

CONCURRENT RESPONDING WITH FIXED RELATIVE RATE OF REINFORCEMENT¹

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Responding by pigeons on one key of a two-key chamber alternated the color of the second key, on which responding produced food according to a variable-interval schedule of reinforcement. From time to time, reinforcement would be available for a response, but in the presence of a particular stimulus, either red or green light on the key. Red or green was chosen irregularly from reinforcement to reinforcement, so that a proportion of the total number of reinforcements could be specified for each color. Experimental manipulations involved variations of (1) the proportions for each color, (2) changeover delay, or, alternatively, (3) a fixed-ratio changeover requirement. The main findings were: (1) relative overall rates of responding and relative times in the presence of a key color approximated the proportions of reinforcements obtained in the presence of that color, while relative local rates of responding changed little; (2) changeover rate decreased as the proportions diverged from 0.50; (3) relative overall rate of responding and relative time remained constant as the changeover delay was increased from 2 to 32 sec, with reinforcement proportions for red and green of 0.75 and 0.25, but they increased above 0.90 when a fixed-ratio changeover of 20 responses replaced the changeover delay; (4) changeover rate decreased as the delay or fixed-ratio was increased.

Concurrent schedules specify that two (or more) reinforcement schedules function simultaneously. There are two (or more) operants, and reinforcement for each is scheduled independently. By one method, each operant and its schedule are assigned to an individual response key. By a second, all of the schedules are assigned to the same key (main key) and different exteroceptive stimuli are associated with each operant-schedule pair. Responses on a second key (changeover key) alternate the exteroceptive stimulus and the schedule in effect on the main key. Each schedule functions continuously, whether or not it is assigned to the main key at a given moment. The two procedures appear to be equivalent (Catania, 1966), but the second provides an advantage: since a changeover is explicit, contingencies and recording functions may be defined more directly.

A feature of concurrent variable-interval (VI) schedules that has been found under certain conditions is the "matching relationship" between relative response rates and reinforcement rates. The relative rate of responding and the proportion of time spent on each schedule approximate the relative rate of reinforcement for a schedule. With concurrent VI 1-min VI 3-min schedules, for example, about 0.75 of the feeder operations are assigned by the VI 1-min schedule. Of the total number of responses emitted, approximately 0.75 are on the VI 1-min key; of the total time, approximately 0.75 is spent responding on that key (Brownstein and Pliskoff, 1968; Catania, 1963, 1966; Herrnstein, 1961).

Because each of the VI schedules functions independently, the subject can confine its responding to one alternative and produce all reinforcements arranged by that schedule without changing over and responding on the other. If one of the schedules is extinction, changeovers are infrequent and the relative rates of reinforcement are always exactly 1.00 and 0.00. If neither of the schedules is extinction, the changeover rate is ordinarily high enough to prevent extreme variability in obtained relative rates of reinforcement from session to session. However, it remains true

¹Dedicated to B. F. Skinner in his sixty-fifth year. The research was performed at the Institute for Behavioral Research and was supported by grants to that Institute: Grant NsG 450 from the National Aeronautics and Space Administration and by an NIH General Research Support Grant #5 501 FR 05636. Reprints may be obtained from D. Alan Stubbs, Department of Psychology, New York University, New York, New York 10453.

that the relative frequency of reinforcement is to some extent controlled by the subject. The present procedure was designed to guarantee a specified relative rate of reinforcement regardless of changeover rate—session-to-session variability was virtually eliminated by requiring that a scheduled feeder operation occur before another was arranged by either schedule. This procedure is similar to concurrent VI schedules in that responses are reinforced intermittently at variable intervals, and also in that a relative frequency of reinforcement can be specified for each main-key color. It is unlike the procedure of concurrent schedules in that reinforcement is not scheduled independently for each response class.

The desired relation between VI schedules may be arranged by halting both VI tape drives when either assigns a reinforcement, instead of the usual procedure of halting only the drive making the assignment. Alternatively, a single VI schedule may be employed to assign all reinforcements in conjunction with a second circuit that specifies a key color. Only a response in the presence of the specified key color is reinforced, and a specified proportion of all of the reinforcements is thereby assigned to the key color.² The latter method was employed here.

