ranging from 1 to 6 sec; Conditions 1 to 6. The number of responses that terminated interresponse times in the interval from 1 to 6 sec constituted 91 to 98% of the total number of responses. The subsequent analysis deals only with this subclass of all responses.

Relative-frequency distributions of interresponse times. Figure 2 shows the relative frequencies of occurrence of the 10 classes of reinforced interresponse times. The relative frequency of a class of interresponse times was computed by dividing the total frequency of occurrence of interresponse times in that class by the total frequency of occurrence of interresponse times in all 10 classes. These relative frequencies exclude interresponse times outside of the interval of reinforced interresponse times, and sum to unity. The results of Condition 5, which replicated Condition 1, were highly similar to the results of Condition 1, and so for the sake of legibility, Figure 2 shows the average of these two conditions.

One way to look for orderly relationships in Figure 2 is to see if the rank orders of the relative frequencies of occurrence of a particular interresponse time tend to be the same as the rank orders of the corresponding relative frequencies of reinforcement. That is, the experimental conditions may be ranked according to the relative frequencies of occurrence of a particular interresponse time and they may also be ranked according to the relative frequencies of reinforcement for that interresponse time. Are these two sets of ranks similar

for any or all classes of interresponse times? One would expect these two sets of rank orderings to be more highly correlated for the shortest and longest interresponse times: over conditions, the relative frequency of reinforcement for intermediate interresponse times did not vary over so wide a range as it did for the shortest and longest interresponse times (see Figure 1, top two panels). This expectation is borne out by the data. For each of the three subjects, each of the relative frequencies of occurrence of the four longest interresponse times has a rank equal to the rank of the corresponding relative frequency of reinforcement. The rank orderings for the shortest interresponse time also are correlated—perfectly so for Birds 2 and 3. The rank orderings for the interresponse times intermediate in length to the shortest and the four longest interresponse times tend to be more nearly randomly related to the rank orderings of the corresponding relative frequencies of reinforcement.

Figure 2 shows that the shape of the relative-frequency distributions depended on the reinforcement distributions. Some relative-frequency distributions were unimodal and others were bimodal. The location of a mode was apt not to be constant over the experimental conditions. It is not clear what mathematical function could describe the various shapes of all of these distributions, although a function is presented below that adequately describes the distributions for the experimental conditions in which all 10 classes of interresponse times were reinforced equally often.

Interresponse-times-per-opportunity distributions. Figure 3 shows the values of the interresponse-times-per-opportunity variable for the 10 classes of reinforced interresponse times. As in Figure 2, Conditions 1 and 5 are averaged. The number of interresponse times in any particular 0.5-sec class outside the interval from 1 to 6 sec of reinforced interresponse times was usually too low to be reliable, but the total number of interresponse times longer than 6 sec was large enough so that it could be used in the denominator of the interresponse times per opportunity for the class of longest reinforced interresponse times. Thus, the present values of the interresponse times per opportunity were obtained by taking the number of interresponse times in a particular class divided by the total number of interresponse

Fig. 2. The relative frequencies of occurrence of 10 classes of reinforced interresponse times extending from 1.0 to 6.0 sec in 0.5-sec intervals. The values are means over the last six days of separate conditions, except for those that are the means over both Conditions 1 and 5, which had the same theoretical reinforcement function.

times in that class or any class of longer interresponse times, not just those classes of longer reinforced interresponse times. Ordinarily, the relative frequency of occurrence of the shortest

class of interresponse times and the interresponse times per opportunity for the shortest class of interresponse times are the same. But here they are slightly different since the inter-

response times per opportunity did, but the relative frequencies did not, take into account interresponse times longer than the longest reinforced interresponse time.

Figure 3 shows that, in general, the interresponse times per opportunity were greater for the longer interresponse times. One may

compare the interresponse-times-per-opportunity curves in Figure 3 with the reinforcements-per-opportunity curves in the right-hand panel of Figure 1: there would seem to be a strong correlation between the general shapes of the two sets of functions. More detailed evidence that there was a correlation between the values

Fig. 3. The interresponse times per opportunity for 10 classes of reinforced interresponse times extending from 1.0 to 6.0 sec in 0.5-sec intervals. The values are means over the last six days of separate conditions, except for those that are the means over both Conditions 1 and 5, which had the same theoretical reinforcement function.

of the reinforcements per opportunity and the corresponding interresponse times per opportunity may be found by examining the kind of rank orderings discussed above in conjunction with the distribution of relative frequencies of interresponse times. For Bird 1, the correlation between the rank orders of the reinforcements per opportunity and the rank orders of the interresponse times per opportunity was perfect for each of the three shortest interresponse times. For Birds 2 and 3, the corresponding correlations for the second and third shortest interresponse times were perfect. For all three birds, the corresponding correlations for longer interresponse times were negligible.

