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CHANGEOVER DELAY AND CONCURRENT SCHEDULES: SOME EFFECTS ON RELATIVE PERFORMANCE MEASURES[1]

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The pigeon and the rat partition total response output between both schedules of a concurrent variable-interval pair. The quantitative nature of a partition seems critically dependent on the relative rates with which the two schedules provide reinforcements for responding, in addition to the changeover delay. The manner in which the changeover delay controls the partition was studied by varying the duration of the changeover delay from 0 to 20 sec with each of two pairs of concurrent variable-interval schedules, *viz.*, Conc VI 1.5-min VI 1.5-min and Conc VI 1-min VI 3-min. Rats served as the subjects and brain stimulation was employed as the reinforcer. When the schedules were Conc VI 1.5-min VI 1.5-min, relative response rate approximated 0.50 at all values of the changeover delay. When the schedules were Conc VI 1-min VI 3-min, relative response rate, computed with respect to the VI 1-min schedule, increased when the duration of the changeover delay increased. Changeover rate decreased when the duration of the changeover delay increased. The decrease was the same for both VI schedules of the Conc VI 1.5-min VI 1.5-min pair but was more rapid for the VI 3-min schedule of the Conc VI 1-min VI 3-min pair.

A concurrent pair of variable-interval (VI) schedules of reinforcement involves the assignment of one schedule to each of two response keys. The VI schedules are independent, and the availability of reinforcement on one of the keys is unaffected by the availability of reinforcement on the other. However, reinforcements made available on a given key are produced by responses on that key only.

The pigeon and the rat typically alternate between the concurrently available keys, responding on one and then on the other. The way a pigeon partitions its responses between the keys has attracted considerable interest, and Catania (1966) has summarized much of the relevant research. A method for quantifying the partition, termed "relative frequency of responding" by Herrnstein (1961) and "relative response rate" by Catania (1966), involves the ratio of two rates of responding. The response rate for one of the keys, *i.e.*, the responses emitted per minute on that key, is divided by the total or overall response rate, *i.e.*, the total responses emitted per minute on the two keys together. Because both keys are available for an identical period of time, the ratio of response rates reduces to the proportion of the total responses emitted on the key in question. Thus, if R_1 responses are emitted on Key 1, and R_2 responses are emitted on Key 2 within a given period of time, the relative rate of responding on Key 1 reduces to $R_1/R_1 + R_2$.

Findley's (1958) data showed that relative response rate varied as a function of the particular VI schedules that are programmed concurrently. Herrnstein (1961) examined that relationship more systematically and found that relative response rate was linearly correlated with relative reinforcement rate. Computation of the latter variable is analogous to the computation of relative response rate, and reduces to the proportion of the total reinforcements produced by responses on a given key. The linear correlation reported by Herrnstein was such that the relative rate of response was approximately equal to (matched) the relative rate of reinforcement. Catania (1963) confirmed that relationship.

Herrnstein reported also the effect of another variable, the changeover delay (COD), on relative response rate. A COD specifies that when the organism changes from responding on one key to responding on the other, a mini-

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mum delay is imposed between the changeover and the next possible reinforced response. Specifically, Herrnstein found that (a) the number of changeovers per session was smaller with a 1.5-sec COD than with no COD, and, (b) the relative response rate approximated the relative reinforcement rate (at the value of the latter that was examined for this comparison, about 0.66) more closely with the COD than without the COD.