The present experiment studied two problems. First, does the matching relationship (Herrnstein, 1961) obtain, given the nonindependence between the two VIs required by the procedure? To answer that question, the proportion of the total number of reinforcements produced by responding in the presence of a given key color was varied. Each proportion yielded a relative rate of reinforcement that was compared with a relative rate of responding. A second question concerned the effects of changeover delays (COD) in choice. The COD specifies a minimum duration that must elapse between a changeover and the possibility of reinforcement. Herrnstein (1961) found that a COD was necessary to yield matching. Shull and Pliskoff (1967) also found that the distribution of responses was a function of COD duration. With concurrent VI 1-min VI 3-min schedules, COD duration was

varied between 0 and 20 sec. As the COD duration increased, the proportion of responses emitted and the time spent with respect to the VI 1-min schedule increased to approximately 0.90. However, as the relative rate of responding and time increased, the relative rate of reinforcement increased for the VI 1-min schedule. In the present experiment, the probability of reinforcement for a given main-key color was fixed by the procedure, while relative response rate and time could vary.

METHOD

Subjects

Three experimentally naive Silver King pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The two keys (Ralph Gerbrands Company) of the pigeon chamber were mounted 9.25 in. (23.5 mm) above the floor, 2.50 in. (6.35 mm) between centers. A force of 15 g (0.147 N) was required to operate each key; each operation produced a click from a relay located behind the work panel. The keys could be transilluminated by different colored lights. Mixed grain was presented by a Lehigh Valley Electronics pigeon feeder.

Procedure

Before the experimental procedure began, the birds were pretrained for 7 to 11 days. Pretraining consisted in establishing the key peck followed by training on a variable-interval schedule of reinforcement.

The experimental procedure was as follows. Left-key (main key) responses were reinforced according to a variable-interval 1.5-min schedule of reinforcement; the intervals were arranged according to a method described by Catania and Reynolds (1968, p. 381). The left key was transilluminated by either red or green light. Each response on the right key (changeover key) changed the color of the left key; the right key was transilluminated by yellow light.

A main-key response could be reinforced once the VI programmer had assigned a reinforcement, but only for a key peck emitted in the presence of a particular stimulus. The specific stimulus (red or green) was changed

²This procedure is closely related to that of Shimp (1966, 1969) and that of Graf, Bullock, and Bitterman (1964). It is sufficiently different in detail, however, and the intents of the several experiments are sufficiently diverse to obviate a lengthy comparison.

irregularly from reinforcement to reinforcement. The overall sequence of reinforcements was scheduled by a 33-position stepping switch. The sequence was changed at irregular intervals during the various experimental conditions.

Right-key responses (changeovers) produced a minimum delay before the possibility of reinforcement. The minimum time was the changeover delay. The VI tape programmer operated during the COD. Once a changeover was emitted, a second could be emitted without a main-key response intervening. Changeovers occurring during the COD initiated a new delay interval. Each session lasted until a bird received 60 food presentations of 3.5-sec access to mixed grain. During food presentation, the keylights and houselights were turned off and the grain tray was illuminated. Sessions were run daily.

The following manipulations were studied.

Changes in relative reinforcement rate. The procedure allows for a specification of the relative rate of reinforcement indirectly by adjusting the proportion of reinforcements that had to be produced in the presence of a specified key color. The relative rates, arranged with respect to the red key color, were: 0.50, 0.75, 0.00, 0.25, 0.90. The duration of the COD was 2 sec for all conditions. The number of sessions for each condition is shown in the last column of Table 1.

Changes in COD. The relative reinforcement rate was maintained at 0.75, and the duration of the COD was varied. The COD durations were: 8, 16, 32, and 0 sec. The numbers of sessions are shown in Table 1.

Fixed-ratio changeover requirement. With no COD, the number of responses required to changeover was varied: fixed-ratio (FR) changeover requirements of one (equivalent to COD = 0 sec) and 20 responses were used (see Table 1). Two changes in procedure were introduced for the FR 20 condition. Once a response was emitted on the changeover key, the main key was darkened and inactivated. After the FR was completed, the alternate main-key color came on; during the ratio requirement, the VI programmer was stopped. For the FR 1 condition, the procedure led simply to an immediate change from red to green or from green to red. After the changeover requirement of the one or the 20 responses was completed, at least one response

on the main key was necessary before another changeover could be effected.