The rank orderings described above in conjunction with Figures 2 and 3 provide some insight into the relationships between responding and reinforcement. A more direct way to study these relationships between responding and reinforcement is to plot the former against the latter. The present data are plotted below in two such ways: each reveals different facets of the complex control of behavior by the present schedule of reinforcement.

Figure 4 shows the relative frequency of occurrence of a class of interresponse times as a function of the obtained relative frequency of reinforcement for that class. For the sake of legibility, only points for the three shortest and for the three longest interresponse times are joined. Unlike the arrangement in Figures 2 and 3, averaging of Condition 1 and its replication, Condition 5, was not necessary for the sake of legibility. The effects of both the relative frequency of reinforcement for a class of interresponse times and of the length of that class are visible in Figure 4. The former effect appears as a tendency for the relative frequency of occurrence of an interresponse time to increase as the relative frequency of reinforcement for that interresponse time increases. The latter effect appears as a tendency for shorter interresponse times to occur more often than longer ones, given a particular relative frequency of reinforcement.

Control by the relative frequency of reinforcement is observable whenever it varied by more than 5 to 10 percentage points, that is to say, its effect appears only for the three shortest and the three longest interresponse times. In general, for these classes of interresponse times, the relative frequency of occurrence of

an interresponse time was an increasing function of its relative frequency of reinforcement, although the functions certainly were not invariably monotonically increasing. The relative frequency of the third shortest interresponse time for Bird 2 did not increase with its relative frequency of reinforcement. Bird 2 was an exception also in that the relative frequency of occurrence of the shortest interresponse time was systematically less than that of the next-to-the-shortest interresponse time.

The cluster of points near the middle of each panel in Figure 4 shows the variability in the relative frequencies of occurrence of the interresponse times for which the relative frequencies of reinforcement varied by only a small amount. As might be expected, no control by the relative frequency of reinforcement can be seen for these interresponse times.

Figure 5 shows the interresponse times per opportunity as a function of the reinforcements per opportunity. As in Figure 4, only points for the three shortest and the three longest interresponse times are joined, to preserve legibility in the figure. Each of the three sets of points in Figure 5 can be described fairly accurately as curvilinear in a narrow interval near the origin, and then linear up until the curve asymptotes. More specifically, the sets of points appear to describe functions that are curvilinear between the origin and a value of roughly 0.05 on the X-axis, and which are then linear from 0.05 on out to roughly 0.35 (Bird 2), 0.40 (Bird 3), or 0.45 (Bird 1), at which values the functions asymptote. The correlations between interresponse times per opportunity and reinforcements per opportunity, restricted to these linear portions of the curves in Figure 5, were 0.87, 0.81, and 0.91, for Birds 1, 2, and 3, respectively. The asymptotic interresponse times per opportunity ranged from roughly 0.45 to 0.60. Figure 5 shows that these asymptotic interresponse times per opportunity correspond to the longest reinforced interresponse times, as they should, since the bottom panel of Figure 1 shows that the reinforcements per opportunity were greatest for the longest interresponse times. Note that for the class of longest reinforced interresponse times an asymptotic value of interresponse times per opportunity equal to, say, 0.5, means that if a subject paused for 5.5 sec, there was a probability of 0.5 that it would respond within the next half-second.

Fig. 4. The relative frequencies of occurrence of 10 classes of reinforced interresponse times extending from 1.0 to 6.0 sec in 0.5-sec intervals, as a function of the corresponding obtained relative frequencies of reinforcement. The points for the three shortest interresponse times, labelled 1, 2, and 3, and the points for the three longest interresponse times, labelled 8, 9, and 10, are joined: for the sake of clarity, those for the four intermediate interresponse times are not. The presented data are means over the last six days of each condition.

The straight line appearing in each panel of Figure 5 is the linear function for which the interresponse times per opportunity equals the reinforcements per opportunity plus 0.10, over the interval for which the data points appear to be linear. That is, it is the function $Y = X + 0.10$, where Y and X are interresponse times per opportunity and reinforcements per opportunity, respectively. It is apparent from Figure 5 that this single function describes the

linear portions of each of the three empirical curves about as well as any single function could.

