EFFECTS OF RATE OF REINFORCEMENT-TIME UPON CONCURRENT OPERANT PERFORMANCE¹

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Three experiments were conducted to investigate the theoretical reduction of rate and duration of reinforcement to their product, rate of reinforcement-time, under concurrent chain schedules. In Exp. I, rate of reinforcement-time was varied by varying rate of reinforcement delivery, holding duration of reinforcement availability constant; in Exp. II, rate of reinforcement-time was varied by holding rate of reinforcement delivery constant and varying duration of reinforcement availability; in Exp. III, rate of reinforcement-time was held constant by varying both rate and duration of reinforcement simultaneously and inversely. For all three experiments, both relative rate of responding and relative time spent in the initial link were found to match approximately the relative rate of reinforcement-time arranged in the terminal link. These data were interpreted as support for the notion that rate and duration of reinforcement may be functionally equivalent and reducible to a single variable, rate of reinforcement-time.

Under concurrent schedules of reinforcement it has been repeatedly found that the rate of responding on a given key is proportional to the rate of reinforcements delivered for that key (*e.g.*, Autor, 1960; Findley, 1958; Herrnstein, 1961, 1964; and Reynolds, 1963). This proportionality between rates of responding and reinforcement has been observed under a variety of procedures for the arrangement of concurrent schedules (two-key, changeover-key, and concurrent chain schedules). A similar, but less direct, relationship between rate of responding and duration of reinforcement has been observed under a two-key concurrent schedules procedure (Catania, 1963).

In view of the similarity of the effects of

rate and duration of reinforcement, Premack (1965) suggested that the two may be reducible to a single variable: total reinforcement time, or rate of reinforcement-time. Neuringer (1967), in an investigation in which reinforcement duration was varied and rate of reinforcement was held constant, found that relative choices approximately matched relative total access to reinforcement. Neuringer defined relative total access to reinforcement as the product of number of reinforcements delivered on a key and the duration of the reinforcements scheduled for that key.

Rate of reinforcement-time for a given key can be defined as the product of the rate of reinforcement and the duration of reinforcement delivered for that key. Thus, if the rate of reinforcement (r) were 120 rft/hr and each reinforcement were of 4.5 sec duration (d), the rate of reinforcement-time ($r \times d = t$) would be 540 sec/hr, or an average of 9 sec/min. The relative rate of reinforcement-time for a given key would be the rate of reinforcement-time for that key (t_1) divided by the sum of t_1 and the rate of reinforcement-time for the other key (t_2):

$$\frac{t_1}{t_1 + t_2}$$

The following three experiments were designed to investigate the comparability of the

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effects of rate and duration of reinforcement and the possibility that both variables may be reducible to rate of reinforcement-time under a concurrent chain schedules procedure. In Exp. I, differing rates of reinforcement-time were produced in the two terminal links of the schedule by varying the rate of reinforcement delivery and holding the duration of each reinforcement presentation constant. Experiment II investigated the effects of rates of reinforcement-time identical to those in Exp. I. In Exp. II, however, differing rates of reinforcement-time in the two terminal links of the schedules were produced by holding the rate of reinforcement delivery constant and equal for the two links and varying the duration of reinforcement presentation. In Exp. III, rate of reinforcement-time was held at a constant and equal value for the two terminal links of the schedules by simultaneously and inversely varying both the rate of reinforcement delivery and the duration of reinforcement availability in the two terminal links. Thus, Exp. III provided a more direct test of the possibility that rate and duration of reinforcement may both be reducible to their product, rate of reinforcement-time.

METHOD

Subjects

Three adult White Carneaux pigeons, maintained at approximately 80% of their free-feeding body weights, served in each experiment. All nine subjects had an experimental history of responding under interval schedules of reinforcement, but none had prior experience under concurrent schedules.

Apparatus

One of three identical standard LeHigh Valley Electronics Model 1519A pigeon test chambers was employed in each of the three experiments. White masking noise was provided to the individual chamber speakers by a Grason-Stadler Model 455c white noise generator. Experimental conditions were arranged and responses were recorded automatically by electromechanical circuitry. All variable-interval (VI) schedules employed constant-probability interval distributions generated from previously randomized terms (Fleshler and Hoffman, 1962).

Procedure

In preliminary training sessions, all birds initially received 4.5 sec access to grain for responding on both keys (available in isolation and on alternate days) according to a VI 60-sec schedule of reinforcement. The key for which reinforcements were delivered during a particular session was transilluminated by either a red light (left key) or a green light (right key). When a stable rate of responding was associated with both keys, the schedule of reinforcement in effect for the two keys was changed from the single VI 60-sec schedule to a chain VI 60-sec VI 30-sec schedule. As before, the key for which reinforcements were delivered during the session was alternated daily and the inoperative key was darkened. Under the chain schedule, responding in the presence of S_2 (white for both keys) in the initial link of the chain was reinforced by a change in the color of the key from S_2 to S_1 (red or green, for the left and right keys, respectively) according to a VI 60-sec schedule. In the presence of S_1 in the terminal link, grain was made available for 4.5 sec according to a VI 30-sec schedule. When responding in S_2 was stable for both keys, the two keys were made concurrently available and the experiments proper were begun.