RESULTS

The following calculations with respect to the red key color were made: relative overall response rate, relative time, relative local response rate, relative reinforcement rate, main-key response rate, and the changeover-key response rate.

1. Relative overall response rate reduces to (Shull and Pliskoff, 1967):

$$\frac{R_R}{R_R + R_G}$$

Responses on the red key (R_R) were divided by total responses, responses on the red key plus responses on the green key (R_G).

2. Relative time:

$$\frac{T_R}{T_R + T_G}$$

Time spent in the presence of the red key was divided by total session time, exclusive of reinforcement cycles (and changeover time during the FR 20 changeover condition).

3. Relative local response rate:

$$\frac{R_R/T_R}{R_R/T_R + R_G/T_G}$$

Responses on the red key were divided by the time spent in the presence of the red key; the result was divided by the sum of those quantities for the red and the green keys.

4. Relative reinforcement rate reduces to:

$$\frac{r_R}{r_R + r_G}$$

The number of reinforcements produced by responding on the red key (r_R) was divided by the total number of reinforcements.

5. Main-key response rate: The total number of responses on the main key (color ignored) was divided by the total time, exclusive of reinforcement time (and changeover time during the FR 20 changeover condition).

Table 1
The Original Data from Which Calculations Were Made. Data Were Totaled Across the Last Five Sessions

Rein. Prop. (Red key)	CO Require- ment	Responses		Time (sec)		Changeovers		Reinforcements		Sessions
		Red	Green	Red	Green	Red	Green	Red	Green	
PIGEON 103										
0.50	COD 2-sec	11855	9822	17824	14350	1212	1211	150	150	41
0.75	COD 2-sec	21883	4699	26562	14530	1212	1211	150	150	41
0.0	COD 2-sec	20	27223	133	28729	100	100	0	300	21
0.25	COD 2-sec	10057	26496	7622	22404	1322	1322	72	228	44
0.90	COD 2-sec	18670	2001	29527	1886	571	572	280	20	30
0.75	COD 8-sec	28536	6307	28913	4808	284	284	224	76	32
0.75	COD 16-sec	29043	6235	30996	4446	151	150	223	77	33
0.75	COD 32-sec	37132	7387	42477	5025	130	133	222	78	32
0.75	COD 0-sec	26064	3952	23336	5900	2801	2802	225	75	33
0.75	FR 1	18006	5533	21274	8112	4089	4093	228	72	8
0.75	FR 20	30157	1163	31902	2607	213	213	227	73	19
0.75	FR 1	17341	5691	20983	8412	4243	4242	225	75	9
PIGEON 104										
0.50	COD 2-sec	16278	15689	15670	16228	662	662	151	149	39
0.75	COD 2-sec	31514	3847	28196	3287	403	404	225	75	32
0.0	COD 2-sec	25	29705	75	28832	50	50	0	300	21
0.25	COD 2-sec	5954	33565	5110	26627	547	548	76	224	43
0.90	COD 2-sec	30644	1876	28696	1695	258	258	280	20	30
0.75	COD 8-sec	33643	6442	27687	5536	304	304	227	73	32
0.75	COD 16-sec	35189	4731	30359	6699	255	255	225	75	33
0.75	COD 32-sec	53217	2608	38107	4977	115	116	226	74	32
0.75	COD 0-sec	27990	6365	21805	7523	2066	2066	225	75	33
0.75	FR 1	26611	7670	20934	8466	2160	2160	224	76	8
0.75	FR 20	44786	541	31834	2733	197	198	225	75	18
0.75	FR 1	31659	5397	23081	6276	2061	2061	226	74	10
PIGEON 108										
0.50	COD 2-sec	14524	13927	16376	14687	1129	1132	149	151	37
0.75	COD 2-sec	4	13690	11	5811	660	660	226	74	32
0.0	COD 2-sec	17755	4681	25638	29093	1	1	0	300	21
0.25	COD 2-sec	6128	17994	6849	24883	677	676	74	226	44
0.90	COD 2-sec	19950	1851	28828	1925	399	399	280	20	30
0.75	COD 8-sec	19783	5924	26195	6402	379	380	223	77	32
0.75	COD 16-sec	17124	5076	30597	6040	186	186	226	74	33
0.75	COD 32-sec	16422	5431	36180	6102	119	120	224	76	32
0.75	COD 0-sec	9190	2846	22206	7829	2050	2050	223	77	32
0.75	FR 1	10558	3241	22960	6751	2178	2178	225	75	9
0.75	FR 20	17135	1766	27932	4434	316	313	223	77	16*
0.75	FR 1	10790	3096	23965	6245	2337	2338	226	74	11