Table 3 shows the relative frequencies of occurrence of the 10 classes of reinforced interresponse times, averaged over the first two conditions (1 and 5) in which all 10 classes were reinforced equally often. The table illustrates that there was a close approximation between the relative frequency of occurrence

Fig. 5. The interresponse-times-per-opportunity for 10 classes of reinforced interresponse times extending from 1.0 to 6.0 sec in 0.5-sec intervals, as a function of the corresponding obtained reinforcements per opportunity. The points for the three shortest interresponse times, labelled 1, 2, and 3, and the points for the two next to the longest interresponse times, labelled 8 and 9, are joined; for the sake of clarity, those for the four intermediate interresponse times are not. The presented data are means over the last six days of each condition.

of an interresponse time and the relative reciprocal of the length of that interresponse time. There were, however, some systematic discrepancies: for example, the relative frequencies of occurrence of the two longest interresponse times were always slightly too low. However, in no case did the relative frequency of an interresponse time, averaged over the three subjects, differ by so much as three percentage points from the relative reciprocal of the length of that interresponse time.

Reinforced interresponse times ranging from 1 to 6 sec; Conditions 10 and 11. The percentage of all responses that terminated interresponse times between 1 and 6 sec in duration, in Conditions 10 and 11, ranged from 93 to 96. The following analysis deals only with interresponse times in the reinforced interval.

Table 4 shows the relative frequencies of occurrence of the 10 classes of reinforced interresponse times in Condition 10, which replicated Conditions 1 and 5 but which followed Conditions 7 to 9, in which the reinforced interresponse times ranged from 0.1 to 0.6 sec. Table 4 reveals that the matching-to-relative reciprocal phenomenon was recovered. A comparison of Table 4 and Table 3 reveals the same small systematic deviations from matching: in all cases, the relative frequency of occurrence of the longest interresponse time was too low.

The four left-hand panels of Figure 6 (solid circles) show that the original shape of the interresponse-times-per-opportunity curves in Conditions 1 and 5 also was recovered. That is, the interresponse-times-per-opportunity curves were increasing functions of the lengths of the interresponse times. These four panels also

Table 3

Relative Frequencies of Occurrence of 10 Classes of Equally-reinforced Interresponse Times

Classes of Reinforced Interresponse Times (sec)	Relative Reciprocal of the Length of an Interresponse Time	Relative Frequency of Occurrence of an Interresponse Time over the last 6 Days of Conditions 1 and 5			
		Average	Bird 1	Bird 2	Bird 3
1.0 to 1.5	0.248	0.220	0.279	0.157	0.224
1.5 to 2.0	0.165	0.163	0.157	0.191	0.142
2.0 to 2.5	0.124	0.122	0.102	0.151	0.114
2.5 to 3.0	0.099	0.111	0.097	0.131	0.104
3.0 to 3.5	0.082	0.102	0.093	0.105	0.108
3.5 to 4.0	0.071	0.090	0.085	0.090	0.096
4.0 to 4.5	0.062	0.078	0.075	0.071	0.088
4.5 to 5.0	0.055	0.060	0.059	0.054	0.066
5.0 to 5.5	0.050	0.033	0.033	0.033	0.033
5.5 to 6.0	0.045	0.019	0.021	0.017	0.020

Table 4
Relative Frequencies of Occurrence of 10 Classes of Equally-reinforced Interresponse Times

<i>Classes of Reinforced Interresponse Times (sec)</i>	<i>Relative Reciprocal of the Length of an Interresponse Time</i>	<i>Relative Frequency of Occurrence of an Interresponse Time over the last 6 Days of Condition 10</i>			
		<i>Average</i>	<i>Bird 1</i>	<i>Bird 2</i>	<i>Bird 3</i>
1.0 to 1.5	0.248	0.237	0.244	0.207	0.260
1.5 to 2.0	0.165	0.190	0.185	0.194	0.191
2.0 to 2.5	0.124	0.124	0.143	0.111	0.119
2.5 to 3.0	0.099	0.107	0.129	0.086	0.105
3.0 to 3.5	0.082	0.088	0.083	0.040	0.086
3.5 to 4.0	0.071	0.081	0.066	0.100	0.077
4.0 to 4.5	0.062	0.062	0.057	0.076	0.054
4.5 to 5.0	0.055	0.055	0.048	0.063	0.055
5.0 to 5.5	0.050	0.037	0.030	0.043	0.038
5.5 to 6.0	0.045	0.019	0.015	0.025	0.016

show the corresponding obtained reinforcements-per-opportunity curves. As before, the interresponse-times-per-opportunity curves and the reinforcements-per-opportunity curves were qualitatively similar in shape.

In summary, two results were recovered in Condition 10: the matching-to-relative-reciprocal relationship and the qualitative similarity in the shapes of the interresponse-times-per-opportunity and reinforcements-per-opportunity curves. These relationships were recovered despite the fact that neither obtained in the intervening Conditions 7 to 9, and that a period of five months ensued between Conditions 9 and 10.

