Rates of concurrent responses and reinforcer duration*

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Rats were rewarded concurrently, at equal frequencies, for pushes at the doors in front of two reinforcement magazines. The duration of the reinforcer given at one magazine was constant, while the reinforcer duration at the other magazine was changed every six sessions. For three rats the constant reinforcer was 3 sec, and for three other rats the constant reinforcer was 1 sec. For all these animals the duration of the alternative reinforcer was varied between 1 and 5 sec. Rate of response at the magazine that delivered the constant reinforcer duration was found to vary inversely with the duration of the reinforcer obtained at the alternative magazine. The matching of relative response rate to relative reinforcer duration was poor, and the results are attributed partly to the general rate-suppressing effects of long reinforcer durations.

If a single response is reinforced with a given frequency of reinforcement in stimulus condition S1 and with a different frequency of reinforcement in an alternative stimulus condition, S2, the rate of response in S1 appears to be controlled by the relative frequency of reinforcement in S1 compared to S2. This effect, which can be reliably produced under free-operant conditioning procedures, has been termed "behavioral contrast" (Reynolds, 1961a, b, c; Catania, 1963a; Pliskoff, Shull, & Gollub, 1968; O'Brien, 1968; Williams, 1965). "Relative frequency" or "relative rate" is defined as the absolute frequency in one condition divided by the sum of the frequencies in both conditions.

The multiple schedule employed by Reynolds for investigating behavioral contrast involved visual or auditory discrimination, with fixed alternation of reinforcement conditions. Another procedure which allows for the assessment of the difference between two conditions of reinforcement has been developed by Findley (1958), Herrnstein (1961), and Catania (1963b) using pigeons. In this procedure two classes of key peck, Ra and Rb, were reinforced concurrently. Catania (1963a) found that when one response, Ra, was reinforced more frequently than Rb, the rate of Ra seemed to be controlled by the relative frequency of reinforcement of Ra. Rachlin & Baum (1969) have suggested that the variable, "duration of reinforcer," acts in the same way. In their experiment, pecks on two keys were concurrently reinforced in identical variable-interval (VI)

schedules. Pecks on one key always produced access to the feeder for a constant period, while pecks at the other key produced reinforcers whose duration varied. The availability of reinforcement at the latter key was signaled by key illumination. The rate of response at the illuminated key producing varied durations of reinforcer remained very low and did not change during the experiment. The rate of response on the unsignaled key varied inversely with the duration of the signaled reinforcers. Catania (1963b) had previously used different pairs of reinforcer durations for two unsignaled keys, with the two durations in each pair always adding to the same value. In this case, the relative rate of each response approximated the relative duration of the reinforcer produced by the response.

These two results, the matching of relative rate of response to relative duration of its reinforcers or to the relative frequency of its reinforcements and the dependence of absolute response rate on the parameters of an alternative reinforcement condition, have considerable importance in quantitative accounts of the relation between response rates, choice, and reinforcement characteristics (Catania, 1963a, 1969; Premack, 1965; Shimp, 1969).

The present experiment attempted to demonstrate that the quantitative relationships established by Catania (1963b) and Rachlin & Baum (1969) in pigeons under a concurrent reinforcement schedule also applied to rats. The basic design of the experiment followed that of Rachlin & Baum (1969), in that the duration of the reinforcers produced by one of the responses was held constant, while the duration of reinforcer produced by the other response was systematically varied. No specific measures were taken to ensure that rates of response on the two

manipulanda were independent, but it was hoped that variation in the absolute rate of the response which produced a constant duration of reinforcer would give some indication of the sensitivity of the response to relative reinforcer duration.

The association between a manipulandum and its assigned reinforcer duration was maximized by using a different magazine for each of the two reward duration. The responses required involved pushing Plexiglas doors placed in front of each reinforcer magazine.