*Pigeon 108 was run two additional sessions during which the pigeon did not respond due to an injury to its beak.

6. Changeover-key response rate: The total number of responses on the changeover key was divided by the total time as defined above.

Table 1 shows the original data summed for the final five sessions under each experimental condition. All calculations were made from those five-day sums.

Figure 1 was plotted from data obtained with the COD equal to 2 sec and shows the relative overall response rate, relative time, and relative local response rate as a function of the relative overall rate of reinforcement. The relative response rates and time measures approximated the relative rates of reinforcement. There was, however, a tendency for relative overall response rate and for relative time to exceed relative reinforcement rate for values of the latter greater than 0.50. Relative local response rate reasonably approximated 0.50 over all conditions for the three subjects. This outcome indicates that the birds responded on the main key at a constant rate under each condition and partitioned time so that relative time (and hence relative response rate) approximated relative reinforcement rate. (Note that if relative overall response rate and relative time are equal, then relative local response rate necessarily must be 0.50.) No point was plotted for relative local response rate at the relative reinforcement rate

0.0, since only a negligible number of responses was emitted on the red key.

Figure 2 shows response rates on both the main key and the changeover key as functions of relative reinforcement rate. Main-key response rate varied across conditions; however, there was no consistent trend in relation to reinforcement rate. Changeover rate, on the other hand, decreased as the relative reinforcement rate diverged from 0.50. An exception was Bird 103, which demonstrated the highest changeover rate at the relative reinforcement rate 0.25 rather than 0.50.

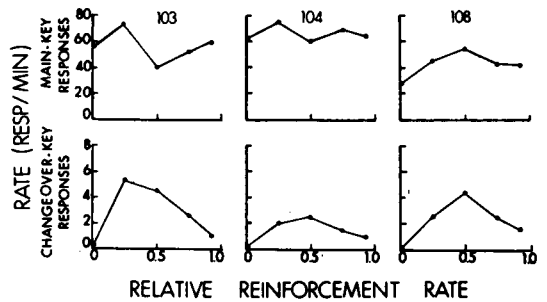


Fig. 2. Main-key response rate and changeover-key response rate as functions of the relative rate of reinforcement.

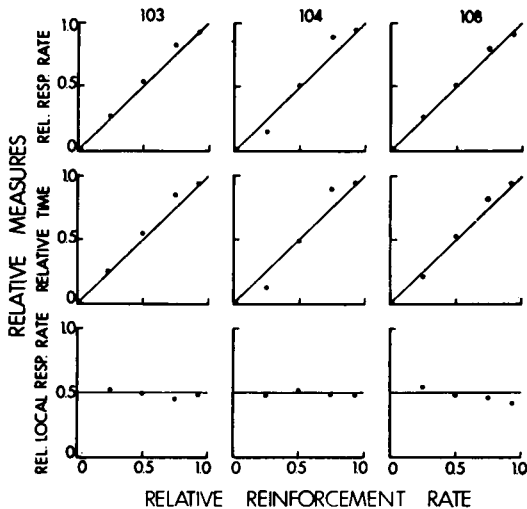


Fig. 1. Relative rate of responding, relative time spent and relative local response rate as functions of the relative rate of reinforcement. Calculations were made with respect to the red key color.