For these two preliminary phases, as well as in the following experimental phases, all sessions consisted of 30 presentations of the grain hopper. Similarly, the data for each phase were regarded stable when the two three-day submeans of rates of responding differed by no more than 10% of the overall six-day means for both the left and the right key, and a minimum of 14 daily sessions had been conducted.

The concurrent chain schedules procedure employed in all three experiments conformed to the basic procedure described by Autor (1960), Herrnstein (1964), and Killeen (1968a, 1968b). The procedure consisted of two states, an initial choice link and a terminal reinforcement link, which alternated regularly. In the initial link, responses changed the color of the keys from S_2 (white for both keys) to S_1 (red or green, for the left and right keys, respectively) according to concurrent VI 60-sec schedules, signaling access into one of the terminal links. As the stimulus for one key was changed from S_2 to S_1 , the other key was darkened and made inoperative. Reinforcements were delivered at

different rates and for different durations in the respective terminal links. Both keys again became concurrently available after a presentation of the grain hopper in one of the terminal links. If a change from S_2 to S_1 became available for a given key but was not collected in a cycle, the change became available for the first response to that key in the next cycle when the two keys again became concurrently available.

The rate of reinforcement (r), duration of reinforcement (d), and resulting rate of reinforcement-time (t) arranged for the various phases of Exp. I, II, and III, and the average number of sessions conducted under those phases, are shown in Table 1. As a VI 60-sec schedule was always in effect for both keys in the initial links, only the conditions in effect for the two keys in the terminal links are shown.

RESULTS

Figures 1 and 2 show the relative rate of left-key responding in the initial link of the schedule (S_2) under the four phases of Exp. I and II, respectively. Data are means of the relative rates of responding for the left key in the initial link for a subject under the last six days of an experimental phase. For both Exp. I and II, the relative rates of reinforcement-time for the left key in the terminal link

were 0.50, 0.33, 0.67, and 0.50 under the four experimental phases, respectively. As can be seen in Fig. 1 and 2, the relative rate of responding on a key in the initial link tended to match the relative rate of reinforcement-time arranged in the terminal link for that key when the data are averaged across birds.

For the present two experiments, as well as for Exp. III, the time spent in the presence of S_2 for a given key was defined as the time elapsing between the first response to S_2 on that key and a subsequent response to S_2 on

Fig. 1. Relative rate of responding in the initial link (S_2) for the left keys under the four phases of Exp. I.

Table 1
Order and Duration of Experimental Conditions

Mean Sessions	Left Key			Right Key		
	r (rft/hr)	d (sec)	t (sec/min)	r (rft/hr)	d (sec)	t (sec/min)
EXPERIMENT I						
63	120	4.5	9	120	4.5	9
28	80	4.5	6	160	4.5	12
35	160	4.5	12	80	4.5	6
23	120	4.5	9	120	4.5	9
EXPERIMENT II						
71	120	4.5	9	120	4.5	9
35	120	3.0	6	120	6.0	12
36	120	6.0	12	120	3.0	6
32	120	4.5	9	120	4.5	9
EXPERIMENT III						
61	120	4.5	9	120	4.5	9
21	180	3.0	9	90	6.0	9
20	90	6.0	9	180	3.0	9
20	120	4.5	9	120	4.5	9

Fig. 2. Relative rate of responding in the initial link (S_2) for the left keys under the four phases of Exp. II.

Fig. 3. Relative time spent in the presence of S_2 for the left keys under the four phases of Exp. I.

the other key. The time elapsing between the first presentation of S_2 in each cycle and the first response to either key (pause time) was excluded from analysis, as it would be impossible to ascertain to which key that time should be assigned. Thus, the total time for the two keys taken together (the denominator for the computation of the relative time spent in the presence of S_2) was, for all subjects, less than the average 1800 sec for which S_2 was available during the session.

The relative time spent in the presence of S_2 for the left key is shown in Fig. 3 and 4 for the four phases of Exp. I and II, respectively. Data are means of the relative times spent in the presence of S_2 for the left key for a subject under the last six days of an experimental phase. Figures 3 and 4 indicate that when the data were averaged across all birds, the relative time spent in the presence of a given key in the initial link tended to match the relative rate of reinforcement-time arranged in the terminal link for that key. As can be seen by comparing Fig. 1 and 2 with Fig. 3 and 4, relative rate of responding clearly tended to covary with relative time spent in the initial link.