The four right-hand panels in Figure 6 present the interresponse-times-per-opportunity curves and reinforcement-per-opportunity curves from Condition 11. In Condition 11, as described earlier, the relative frequencies of reinforcement for the 10 classes of reinforced interresponse times were arranged so that the reinforcements per opportunity for these classes were constant at a value equal to 0.2 (except for the class of longest reinforced interresponse times, for which the reinforcements per opportunity was necessarily equal to 1.0). A comparison of the reinforcements-per-opportunity curves in the left-and-right-hand panels of Figure 6 shows that the reinforcements per opportunity for the shorter interresponse times were greater in Condition 11 than in Condition 10, and that the reinforcements per opportunity for the longer interresponse times (excluding the longest) were smaller in Condition 11 than in Condition 10. A comparison of the corresponding

interresponse-times-per-opportunity curves reveals parallel differences: the interresponse times per opportunity for the shorter interresponse times were greater in Condition 11 than in Condition 10, but the interresponse times per opportunity for the longer interresponse times (except the longest) tended on the average to be slightly smaller in Condition 11 than in Condition 10.

For each subject, flattening the reinforcements-per-opportunity curve narrowed the range of obtained values of interresponse times per opportunity. However, the interresponse-times-per-opportunity curves in Condition 11 were not entirely flat. Whether the U-shaped interresponse-times-per-opportunity curve for Bird 3 would have been recovered subsequent to other experimental manipulations is, of course, not possible to say. But, all three curves definitely were not flat over the longest reinforced interresponse times: the curves began to rise in a region near the seventh-shortest reinforced interresponse time. Presumably, this rise reflects the increase in the reinforcements per opportunity to 1.0 in the longest reinforced interresponse time. The upper bound of the seventh-shortest interresponse time (4.0 to 4.5 sec) was only 1 sec from the lower bound of the longest interresponse time (5.5 to 6.0 sec).

When the reinforcements per opportunity are set equal to a constant value of 0.2, as in Condition 11, the interresponse times per opportunity should not only be constricted to a narrower range, they should also approximately equal 0.3, according to the linear function $Y = X + 0.1$ in Figure 5. The dashed hori-

Fig. 6. The mean interresponse times per opportunity (solid circles) and the mean obtained reinforcements per opportunity (open circles) for the last six days of Condition 10 (the four panels on the left) and of Condition 11 (the four panels on the right). In both of these conditions, the reinforced interresponse times ranged from 1.0 to 6.0 sec in 0.5-sec intervals. The dashed horizontal lines in the righthand panels, *i.e.*, for Condition 11, represent the constant interresponse-times-per-opportunity value of 0.3 which is predicted by the linear function summarizing the data in Figure 5.

zontal lines in the four right-hand panels of Figure 6 correspond to the value of interresponse times per opportunity equal to 0.3. Figure 6 shows that the value of 0.3 compares favorably with the obtained data over the first seven classes of reinforced interresponse times. Indeed, the value of interresponse times per opportunity averaged over all three birds and the first seven classes of reinforced interresponse times was 0.312, which is remarkably close to the computed 0.300. Beyond the seventh class, the interresponse times per opportunity increased, as noted above.

Reinforced interresponse times ranging from 0.1 to 0.6 sec; Conditions 7 to 9. In Conditions 7 to 9, the percentage of all responses that terminated interresponse times between 0.1 and 0.6 sec ranged from 55 to 89. Thus, the percentage of responses that fell in the interval of reinforced interresponse times was reasonably high, but it was smaller than it was when the reinforced interresponse times ranged from 1.0 to 6.0 sec.

The relative-frequency distributions of interresponse times and the interresponse-times-

per-opportunity curves are not presented for Conditions 7 to 9 because by themselves they revealed only a minimal degree of orderliness. In particular, the shapes of the interresponse-times-per-opportunity curves were not at all the same over the three conditions, and neither were the shapes of the relative-frequency distributions of interresponse times. Therefore, the relative frequencies of the interresponse times and the interresponse times per opportunity are presented as functions of corresponding reinforcement parameters, as in Figures 4 and 5 above. Figure 7 shows the relative frequency of occurrence of an interresponse time as a function of the relative frequency of reinforcement of that interresponse time. This function was qualitatively different for the shortest and longest interresponse times. Therefore, the interresponse times were grouped, rather arbitrarily, into those ranging from 0.10 to 0.35 and from 0.35 to 0.60 sec, and the corresponding points appear separately in the left and right columns of Figure 7. Figure 7 shows that the relative frequencies of occurrence of the five longest interresponse times