Figure 3 shows relative overall response rate, relative time, and relative local response rate as functions of the changeover delay with the relative reinforcement rate fixed at 0.75. The points at the COD of 2 sec are the same as those plotted in Fig. 1 at the relative reinforcement rate of 0.75. Relative response rate and relative time remained approximately constant across CODs; however, relative time was generally closer to 0.75 at the COD equal to 0 sec than at other values of the COD. Only Bird 104 showed the same effect for relative response rate. The range of variation across conditions was less than 0.10 for Birds 103 and 108 and less than 0.15 for Bird 104. Excluding the 0-sec COD, the range was less than 0.10 in every case. Both relative response rate and relative time measures were generally above 0.75, the relative reinforcement rate; the only exceptions were that relative time was lower than 0.75 for Birds 104 and 108 at the 0-sec COD and that relative response rate was lower for Bird 108 at the 32-sec COD. As the COD increased, relative local response rate decreased below 0.50 for Bird 103 and 108 and increased above 0.50 for Bird 104. Relative

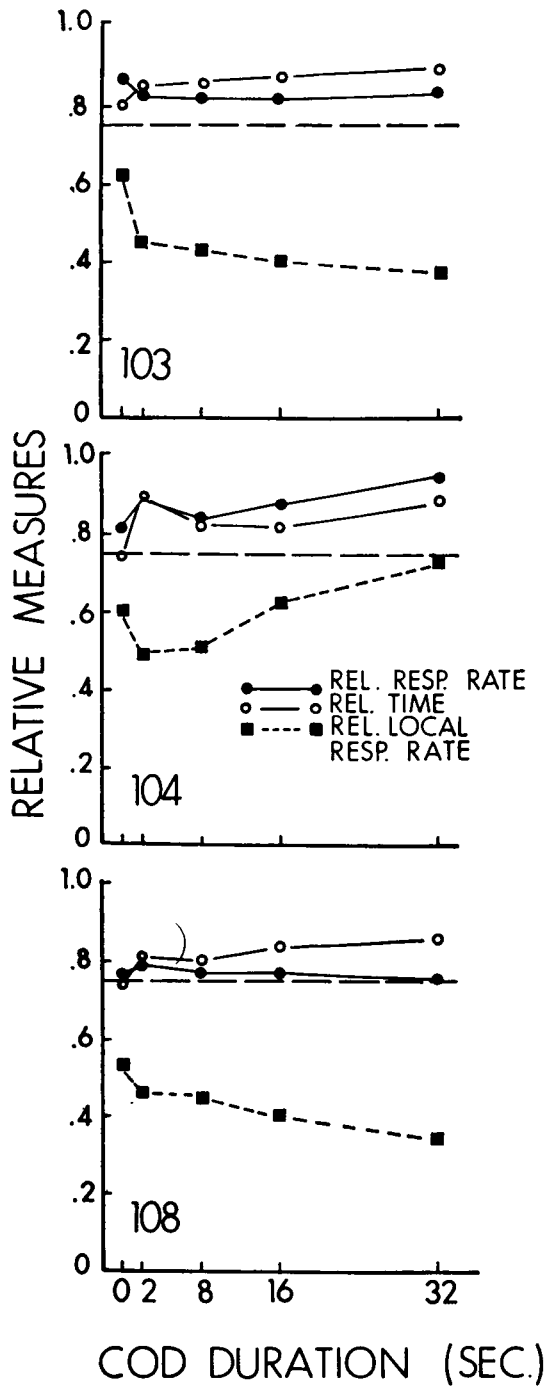


Fig. 3. Relative response rate, relative time spent, and relative local response rate as functions of variations in the duration of the COD. The relative rate of reinforcement was 0.75. Calculations were made with respect to the red key color.

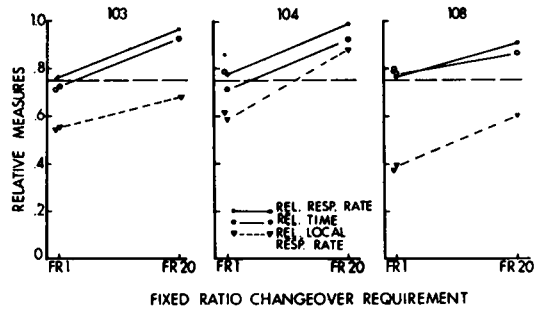


Fig. 4. Relative response rate, relative time spent, and relative local response rate as functions of variation of the fixed-ratio changeover requirement. The relative rate of reinforcement was 0.75. Calculations were made with respect to the red key color.

local response rate was greater than 0.50 for all birds at the 0-sec COD.