The present study sought to evaluate further the effect of the COD on relative response rate and on changeover rate by varying the duration of the COD with each of two pairs of concurrent VI schedules of reinforcement. The procedure of concurrent scheduling described by Findley (1958) was used. That is, both variable-interval schedules of the concurrent pair were programmed on a single lever (the main lever); each schedule was paired with a distinctive exteroceptive stimulus, and responses were effective for only one schedule at a given time. Access to the other schedule could be obtained by responding on a second lever (the changeover lever). The variable-interval programmers ran concurrently, and reinforcements were independently assigned. A reinforcement assigned by a particular schedule could be produced by a response on the main lever only when that schedule was in effect on the main lever; a reinforcement assigned by the other schedule could be produced only after a changeover assigned the other schedule to the main lever. Findley's procedure and the method used by Herrnstein appear to be formally equivalent. In addition, Catania (1963) has demonstrated the linear correlation with Findley's technique, so that the two techniques appear also to be functionally equivalent, at least with respect to matching, *i.e.*, the approximate equivalence between the relative rates of responding and reinforcement.

METHOD

Subjects and Apparatus

Four male, albino rats were anesthetized and surgically implanted with chronic, bipolar, stainless steel electrodes. The uninsulated tips, 10 mils in diameter, were located in the vicinity of the mammillary bodies of the posterior hypothalamus. Two of the rats, S1 and S2, served in a previous experiment involving only continuous reinforcement. The remaining rats, S3 and S4, were experimentally naive. Food and water were freely available in the home cages.

The front wall of the animal chamber was fitted with two levers spaced about 6 in. apart. The main lever, located on the left, was a Gerbrands rat lever with a flat, paddle-like sheet of metal bolted to the top. This assembly protruded 1.5 in. into the chamber. The changeover lever, located on the right, was a standard Lehigh Valley Electronics rat lever. Stimulation was delivered to the rat through a hearing-aid cord that was fixed to a mercury-pool commutator mounted about 12 in. above the chamber. The hearing-aid cord was lightly spring-loaded to keep it taut, and the rat could move freely to all parts of the chamber and turn 360° without twisting the cord.

Procedure

After preliminary training (one session, about 1 hr in duration) involving continuous reinforcement and VI schedules of brief mean interreinforcement duration, the four rats were shifted to the VI reinforcement schedules. For Rats S1 and S2, the schedules programmed on the main lever were: VI 1-min in the presence of a tone and VI 3-min in the presence of clicks (about 5 per sec). For Rats S3 and S4, the schedules were: VI 1.5-min (tone) and VI 1.5-min (clicks). The exteroceptive stimuli were provided by a Foringer Cat. #1166 multiple stimulus source.

Throughout the experiment, a single response on the changeover lever alternated the schedule assignment (and correlated exteroceptive stimuli) on the main lever. In addition, a changeover started a timer, the COD timer. A reinforcement could not be produced by a response on the main lever for the duration specified by the timer, although the VI programmers continued to operate and reinforcement could be assigned. When a reinforcement was assigned, the tape programmer was stopped, and did not start again until after the reinforcement was delivered. The first response on the main lever after the COD interval could be reinforced. After a changeover, the changeover lever was inactivated until at least one response was emitted on the main lever, *i.e.*, successive responses on the changeover lever produced only one schedule change. However, the COD interval began anew with each perseverative response on the changeover lever. Thus, the COD specified the minimum time interval between a response on the changeover lever and the possibility of reinforcement for a response on the main lever. After at least one response on the main lever, a response on the changeover lever produced a schedule change (and new COD interval) even if the COD initiated by the previous changeover had not elapsed.

A reinforced response on the main lever lit a lamp (Dialco Series 81-0410 base with #1829 bulb) mounted on the front wall about 2 in. above the main lever. In the presence of this light, each of 20 successive responses on the main lever produced a 125-msec train of 100 Hz sine wave stimulation. Current intensities, between 150 and 300 μA, were held constant for each rat and were continually monitored on an oscilloscope. When the twentieth train terminated, the light above the lever was turned off, and the VI schedules were reinstated. During a reinforcement period, the cumulative recorders and the VI programmers were stopped; stimulation-producing responses were counted separately from other responses on the main lever. The information was not automatically recorded, but no rat was ever observed to pause or press the changeover lever during a reinforcement period; the performances obtained during a reinforcement period under similar conditions have been documented elsewhere (Pliskoff, Wright, and Hawkins, 1965). Cumulative records of these performances were not obtained in the present experiment.