were monotonically increasing functions of the relative frequencies of reinforcement for those interresponse times, except for the sixth-shortest interresponse time for Bird 3. On the other hand, the relative frequencies of occurrence of the five shortest interresponse times were generally not orderly functions of the relative frequencies of reinforcement for those interresponse times: for Bird 1, the functions for the four shortest interresponse times were monotonically increasing, but for Bird 2, only the functions for the second- and fifth-shortest interresponse times were monotonically increasing. For Bird 3, none of the functions was

monotonically increasing. Figure 7 reveals another functional difference between the five shortest and the five longest interresponse times. That is, for a given relative frequency of reinforcement, there was no systematic relationship between the relative frequencies of occurrence of the five shortest interresponse times and their lengths. However, among the five longest interresponse times, given a particular relative frequency of reinforcement, a shorter interresponse time tended to occur more often than a longer one, for both Bird 1 and Bird 2. However, for Bird 3, this relationship was not obtained.

It can be seen from the arrangement of data points above a relative frequency of reinforcement equal to 0.10 in Figure 7 that the relative frequency of occurrence of an interresponse time did not even remotely approximate the relative reciprocal of its length when all 10 interresponse-time classes were reinforced equally often: the relative reciprocal of the interresponse times did not even describe the ordinal rankings of the relative frequencies of occurrence of the interresponse times.

Figure 8 shows the interresponse times per opportunity plotted against the reinforcements per opportunity. The data points in Figure 8 can barely be said to form any functions at all, so highly variable are they. Perhaps, one could say that the functions are unimodal with their modes located somewhere between 0.2 and 0.4 on the X-axis and between 0.3 and 0.7 on the Y-axis, and that the left-hand asymptotes are very near to 0.0, but that the right-hand asymptotes vary from approximately 0.05 to 0.25. The functions, variable as they are, do not resemble the corresponding ones in Figure 5 for reinforced interresponse times ranging from 1.0 to 6.0 sec.

DISCUSSION

The relationships obtained here depended in large measure on the interval of reinforced interresponse times, *i.e.*, on whether the reinforced interresponse times ranged from 0.1 to 0.6 sec or from 1.0 to 6.0 sec. Therefore, the two sets of data are discussed separately.

Reinforced Interresponse Times Ranging from 1.0 to 6.0 Sec

Relative frequencies of reinforcement. When viewed at first glance in terms of the rel-

Fig. 7. The relative frequencies of occurrence of 10 classes of reinforced interresponse times extending from 0.1 to 0.6 sec in 0.05-sec intervals, as a function of the corresponding obtained relative frequencies of reinforcement. The left and right columns are for the five shortest interresponse times, labelled 1, 2, 3, 4, and 5, and for the five longest interresponse times, labelled 6, 7, 8, 9, and 10, respectively. The presented data are means over the last six days of each condition.

Fig. 8. The interresponse-times-per-opportunity for 10 classes of reinforced interresponse times extending from 0.1 to 0.6 sec in 0.5-sec intervals, as a function of the corresponding obtained reinforcements per opportunity. The presented data are means over the last six days of each condition.

ative-frequency distributions of interresponse times, the effects of the changes in the relative frequencies of reinforcement for the various interresponse times may not seem overwhelmingly great (Figure 2). However, it must be recalled that the variation in the relative frequency of reinforcement for any given interresponse time was never more than 0.2, and was in fact vanishingly small for the several classes of interresponse times near the middle of the interval of reinforced interresponse times (see Figure 1). Furthermore, the lower and upper bounds of this interval were fixed. Both of these procedural details imposed strong restraints on the variations in the relative-frequency distributions of interresponse times. Therefore, one probably should not

conclude from the comparatively small variations in the relative-frequency distributions of interresponse times that control by the relative frequency of reinforcement was weak. Indeed, a rather strong case could be made for the opposite view, because a change of only 0.05 to 0.10 in the relative frequency of reinforcement for an interresponse time was sufficient to change the relative frequency of occurrence of that interresponse time (see Figure 4).

The relative length of an interresponse time also was seen to determine the relative frequency of occurrence of that interresponse time. The joint effect of the relative length of an interresponse time and the relative frequency of reinforcement for that interresponse time were displayed in Figure 4. In the special case for which all 10 classes of interresponse times were reinforced equally often, the relative frequency of occurrence of an interresponse time closely approximated the relative reciprocal of its length.

Reinforcements per opportunity. The interresponse-times-per-opportunity curves were generally of the same shape as the reinforcements-per-opportunity curves, and when the former were plotted against the latter, a function emerged that was linear over a restricted interval between a point near the origin and a point at which the curve asymptoted. Over this interval, the correlation between interresponse times per opportunity and reinforcements per opportunity ranged from 0.81 to 0.91. The linear relationship was well summarized by the function $Y = X + 0.10$, where X ranges from 0.05 to between 0.35 and 0.45, depending on the subject, Y is the predicted interresponse times per opportunity, and X is the reinforcements per opportunity.