Figure 4 shows relative measures obtained with the two fixed-ratio changeover requirements. The unconnected points at FR 1 are from the redetermination shown in the final row of Table 1. Relative overall response rate and relative time increased when the changeover requirement was changed from FR 1 to FR 20. Relative overall response rate and relative time were higher with the FR 20 condition than they had been under any value of the COD. Relative local response rate also increased under the FR 20 requirement. With reinstatement of the FR 1 condition, the pigeons' performances were quite similar to those established under the original determination. Only for Bird 104 did two comparison measures (relative overall response rate) differ by more than 0.05.

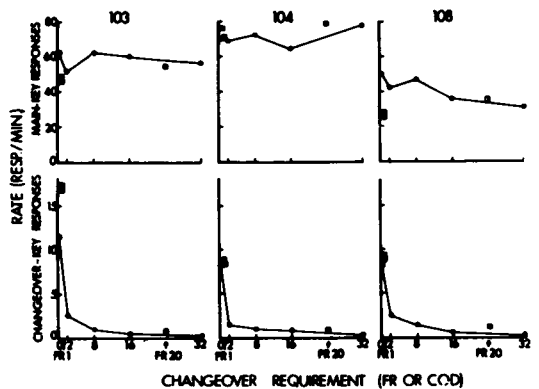


Fig. 5. Main-key response rate and changeover-key response rate as functions of differences in the changeover requirement. Variations in COD and FR requirements are both shown, and their placement on the same horizontal is for convenience of comparison only.

Figure 5 shows main-key and changeover-key response rates as functions of the changeover requirement. The several COD durations and the two FR requirements are plotted on the horizontal axis. For the FR 20 condition, the vertical axis of the lower row shows changeovers per minute, rather than changeover-key responses per minute. Also, the changeover delays and fixed-ratio requirements are presented together only to emphasize the similar effects on performance obtained by increasing either; correspondence in any other sense is not intended. Main-key response rates were somewhat variable across conditions. For Bird 108, main-key response rate decreased with increases in the COD. There was a decrease in changeover rate for all birds as a function of increases in the COD. Finally, changeover rate decreased also for the FR 20 requirements as compared with the FR 1 requirement.

DISCUSSION

The procedure provided that responses produce food intermittently in the presence of different stimuli, and the proportion of the feeder operations that had to occur in the presence of a given stimulus was specified. Certain behavioral effects observed in the present experiment are similar to those observed with the more usual procedure for concurrent VI VI schedules. It was seen that: (1) the relative overall rate of responding broadly approximated the relative rate of reinforcement; (2) the relative amount of time spent in the presence of each stimulus also approximated the relative rate of reinforcement; (3) given brief COD values, relative local rate tended to be equal in the presence of the different stimuli; (4) with a fixed COD (2 sec), changeover rate decreased the greater the divergence of the relative reinforcement rate from 0.50; (5) with a fixed rate of reinforcement (0.75), changeover rate decreased as a function of increases in the COD.

A matching relation between relative rate of responding and relative rate of reinforcement has been observed for pigeons with concurrent VI VI schedules (Catania, 1963, 1966; Herrnstein, 1961). In those experiments, relative reinforcement rate was manipulated by varying the average interreinforcement interval for each of the VI schedules.

Pigeons have been observed to match relative time and relative rate of reinforcement (Brownstein and Pliskoff, 1968; Catania, 1966). Catania observed the relation between relative time and relative reinforcement rate with concurrent VI VI schedules. Brownstein and Pliskoff observed such a relation with response-independent concurrent VI VI schedules. Food was delivered independently of behavior; responses on the only available key changed from one response-independent VI to the other. Whereas in Catania's experiment, the relative rate of responding also was related to relative reinforcement rate, responding was absent in the experiment by Brownstein and Pliskoff.