All of the rats were exposed to an ascending and descending series of COD durations. Table 1 shows the durations of the COD studied (first column), the sequence of COD durations and the number of 2-hr (approximately) daily sessions for each duration (second column). Adjustment to a new value of the COD ordinarily occurred within the first session devoted to the new value. A median based on five sessions was as likely to be drawn from the first session as from the last. The numbers in parentheses in Table 1 indicate the session number from which the median for that statistic was drawn. As often occurred, the same median value was obtained on two (or more) of the five sessions. In such instances, the session number in parentheses is the earlier (earliest) session on which the value was obtained.

RESULTS

The following data were collected during each session:

1. The numbers of responses emitted when the VI schedule correlated with the tone stimulus, (R_t), and when the VI schedule correlated with the click stimulus, (R_c), were assigned to the main lever.
2. The numbers of seconds during which the VI schedule correlated with the tone stimulus, (T_t), and during which the VI schedule correlated with the click stimulus, (T_c), were assigned to the main lever.
3. The numbers of reinforcements obtained from the VI schedule correlated with the tone stimulus, (r_t), and from the VI schedule correlated with the click stimulus, (r_c).
4. The total number of changeovers, (S).

The following calculations were made each day from these data:

1. The relative response rate with respect to the VI schedule correlated with the tone stimulus, *i.e.*,

$$\frac{\frac{R_t}{T_t + T_c}}{\frac{R_t}{T_t + T_c} + \frac{R_c}{T_t + T_c}} = \frac{R_t}{R_t + R_c} \quad \text{(Rel Resp);}$$

2. The relative time with respect to the VI schedule correlated with the tone stimulus, *i.e.*,

$$\frac{T_t}{T_t + T_c} \quad \text{(Rel Time);}$$

3. The relative reinforcement rate with respect to the VI schedule correlated with the tone stimulus, *i.e.*,

$$\frac{\frac{r_t}{T_t + T_c}}{\frac{r_t}{T_t + T_c} + \frac{r_c}{T_t + T_c}} = \frac{r_t}{r_t + r_c} \quad \text{(Rel Rein);}$$

4. The rate of changeovers when the VI schedule correlated with the tone stimulus was assigned to the main lever, *i.e.*,

$$100 \quad \frac{1/2\,S}{T_t} \quad \text{(CO/100 sec, Tone);}$$

and when the VI schedule correlated with the click stimulus was assigned to the main lever, *i.e.*,

$$100 \quad \frac{1/2\,S}{T_c} \quad (\mathrm{CO}/100\ \mathrm{sec,\ Clicks}).$$

A median was obtained for each of the calculations. The medians were based on the five sessions (or last five if 10 sessions were conducted) devoted to each duration of the COD. The medians are shown in Table 1, and all of the figures to be discussed were plotted from the medians shown in the table.

Table 1

First column: the sequence of COD durations. Second column: the number of sessions devoted to each value. Remaining columns: median values of the several performance measures calculated according to formulas shown in text. The number in parentheses beside a median indicates the session (out of five) that provided the median. All medians were computed with respect to the VI schedule correlated with the tone stimulus, *i.e.*, the VI 1-min for Rats S1 and S2.