SUBJECTS

Six male Long-Evans rats were about 3 months old at the start of training. They were maintained on a 22-h food-deprivation regimen throughout the experiment, with each rat being allowed to eat two Standard Purina Rat Chow pellets after the daily session.

APPARATUS

One wall of the experimental chamber contained two Plexiglas doors, 50 mm high and 38 mm wide, suspended from horizontal hinges at the top and spaced 76 mm apart. The bottoms of the doors and the metal platforms that extended behind them were at the same level as the floor of the chamber. A hole, 13 mm in diam, was drilled in the platform behind each door. A 16% sucrose solution could be pumped from a reservoir in a horizontal jet 7 mm below the hole. The rats could lick at this solution only by inserting their tongues through the hole while the pump was on. Excess solution ran back into the reservoir, and thus the duration of access to the sucrose solution could be limited to the period for which the pump was on. The period was defined as "duration of the reinforcer." The doors to the reinforcement magazine had to be pushed back about 13 mm to uncover the holes, and a response was defined as a 6-mm displacement of a door. The displacement and force (.13 N) needed to record a response were carefully matched for the two doors, and an identical 6-W light was mounted behind each door. The experimental chamber was housed in a sound deadened cupboard and ventilated by a fan.

PROCEDURE
Pretraining

Throughout the experiment daily sessions lasted for 40 min. For the first three sessions only, the rats were 22 h deprived of water as well as food. During the first two sessions the doors were fastened back and the pumps operated continuously, so that the rats had free access to sucrose solution at both magazines. For the next two sessions, responses on either door were reinforced on a training schedule. On the schedule and

Table 1
The Sequence of Changes in Reinforcer Duration

S1, S5, S6		S2, S3, S4		
Left door reinforcer (seconds)	Right door reinforcer (seconds)	Left door reinforcer (seconds)	Right door reinforcer (seconds)	Number of sessions
3	3	3	3	10
1	3	1	3	6
4	3	1	5	6
2	3	1	2	6
5	3	1	4	6
3	3	1	1	6
3	1	3	1	15
3	4	5	1	6
3	2	2	1	6
3	5	4	1	6
3	3	1	1	6

Table 2
Responses per Minute on the Doors Producing Constant (C) or Varied (V) Reinforcer Duration, and Relative Response Rate on the Door with Constant Reinforcer Duration (C), for Each Pair of Reinforcer Durations (Experiment 1).

Reinforcer durations (seconds)	Means for three rats			Rat S2 (Rat S1)			Rat S3 (Rat S5)			Rat S4 (Rat S6)		
	Abs.	Rate	Rel. Rate	Abs.	Rate	Rel. Rate	Abs.	Rate	Rel. Rate	Abs.	Rate	Rel. Rate
C:V	C	V	C	C	V	C	C	V	C	C	V	C
1:1	30.4	26.8	.533	28.8	36.4	.442	38.4	22.3	.633	24.1	21.8	.525
1:2	22.1	28.2	.444	25.2	39.6	.389	26.8	27.3	.495	14.4	17.7	.449
1:3	21.1	23.4	.472	19.8	21.3	.482	27.6	29.9	.480	15.8	19.1	.453
1:4	17.9	26.1	.405	19.4	29.4	.398	20.9	27.6	.431	13.4	21.3	.386
1:5	13.1	21.0	.381	15.4	26.0	.372	15.2	21.0	.420	8.7	16.1	.351
(3:1)	24.5	17.4	.589	19.5	16.9	.536	24.4	20.0	.550	32.5	15.2	.681
(3:2)	22.3	15.4	.592	22.5	14.7	.605	21.5	14.9	.591	22.8	16.5	.580
(3:3)	18.4	15.7	.539	18.9	16.6	.532	16.3	15.5	.513	20.0	14.9	.573
(3:4)	15.5	12.7	.550	15.4	11.3	.577	15.0	12.9	.538	16.2	14.0	.536
(3:5)	19.0	14.2	.572	21.4	16.7	.562	20.9	15.0	.582	14.7	11.0	.572