It has been suggested that the relation between relative rates of responding and reinforcement may be a byproduct of the way in which animals partition time between concurrent VI VI schedules (Catania, 1966; Brownstein and Pliskoff, 1968; Shull and Pliskoff, 1967). If pigeons partition only time, then responding should occur at the same local rate in the presence of either stimulus. Changes in relative response rate result simply from changes in the number of responses emitted in the presence of the different stimuli. The local response rates should therefore be equal. Catania (1966) found in fact that both relative overall response rate and relative time matched reinforcement rate with concurrent VI VI schedules (given a 2-sec COD). Thus, the relative local rate of responding would necessarily approximate 0.50, as was the case in the present experiment.

With concurrent VI VI schedules, changeover rate has been found to decrease as a function of the divergence of relative reinforcement rate from 0.50 (Brownstein and Pliskoff, 1968; Herrnstein, 1961). Herrnstein demonstrated this relation with concurrent VI VI schedules and Brownstein and Pliskoff found that the relation obtained also with the response-independent procedure previously described.

Changeover rate decreases as a function of increases in the COD (Brownstein and Pliskoff, 1968; Herrnstein, 1961; Shull and Pliskoff, 1967). Herrnstein demonstrated that changeover rate was lower with a 1.5-sec COD than with no COD. Brownstein and Pliskoff (1968), with the response-independent procedure, found that changeover rate was a decreasing

function of the COD. Using rats as subjects and brain stimulation as the reinforcer, Shull and Pliskoff (1967) also found that changeover rate was a decreasing function of the COD; changeover rate decreased both with concurrent VI 1.5-min VI 1.5-min schedules and with concurrent VI 1-min VI 3-min schedules of reinforcement.

There are also differences between the present procedure and results and the usual procedure and results with concurrent VI VI schedules. In the present experiment, relative overall response rate and relative time remained approximately constant as the COD increased. Shull and Pliskoff (1967) found, with concurrent VI 1-min VI 3-min schedules, that both relative response rate and relative time, computed with respect to the VI 1-min schedule, increased as the COD increased in duration. The difference in results between the present study and the study by Shull and Pliskoff could have resulted from differences in the effect of responding on relative rate of reinforcement. With concurrent schedules, changes in the relative rate of responding can affect the relative reinforcement rate. Shull and Pliskoff found that as relative response rate and relative time increased on the VI 1-min schedule, the relative rate of reinforcement also increased. In the present study, changes in relative overall response rate and relative time could not result in changes in the relative reinforcement rate. Relative reinforcement rate was constant at 0.75 while the COD varied. However, there were other differences between the two studies. In the experiment by Shull and Pliskoff, rats rather than pigeons were subjects, brain stimulation rather than food was used as a reinforcer, and Shull and Pliskoff had fewer sessions per condition (5 to 10 sessions).

It is not clear how the changeover delay serves to modulate responding on concurrent VI VI schedules of reinforcement so as to produce matching. Shull and Pliskoff (1967, p. 526) suggested that the COD in conjunction with relative reinforcement rate determines the distribution of responses between the two variable-interval schedules during the session. Their analysis assumed that the organism responds at a uniform local rate throughout the session, or, in other words, that the local response rates for the two schedules of a concurrent pair are the same. How-

ever, the COD affects local response rate when the latter is examined in detail, rather than calculated from data collected over an entire experimental session. As yet unpublished data by Silberberg and Fantino and by Pliskoff and Green show that the local response rate is higher during the interval following a changeover when the COD is timing than after that interval has expired. Local response rate is, therefore, bivalued when examined in detail, and the "uniform" local rate is an average of the two values. Presumably, the higher response rate immediately following a changeover results from the complex contingencies existing at that moment, *i.e.*, a COD superimposed upon a VI schedule with a probability of reinforcement at the expiration of the COD dependent upon (a) the length of the VI interval currently timing, (b) the duration of the COD, and (c) the time since that schedule was last sampled.

The FR changeover requirement that we examined was designed to simplify the post-changeover contingencies to some extent. The experiment is essentially halted as soon as the first response of the FR is emitted on the changeover key—the VI tapes stop, the main key is darkened and inactivated, and the cumulating-time recorders are stopped. When the final response of the FR is emitted, the changeover is completed and the experiment is reinstated. The schedule at that moment on the main key is a variable interval without the added complexity of a superimposed COD. Whether the FR changeover requirement is a procedural factor more useful than the COD remains to be determined.

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Received 11 July 1969.