		With respect to VI (tone)				
COD (sec)	*Sess*	*Rel Resp*	*Rel Time*	*Rel Rfts*	*CO/100 sec Tone*	*CO/100 sec Clicks*
RAT S1: Conc VI 1-min (tone) VI 3-min (clicks)						
0	10*	0.53(1)	0.45(4)	0.72(1)	5.1(2)	4.0(3)
2.5	5	0.61(3)	0.53(4)	0.73(1)	3.6(4)	4.1(4)
5.0	5	0.66(3)	0.66(1)	0.75(1)	1.5(4)	3.1(3)
7.5	5	0.67(2)	0.74(3)	0.75(1)	1.1(1)	2.8(4)
12.5	5	0.74(2)	0.80(1)	0.79(1)	0.46(1)	1.8(1)
20.0	5	0.90(2)	0.89(5)	0.91(2)	0.17(3)	1.3(2)
20.0	5	0.90(3)	0.85(3)	0.90(3)	0.12(3)	0.66(3)
10.0	10	0.85(4)	0.80(2)	0.84(4)	0.38(4)	1.4(1)
2.5	5	0.76(2)	0.68(2)	0.75(2)	2.6(2)	5.3(4)
0.0	10	0.73(2)	0.62(3)	0.73(1)	5.3(2)	8.7(5)
RAT S2: Conc VI 1-min (tone) VI 3-min (clicks)						
0	10*	0.54(2)	0.52(3)	0.73(1)	7.0(5)	7.5(5)
2.5	5	0.58(1)	0.57(2)	0.74(3)	4.1(1)	5.6(1)
5.0	5	0.62(2)	0.60(2)	0.73(1)	2.7(2)	4.0(2)
7.5	5	0.70(2)	0.68(4)	0.75(2)	1.7(1)	3.1(1)
12.5	5	0.75(1)	0.77(3)	0.79(1)	0.58(1)	2.0(2)
20.0	5	0.88(1)	0.87(1)	0.90(5)	0.18(5)	1.2(4)
20.0	5	0.89(4)	0.89(1)	0.91(3)	0.12(4)	0.86(2)
10.0	10	0.71(2)	0.73(2)	0.78(5)	0.61(1)	1.8(4)
2.5	5	0.69(2)	0.64(4)	0.73(3)	4.3(4)	7.7(4)
RAT S3: Conc VI 1.5-min (tone) VI 1.5-min (clicks)						
0	5	0.49(4)	0.43(3)	0.48(2)	6.9(4)	5.3(1)
3.0	5	0.49(1)	0.44(1)	0.48(2)	3.9(2)	2.9(2)
9.0	5	0.49(3)	0.45(1)	0.49(1)	1.5(4)	1.2(4)
13.0	5	0.48(4)	0.45(5)	0.47(5)	1.1(2)	0.96(3)
20.0	5	0.46(4)	0.43(5)	0.46(2)	0.80(2)	0.59(1)
20.0	5	0.47(2)	0.42(1)	0.46(1)	0.76(2)	0.47(5)
11.0	10	0.50(1)	0.44(2)	0.49(2)	2.0(2)	1.6(2)
2.5	5	0.48(2)	0.46(2)	0.50(1)	5.2(3)	4.3(3)
RAT S4: Conc VI 1.5-min (tone) VI 1.5-min (clicks)						
0	5	0.50(1)	0.48(1)	0.52(3)	7.3(5)	6.8(5)
3.0	5	0.50(1)	0.46(2)	0.49(1)	3.3(1)	2.7(5)
9.0	5	0.53(3)	0.53(4)	0.51(3)	1.1(5)	1.3(5)
13.0	5	0.47(2)	0.46(3)	0.49(1)	1.2(3)	1.0(2)
20.0	5	0.51(4)	0.48(2)	0.48(5)	0.49(4)	0.52(4)
20.0	5	0.47(3)	0.42(3)	0.44(2)	0.38(1)	0.29(4)
11.0	10	0.47(1)	0.47(1)	0.49(2)	1.5(2)	1.4(1)
2.5	5	0.50(3)	0.49(3)	0.51(1)	3.9(3)	3.7(3)

*The first five sessions were permitted for adjustment to the VI schedules.