It should carefully be noted that the extent to which this linear function describes the relationship between interresponse times per opportunity and reinforcements per opportunity in a wide variety of synthetic variable-interval schedules remains untested. Specifically, the range of interresponse times for which it holds is unknown, and the general class of reinforcements-per-opportunity functions for which it holds is also unknown. In regard to the latter, note in particular that each reinforcements-per-opportunity function in the present experiment either was an increasing or a constant function of interresponse-time duration. No decreasing reinforcements-per-opportunity

curve was used here because of anticipated practical difficulties: with a sharply decreasing reinforcements-per-opportunity function, the resulting proportion of responses terminating the longer interresponse times might well be too few, in the present context, to maintain an adequate total number of reinforcements per hour.

Some earlier data bear on this same issue of the generality of the linear function obtained here between interresponse times per opportunity and reinforcements per opportunity. The same function, defined over approximately the same restricted interval as in the present experiment, appears to summarize the relationship between interresponse times per opportunity and reinforcements per opportunity in an experiment in which thirsty rats' bar-pressing behavior was reinforced by access to water according to ordinary variable-interval schedules (see the data in Figure 1 in Reynolds and McLeod, 1970). The same linear function summarizes their data despite the difference in the species (rats and pigeons), the reinforcers (water and grain), bin widths in which interresponse times were recorded (1.0 sec and 0.5 sec) and the absolute lengths of the interresponse times (0 to 15 sec and 1 to 6 sec). Also, small values of interresponse times per opportunity there corresponded to long interresponse times, while here they corresponded to short ones. All of these comparisons would appear to confirm that this linear function has wide applicability. However, it is possible that a strong correlation between interresponse times per opportunity and reinforcements per opportunity has different meanings in ordinary and synthetic variable-interval schedules. Any correlation between responding and reinforcement in an ordinary variable-interval schedule may depend at least in part on the interaction between responding and reinforcement that exists there, but in the present synthetic variable-interval schedule, there is no such interaction. Thus, it is possible that the same correlation arises for different reasons in the two kinds of variable-interval schedule. The resolution of this issue plainly is an interesting problem for future research.

Comparisons with other concurrent and synthetic schedules. The relationship between the relative frequency of occurrence of an interresponse time and the relative frequency of reinforcement of that interresponse time was

not the same here as in previous one-key and two-key concurrent schedules of reinforcement for two interresponse times. This fact can be seen because the relative reciprocals of the lengths of the shortest and of the next-to-the-shortest interresponse times in the present synthetic variable-interval schedule were approximately equal to the relative reciprocals of the longer interresponse times in the previous concurrent variable-interval variable-interval schedules of reinforcement for two interresponse times used by Shimp (1968), Staddon (1968), and Moffitt and Shimp (1971). Accordingly, one may ask if the relative frequency of occurrence of the shortest interresponse time, and of the next-to-the-shortest interresponse time, depended here on the corresponding relative frequencies of reinforcement in the same way as the relative frequency of occurrence of the longer interresponse time depended on its relative frequency of reinforcement in these previous two interresponse-time experiments. The briefest comparison of the curves in Figure 4 with the corresponding data from the earlier experiments convinces one that the functions are not the same (see Figure 3 in Moffitt and Shimp, 1971). Stated differently, knowing both the relative frequency of reinforcement for a class of interresponse times, and the relative reciprocal of the length of the interresponse time is not always enough to allow one to predict the relative frequency of occurrence of that interresponse time. It is also easy to see that the way in which the interresponse times per opportunity depends on the corresponding reinforcements per opportunity is not the same in the present synthetic variable-interval as in the previous concurrent variable-interval variable-interval schedule for two interresponse times.

The matching-to-relative-reciprocal relationship here is the same as that obtained previously in one-key and two-key concurrent variable-interval variable-interval schedules of reinforcement for two interresponse times (Experiment I in Shimp, 1969b, 1971; Moffitt and Shimp, 1971) and in two-key concurrent variable-interval variable-interval schedules of reinforcement in which the time intervals were black-outs instead of interresponse times (Chung and Herrnstein, 1967; Experiment II in Shimp, 1969b; Experiments I and II in Herbert, 1970). One would hope that future theories for concurrent operant behaviors

would conceptually unify the apparently similar results from experiments on interresponse times and experiments on choice behavior. At the present time, little can be said except that parallel outcomes in these two classes of experiment suggest that a common underlying mechanism may be at work in both.