on the subsequent variable-interval (VI) schedules, two pushes at the same door were involved in a reinforcement. The first response turned on the light at the appropriate magazine; in the presence of the light, the next door push operated the appropriate sucrose pump for the fixed time specified as reinforcer duration. The light remained on for the duration of the reinforcer. After this training, responses on the two doors were reinforced concurrently on independent VI schedules. When a reinforcement was set up on one of the schedules, the tape programmer for that schedule stopped until the reinforcement had occurred. Only the onset of a response could produce reinforcement; if a reinforcement was set up while the appropriate door was being held open, the rat had to release the door and open it again to turn on the magazine light and then make a further response to start the pump. Reinforcements were not allowed immediately after a switch from one door to the other: a 2-sec interval had to elapse after release of one door before a push on the other door could initiate a

reinforcement. For the first two sessions, 30-sec VI schedules were used. Then the regular VI schedules, which had mean intervals of 80 sec, were introduced. The intervals of the two concurrent VI schedules were identical and the duration of reinforcers obtained at both doors was 3 sec.

Testing with Varied Reinforcer Duration

After 10 sessions, when the duration of both reinforcers was 3 sec, the six rats were divided into two groups which were matched for average rates of response. For one group the durations of reinforcers at one door continued to be 3 sec, while the duration of reinforcers obtained at the alternative door was changed every six sessions. The other group went through a similar sequence of changes in the duration of one of the reinforcers, but the reinforcer at the other door was always 1 sec. Five values of reinforcer duration were studied: Each value was retested, but with the "constant" and "varied" reinforcer locations reversed. Because the first time this reverse took place response rates were

very erratic, testing was continued for 15 sessions before the next change in reinforcer duration took place. The pairs of reinforcer durations used for each group of rats are listed in Table 1. The number of reinforcements at each magazine, the number of responses at each door, and the total time each door was held open were recorded every session.

RESULTS AND DISCUSSION

Each response was reinforced about 24 times per session. The total of 48 reinforcements per 40-min session gives an average interreinforcement interval of 50 sec, instead of the 40 sec possible with the two 80-sec VI schedules. Observation of the animals suggested that two factors contributed to the increase: (1) responding on the "wrong" door while a reinforcement was set up for the other door; (2) the requirement of a 2-sec interval between responses on different doors, which sometimes prevented a reinforcement from being obtained until some time after it had been set up.
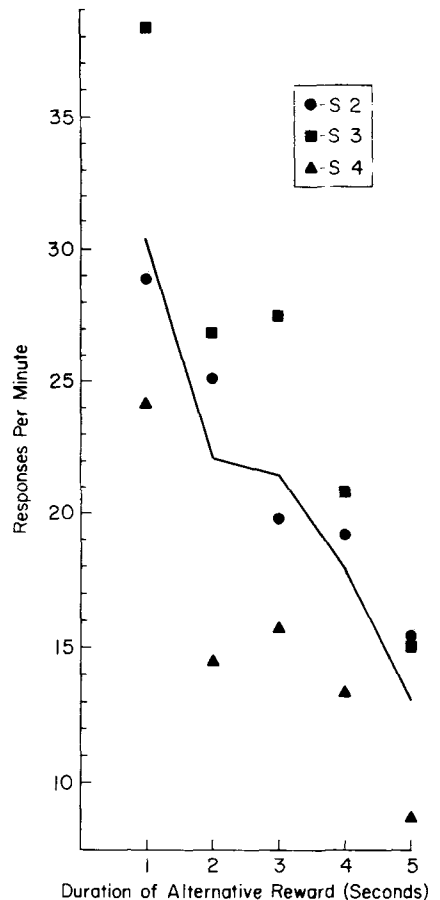