Response (and reinforcement) rates were computed with respect to total session time, *i.e.*, $T_t + T_c$, even though the VI schedules were assigned to the main lever successively, and the total duration of assignment of a particular VI schedule could vary from session to session. Alternatively, response rates could have been calculated by dividing the response count with respect to a particular VI schedule by the time during which only that VI schedule was assigned to the main lever, *e.g.*, R_t/T_t. Catania (1966, p. 224) has referred to the latter calculation as "local rate" and the former, used in this experiment, as "overall rate". The choice of overall rate was based on the rational and empirical grounds stated by Catania (1966, p. 224): "The rationale for this choice is provided by the equivalence of the two-key (*cf.* Herrnstein, 1961) and CO-key (*cf.* Catania, 1963) procedures and the fact that, even when the organism is responding in one schedule, the other schedule is always available and can be reached with a CO response. In addition, a surprising outcome of many detailed studies of components of concurrent performances is that local measures of performance often behave in a less orderly way than overall measures" (authors' parenthetical references).

Table 2 consists of the original data used to calculate the medians shown in Table 1. All of the data appearing in a single row of Table 2 were not necessarily obtained during the same experimental session; they represent five medians that may have been drawn from different sessions. In each row of Table 2, however, the following entries were (of necessity) drawn from the same session: both response counts, both durations, both reinforcement counts. Each changeover count (and associated duration) was drawn separately.

In Fig. 1 and 2, three relative performance measures, relative response rate, relative time and relative reinforcement rate, computed with respect to the VI schedule correlated with the tone stimulus, have been plotted against COD duration.

The data for Rats S1 and S2, for which the tone stimulus was paired with the VI 1-min schedule, are shown in Fig. 1.

As the COD increased during the ascending series (solid lines) from COD = 0 sec to COD = 12.5 sec, relative response rate and relative time with respect to the VI 1-min schedule increased monotonically from about 0.53 to about 0.75. At the 20-sec COD, both statistics for both rats were about 0.90. Relative reinforcement rate also rose as a function of increasing COD duration. The rise was smaller, however, than in the case of the relative response rate and time statistics. Whereas the latter statistics increased about 0.20 as the COD was increased from 0 to 12.5 sec, relative reinforcement rate increased about 0.07 over the same range. At COD = 20 sec, relative reinforcement rate increased for both rats to about 0.90. The descending series of COD durations (dashed lines) essentially reversed these trends; the three relative performance measures decreased monotonically for both rats. While the ascending and descending functions were similar for Rat S2, discrepancies showed for Rat S1; note, particularly, the functions for relative response rate.

Although only five sessions were given at each COD duration during the ascending series, there was no evidence of within-condition trends. If such trends were evident, one would expect the relative response rate for the fifth session at a particular COD value to be reliably higher than the relative response rate for

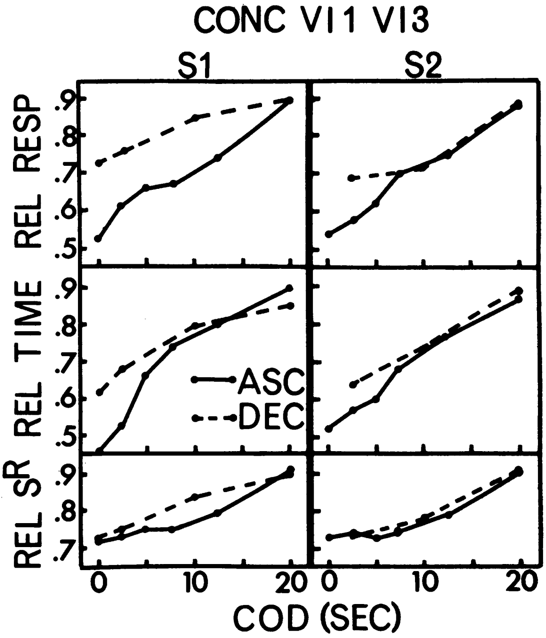

Fig. 1. Median relative response rate, relative time, and relative reinforcement rate plotted against the duration of the COD. The schedules were Conc VI 1-min VI 3-min, and the three statistics were computed with respect to the VI 1-min (tone) schedule.