The linear function $Y = X + 0.10$ obtained here between interresponse times per opportunity and reinforcements per opportunity is intriguingly similar to the matching function $Y = X$, obtained in two-key and three-key concurrent variable-interval schedules of reinforcement, between the relative frequency of responding on a key, (Y), and the relative frequency of reinforcement for responding on that key, (X), (Herrnstein, 1961; Reynolds, 1963). One would hope that in the future, theories of concurrent operant behaviors would manage conceptually to unify these similar functions. It is not immediately clear how any existing theory (Herrnstein, 1970; Lander and Irwin, 1968; Shimp, 1969a) might achieve this unification.

In short, one relationship, that between the relative frequency of occurrence of an interresponse time and its relative length, was the same here as in previous two interresponse-time experiments. However, relationships between relative frequencies of responding and relative frequencies of reinforcement, and between interresponse times per opportunity and reinforcements per opportunity, were not the same here as in the previous experiments. At the present time, it is impossible to pinpoint which procedural differences contribute to these functional differences.

Reinforced Interresponse Times Ranging from 0.1 to 0.6 Sec

There did appear to be some relationships, although weak ones, between responding and reinforcement, particularly for the five longest interresponse times, *i.e.*, for those in the interval from 0.35 to 0.60 sec. Among these interresponse times, the relative frequencies of occurrence tended to be monotonically increasing functions of the corresponding relative frequencies of reinforcement, and for two of three birds, the relative frequency of occurrence of a shorter interresponse time tended to be greater than the relative frequency of occurrence of a longer one, for a given relative frequency of reinforcement. There also was a

relationship, albeit a crude one, between interresponse times per opportunity and reinforcement per opportunity.

None of the functions obtained here when the reinforced interresponse times extended from 0.1 to 0.6 sec was the same as any obtained previously, either in the present experiment when the interval of reinforced interresponse times extended from 1.0 to 6.0 sec, or in previous experiments with concurrent schedules of reinforcement for two classes of interresponse times. In particular, the relative frequency of occurrence of an interresponse time did not approximately equal the relative reciprocal of the length of that interresponse time, when all were reinforced equally often. Nor was the interresponse times per opportunity a linear function of the reinforcements per opportunity. The present results are in agreement with earlier data indicating that relatively short interresponse times conform to different laws than do longer ones (*e.g.*, Blough, 1963, 1966; Ray and Sidman, 1970). However, one clearly may not conclude that these shorter interresponse times are not susceptible to any experimental control at all.

Discussion of Independent and Dependent Variables

The present results bear on the issue of which independent and dependent variables are appropriate in the experimental analysis of operant behavior in general and of interresponse times in particular. Anger (1956) recommended the use of the interresponse-times-per-opportunity dependent variable for interrelated empirical and theoretical reasons. Stated briefly, these reasons were that both he and Mueller (1950) obtained flat interresponse-times-per-opportunity curves early in training with rats on interval schedules of reinforcement, and that such empirical curves follow immediately from the intuitively plausible theoretical assumption that a subject chooses, every brief period of time, whether or not to respond. This way of responding sometimes is described as "go, no-go" behavior. This assumption appeals to those who prefer to regard the time since the last response as a stimulus. According to this view, an organism in the "presence" of such a stimulus would have some conditional probability of responding, and clearly, the interresponse times per opportunity would be a natural estimate of that

probability (see for example, Reynolds and McLeod, 1970). There are more opportunities for shorter interresponse times than for longer ones when an organism is responding in this "go, no-go" fashion. A flat interresponse-times-per-opportunity curve would be obtained from a subject whose behavior was governed by this "go, no-go" principle, if the probability of a "go, no-go" fashion. A flat interresponse-times-Anger's and Mueller's data indicate that this "go, no-go" assumption works quite well for initial behavior on first exposure to a schedule, and one's desire for parsimony may lead to the adoption of the same assumption for steady-state behavior as well. (Also see Bush and Mosteller, 1955, and Estes, 1950, for additional reasons for assuming an underlying "go, no-go" process, but see Figure 9-2 in Weiss, 1970, for evidence that the interresponse-times-per-opportunity curve may not always be flat at the beginning of training.) One may occasionally find the implication, perhaps implicit, that the status of the "go, no-go" assumption is that of a well-established principle. For example, note the following comments from Reynolds and McLeod (1970, page 99), who were writing of Anger's work and of why he chose the interresponse-times-per-opportunity variable: "He chose interresponse times per opportunity as the dependent variable rather than raw frequency because the latter distribution fails to take into account the fact that there are a great many more opportunities to emit short than long interresponse times: any response terminating a short interresponse time removes the opportunity for a response terminating a longer interresponse time."