For Exp. III, Fig. 5 shows the relative rate of responding in S_2 for the left key under the five experimental phases. Data are means of the relative rates of responding for the left key in the initial link for a subject under the last six days of each experimental phase. Although there were substantial changes in both the rate and the duration of reinforcement presentation, under the initial four phases of Exp. III, the relative rate of reinforcement-

time in the terminal link was always 0.50. As Fig. 5 indicates, there was little change in the relative rate of responding under these initial four phases. Accordingly, essentially two alternatives were possible: (1) since the relative rates of responding did match the relative rates of reinforcement time, although they did not systematically change when either rate or duration of reinforcement was changed, these data support Premack's (1965) contention that both rate and duration of reinforcement are reducible to their product; or (2) all three subjects were insensitive to the variations of rate and duration of reinforcement under these four experimental phases. In order to vitiate the second alternative, an additional fifth experimental phase was undertaken for all sub-

Fig. 4. Relative time spent in the presence of S_2 for the left keys under the four phases of Exp. II.

Table 2
Conditions and Duration of Fifth Phase of Experiment III

Sessions	Left Key			Right Key		
	<i>r</i> (rft/hr)	<i>d</i> (sec)	<i>t</i> (sec/min)	<i>r</i> (rft/hr)	<i>d</i> (sec)	<i>t</i> (sec/min)
P-1776						
48	80	4.5	6	160	4.5	12
P-4983						
36	120	6.0	12	120	3.0	6
P-1400						
26	120	3.0	6	120	6.0	12

jects. The details of this additional phase are shown in Table 2. The fifth phase of Exp. III involved the replication of portions of Exp. I (P-1776) and Exp. II (P-4983 and P-1400). In contrast to the previous four phases, the data from the fifth phase are within the range of those from the corresponding phases of Exp. I and II. Thus, the data from the fifth phase of Exp. III, in addition to replicating portions of Exp. I and II, also indicated the sensitivity of these subjects to variations in rate and duration of reinforcement.

The relative time spent in the presence of S_2 for the left key is shown in Fig. 6 for the five phases of Exp. III. Data are means of the relative times spent in the presence of S_2 for the left key for a subject under the last six days of an experimental phase. As was the case for the relative rate of responding, the relative time spent in the initial link remained relatively unchanged under the initial four phases

of the experiment in which the relative rate of reinforcement-time remained unchanged. Similarly, the relative time spent in S_2 tended to match the relative rate of reinforcement-time arranged in the terminal links under the fifth phase of Exp. III, replicating portions of Exp. I and II. As was the case for the preceding two experiments, comparison of Fig. 5 and 6 again clearly shows the covariance of the relative rate of responding and the relative time spent in the initial link.

DISCUSSION

Premack (1965) suggested: "If, in fact, rate and duration prove to yield comparable functions, it would be additionally desirable to reduce both cases to the same variable. . . *i.e.*, the rate by duration product (p. 153)." In Exp. I and II the effects of the same values of the rate by duration product, rate of reinforce-

Fig. 5. Relative rate of responding in the initial link (S_2) for the left keys under the five phases of Exp. III.

Fig. 6. Relative time spent in the presence of S_2 for the left keys under the five phases of Exp. III.

ment-time, were found to be comparable, offering indirect evidence for the validity of Premack's notions. More direct evidence for the reduction of rate and duration of reinforcement to their product was offered by the data from Exp. III.

In Exp. III, there was a slight tendency for both relative rates of responding and relative time spent in the initial link to vary more directly with relative rates of reinforcement in the terminal link than with relative duration of reinforcement in the terminal link. This tendency was consonant with the generally greater sensitivity (better match) of relative responding and time spent in the initial link to relative rate of reinforcement in the terminal link (Exp. I) than to relative duration of reinforcement in the terminal link (Exp. II). The data from these three experiments, when taken together, do support Premack's (1965) notion that both rate and duration of reinforcement are comparable methods of distributing a block of more probable responding (reinforcement) across the session under concurrent schedules of reinforcement.

Another interesting finding is the covariance of relative rate of responding and relative time spent. Inasmuch as these were nearly the same under all conditions of the three experiments, it is possible that the match between relative rate of responding and relative rate and/or duration of reinforcement is a consequence of the allocation of time and the maintenance of a relatively constant local rate of responding (*cf.*, Catania, 1966; Baum and Rachlin, 1969). While this conclusion would follow simply from a division of number of responses emitted on a key by the actual time spent in the presence of that key, it is possible, as Shimp (1969) commented, that such overall rates do not accurately reflect the behavior that occurs. Certainly more research is necessary to elucidate this point, as well as to extend the range of rates and durations of

reinforcement for which Premack's (1965) notions are valid.

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