Table 2

The Original Data from Which the Medians Shown in Table 1 Were Calculated

	Resp		*Time (sec)*		*Rfts*		*CO/sec*	
COD	*Tone*	*Clicks*	*Tone*	*Clicks*	*Tone*	*Clicks*	*Tone*	*Clicks*
RAT S1: Conc VI 1-min (tone) VI 3-min (clicks)								
0	674	605	2937	3557	89	34	173/3374	153.5/3817
2.5	1052	678	3423	3036	90	34	124/3423	124/3036
5.0	1189	612	4182	2175	86	28	61.5/4123	56.5/1820
7.5	1118	548	4688	1690	84	28	52.5/4586	55.5/1999
12.5	1867	667	5125	1302	84	22	23.5/5125	23.5/1302
20.0	1769	198	5791	685	87	9	10/5821	8.5/650
20.0	1952	230	5940	1056	97	11	7/5940	7/1056
10.0	1787	318	5049	1268	83	16	19/5014	27/1990
2.5	1861	598	4154	1931	90	30	110/4154	97/1822
0.0	972	367	3751	2265	89	33	195/3679	191/2195
RAT S2: Conc VI 1-min (tone) VI 3-min (clicks)								
0	582	491	3227	3039	87	33	227/3259	227/3019
2.5	1387	985	3568	2692	88	31	173/4223	173/3115
5.0	1930	1171	3789	2530	83	30	101.5/3789	101.5/2530
7.5	1441	629	4313	2038	84	28	68.5/4129	68.5/2190
12.5	1618	532	4887	1492	84	22	29/5024	33/1620
20.0	3270	445	5548	861	88	10	10/5428	7.5/630
20.0	2442	305	5929	744	91	9	6.5/5482	9.5/1109
10.0	1894	783	4566	1711	83	24	28/4591	23.5/1308
2.5	1859	844	3961	2201	90	33	170/3961	170/2201
RAT S3: Conc VI 1.5-min (tone) VI 1.5-min (clicks)								
0	832	875	2739	3650	45	48	186/2715	135.5/2559
3.0	1105	1158	2898	3641	61	65	107/2768	107/3651
9.0	830	866	3235	3947	59	62	43/2927	43/3666
13.0	1070	1146	3147	3823	47	53	34.5/3119	32.5/3372
20.0	1174	1358	2803	3758	41	48	25/3119	25/4263
20.0	1153	1287	2771	3785	41	48	21.5/2819	18.5/3941
11.0	1513	1497	3020	3906	53	55	61/3020	61/3906
2.5	1138	1243	3013	3585	60	61	156/3000	156/3636
RAT S4: Conc VI 1.5-min (tone) VI 1.5-min (clicks)								
0	723	728	2249	2422	65	60	220/3025	220/3222
3.0	756	771	2921	3451	52	54	107.5/3244	107.5/3926
9.0	848	761	4537	4043	45	44	37.5/3355	37.5/2990
13.0	1197	1342	2999	3472	48	50	35.5/2999	39.5/3790
20.0	988	934	3120	3368	38	41	16.5/3350	16.5/3181
20.0	1081	1206	2783	3836	41	52	13/3418	10/3424
11.0	1360	1564	3059	3426	53	55	46.5/3071	49.5/3426
2.5	1346	1358	3083	3201	63	60	120/3083	120/3201

the first session at that value. For the six COD values studied in the ascending series, the relative response rate for the fifth session was higher than that for the first session three times out of six opportunities for Rat S1 and twice for Rat S2. Furthermore, in no case during the ascending series for either rat was the relative response rate obtained on the last day at a particular COD value higher than the relative response rate on the first day at the next larger COD. The descending series is more difficult to interpret. With respect to the five sessions used to determine the medians shown in Table 1 (note that totals of 10 sessions were given for the 10- and 0-sec CODs), the following relationships were observed. The relative response rate for the fifth session at a given duration of the COD was lower than for the first session once in four opportunities for Rat S1 but twice in three opportunities for Rat S2. The relative response rate was higher for the first session at a new, lower COD duration than during the final session of the previous, larger COD twice in three opportunities for Rat S1 and once in two opportunities for Rat S2.