Fig. 1. The mean rate of response at the door that delivered 1-sec reinforcers, plotted against the duration of the reinforcers (rewards) produced by responses at the alternative door.
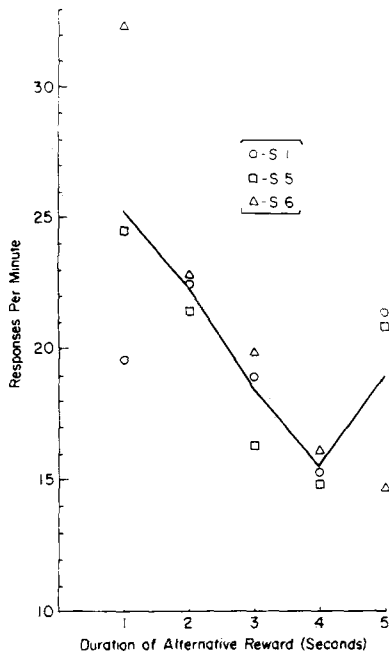
Fig. 2. The mean rate of response at the door that delivered 3-sec reinforcers, plotted against the duration of the reinforcers (rewards) produced by responses at the alternative door.

The mean response rates and durations for the last three sessions with a particular pair of reinforcer durations was used to represent performance for that test. Every pair of reinforcer durations was tested twice, and the scores obtained on these two tests were averaged for each rat. Figure 1 shows the rate of response at the door which delivered 1-sec reinforcers as a function of the duration of reinforcers obtained by responses at the other door. The rate of response on the door giving a 1-sec access to the sucrose solution decreased as the duration of the alternative reinforcer increased from 1 to 5 sec.

Similar data for the three rats that always obtained 3-sec reinforcers at one of the magazines is presented in Fig. 2. The absolute rate of the response reinforced with a constant reinforcer duration appears to be related to the relative duration of its reinforcers. The relationship broke down when the alternative reinforcer was 5 sec, but the reason for this is not clear. Figure 2 shows, however, that the rate of response for a 3-sec reinforcer decreased systematically as the duration of the alternative reinforcer ranged from 2 to 4 sec. There was no overlap between scores at the three points in the 2- to 4-sec range.

The average response rate on each manipulandum and the relative rate at the door producing a constant reinforcer duration are given in Table 2. The relative

rate (the rate at "constant" door divided by the sum of both absolute response rates) did not closely match the relative duration of the "constant" reinforcer, especially in the case of the 3-sec constant reinforcer. Response-duration data did not show orderly changes, and thus the comparatively low response rates produced by long reinforcer durations could not be attributed to the animals taking more time to make individual responses. It seems more likely that the lack of matching was due to the brief experience allowed with each pair of reinforcer values.

In general, the absolute rate of a response that produced reinforcers of constant duration was found to vary inversely with the duration of reinforcers delivered by an alternative manipulandum. This result is similar to that obtained with pigeons by Rachlin & Baum (1969). However, the data in Table 2 show that the sum of both response rates was inversely related to the sum of the two reinforcer durations being used. This suggests a satiation factor, or general rate-suppressing effect of increasing reinforcer amount. Rachlin & Baum (1969) noted that their pigeons weighed about 10 g more after a session with the longest (16-sec) value than with the shortest (1-sec) value of the varied reinforcer, and thus satiation effects may have contributed to the variations in rate of key pecking which they reported. This type of satiation factor needs to be more stringently controlled before the effects of reinforcer duration on rate of response and choice behavior can be properly evaluated.

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Effects of agroclavine on wheel-turning activity in mice

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Five groups of mice received 0, 30, 90, 270, or 810 mg/kg body weight of agroclavine, a drug chemically similar to LSD. Over 5 consecutive days smaller dosage levels either enhanced or produced little change in wheel-running activity, while higher dosages produced a decrement.

LSD is a well-known hallucinogenic compound derived from ergot alkaloids. Catagnoli & Tonalo (1966) show that LSD, agroclavine, and elymoclavine are very similar structurally. Agroclavine differs from elymoclavine by lacking a hydroxyl