The present results agree with, indeed even strengthen, this prevailing view that the interresponse-times-per-opportunity variable is an important dependent variable, because it here entered into a lawful relationship with an independent variable, namely, the reinforcements per opportunity. The linear function between these two variables provides some empirical justification for the current general tendency to use interresponse times per opportunity to describe steady-state interresponse-time distributions in interval schedules. Recall that previous empirical justification for this practice rested largely upon interresponse-time distributions obtained at the very beginning of training.

However, other features of the present re-

sults imply that the relative-frequency distribution of interresponse times is an important dependent variable. In particular, the matching-to-relative-reciprocal phenomenon requires the relative-frequency distribution for its expression.

The relative-frequency distribution of interresponse times has, like the interresponse times per opportunity, a corresponding theoretical model. A preference for this model would lead to the adoption of the relative-frequency distribution of interresponse times as a favored dependent variable in the same way that preference for the "go, no-go" model leads to the adoption of interresponse times per opportunity. The theoretical assumption appropriate to a preference for the relative-frequency distribution of interresponse times is that an organism chooses how long to wait before the next response, *i.e.*, that it chooses among interresponse times. This view might interpret different interresponse times as consisting of different "waiting behaviors". According to this view, there are as many opportunities for longer as for shorter interresponse times, if the subject immediately upon terminating one interresponse time, chooses how long to wait before the next response. With rare exceptions (see for example, Shimp, 1969*a, b*) this possible view has not been seriously entertained. However, any lawful relationship involving the relative-frequency distribution of interresponse times, such as the matching-to-relative-reciprocal relationship, indirectly tends to support this view, just as any lawful relationship involving interresponse times per opportunity tends to support the "go, no-go" assumption.

At the present time, since the relative-frequency distribution of interresponse times and the interresponse times per opportunity are both needed to supply an adequate description of the empirical relationships obtained in the present experiment, it would seem advisable to hold in abeyance a decision concerning the correctness of either corresponding theoretical model. Indeed, it seems possible that sometimes one, and sometimes the other, theoretical model will better describe any given set of data. Therefore, one might be prepared to employ whichever model is suitable for a given set of data, rather than necessarily to assume, as tradition would have it, that there are more opportunities for long than for short interre-

sponse times, and that interresponse times per opportunity are more sensitive, less biased, or in any other way, better, measures of long pausing behavior than are the relative frequencies of occurrence of long interresponse times.

The reader will note that a discussion parallel to the one above comparing the usefulness of different dependent variables could be provided for the different independent variables. Suffice it here to note that at the present time, both the relative-frequency distribution of reinforcements for different interresponse times and the reinforcements-per-opportunity distribution are needed for a complete account of the lawful relationships obtained in the present experiment.

CONCLUSION

Three of the most important contributions of Anger's early work on variable-interval and synthetic variable-interval schedules (Anger, 1954, 1956) consisted of directing attention to: (1) the vital role in the analysis of response rate played by the relative-frequency distribution of reinforcements for different classes of interresponse times; (2) interresponse times per opportunity as a useful dependent variable, and, (3) the unavoidable interaction between responding and reinforcement in classical reinforcement schedules. The present experiment relates to all three of these points. Regarding the first two points, it was found that both the relative-frequency distribution of reinforcements for different classes of interresponse times and the interresponse times per opportunity entered into various lawful relationships. However, it was emphasized here that these two variables are not the *only* appropriate independent and dependent variables: the relative-frequency distribution of interresponse times and the reinforcements per opportunity both were necessary for a description of the orderly relationships obtained here. One can scarcely doubt that these relationships will prove valuable in guiding the development of a unified theory for concurrent operants embracing both choice behavior and response rate, particularly since some of the relations obtained here bear more than a passing resemblance to those obtained in choice situations. Previous attempts to develop a unified theory for discrete-trials behavior, choice behavior, and free responding, have

met with only partial success (Herrnstein, 1970; Jenkins, 1970; Lander and Irwin, 1968; Logan and Ferraro, 1970; Norman, 1966; Shimp, 1969a) perhaps due in some measure to the previous lack of equivalent empirical relationships in these situations.

The present experiment also bears on the third of Anger's contributions listed above. The presence of an unavoidable interaction between responding and reinforcement in classical schedules has made some investigators adopt seemingly pessimistic views of how far an analysis of relationships between responding and reinforcement may lead us toward a genuine understanding of behavior maintained by schedules of reinforcement (see, for example, Blough and Blough, 1968; Reynolds and McLeod, 1970). The present results indicate the advisability of looking for these relationships in contexts in which the troublesome interaction is removed: classical reinforcement schedules simply may not be appropriate contexts in which to search for some of the laws governing the behavior they maintain.

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