The data for Rats S3 and S4 are shown in Fig. 2. Both VI schedules of the concurrent pair were VI 1.5-min.

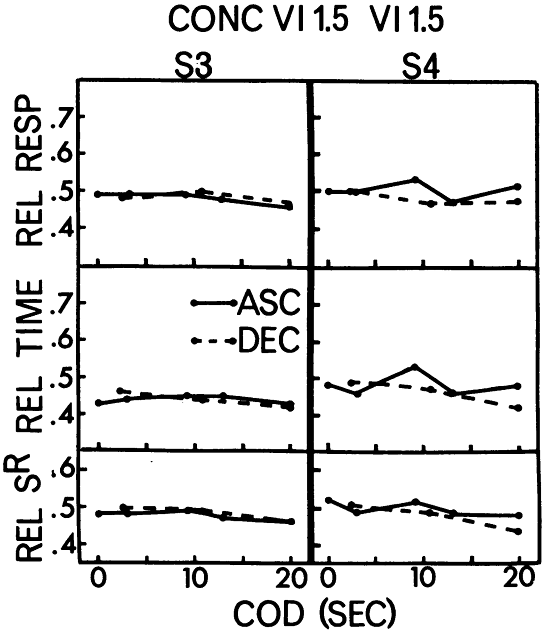

Fig. 2. Median relative response rate, relative time and relative reinforcement rate plotted against the duration of the COD. The schedules were Conc VI 1.5-min VI 1.5-min, and the three statistics were computed with respect to the VI 1.5-min schedule associated with the tone stimulus.

The ascending series of COD durations showed no systematic trend with respect to any of the relative performance measures as COD duration was increased. The descending series of COD durations appears to have been correlated with a very slight, systematic (and probably unimportant) trend. Relative reinforcement rate and relative time increased with decreasing COD duration. The increases were small, about 0.06, from COD = 20 sec to COD = 2.5 sec. The trend did not appear clearly in the relative response rate statistic for either rat.

Figures 3 and 4 show the effects of COD duration on changeover rates. Note that the legend for these figures is different from that for the preceding figures. The solid and dashed lines represent the frequencies of changeovers per 100 sec of cumulated time for the indicated VI schedules. In general, the lower a changeover rate for an indicated schedule, the less the disposition to terminate an assignment of that schedule to the main lever. The results of the ascending series of COD durations for each rat are shown in the upper halves of the figures, and the results for the descending series, in the lower halves.

There was an inverse relationship between the rate of changeovers and the duration of the COD. When the VI schedules of the concurrent pair provided reinforcements at different rates (Fig. 3), the changeover rate was higher for the VI schedule that provided fewer reinforcements. In other words, the rat was more likely to changeover from VI 3-min to VI 1-min than vice versa. When, however, reinforcements were provided at the same rate (Fig. 4), changeovers occurred at about the same rate for the two VI schedules.

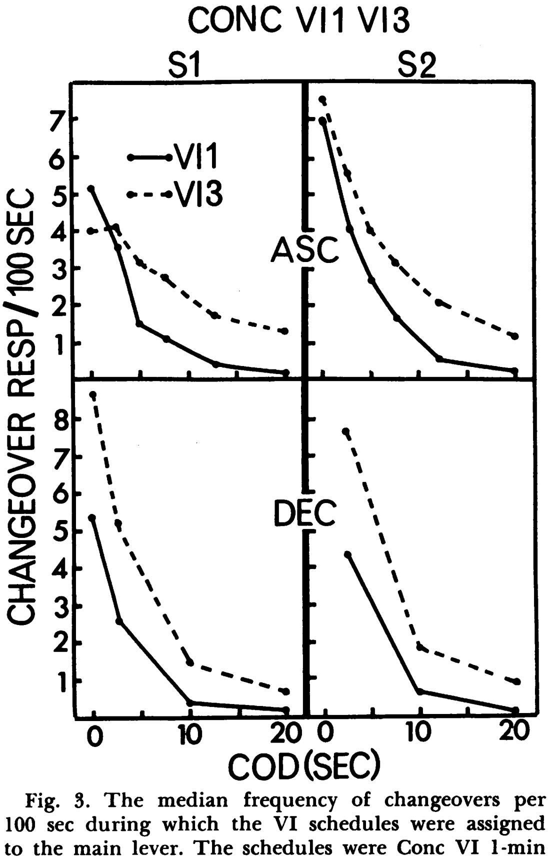

Fig. 3. The median frequency of changeovers per 100 sec during which the VI schedules were assigned to the main lever. The schedules were Conc VI 1-min VI 3-min.

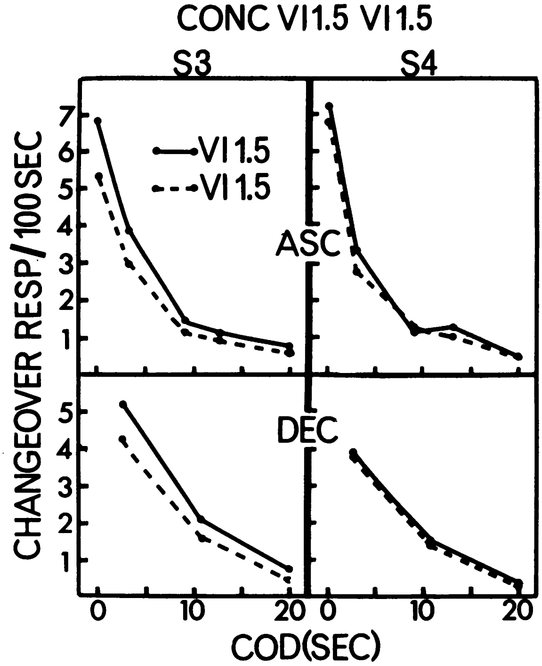

Fig. 4. The median frequency of changeovers per 100 sec during which the VI schedules were assigned to the main lever. The schedules were Conc VI 1.5-min VI 1.5-min.

The data just described are presented in a different way in Fig. 5.

For Rats S1 and S2, the changeover rate on the VI 3-min schedule was divided by the changeover rate on the VI 1-min schedule, and the resulting ratios have been plotted against values of the COD. It is evident from Fig. 5 that the ratios are monotonically increasing with increasing values of the COD. Stated otherwise, the larger the COD, the more rapid the changeover from the VI 3-min to the VI 1-min schedule *relative* to the changeover from the VI 1-min to the VI 3-min schedule. For Rats S3 and S4, the change-over rate on the VI 1.5-min schedule correlated with the click stimulus was divided by the changeover rate on the schedule correlated with the tone stimulus. It is clear from Fig. 5 that those ratios were not systematically changed by varying the COD.

When all of the data were collected, the four rats were sacrificed and perfused with saline and a 10% formaline solution. Frozen sections 50 μ thick were prepared, stained with Chresyl violet, and mounted for microscopic examination. Figure 6 consists of a photomicrograph for each rat; the heavy markers indicate the electrode tracks. During the experiment, the electrode tips for Rat S1 were lateral to the habenulo-interpeduncular tract. For Rat S2, the electrode tips were dorsal to the mammillary peduncle, and for Rat S3, they were just dorsal to the mammillothalamic tract and mammillary peduncle. The electrode tips for Rat S4 were somewhat more posterior than the placements described, resting in the ventral tegmental nucleus of Tsai.

Additional details of electrode-tip placements may be determined by examining the photomicrographs in conjunction with one of the standard atlases of the rat brain, *e.g.*, Massopust (1961), DeGroot (1959), Zeman and Innes' revision of Craigie (1963).

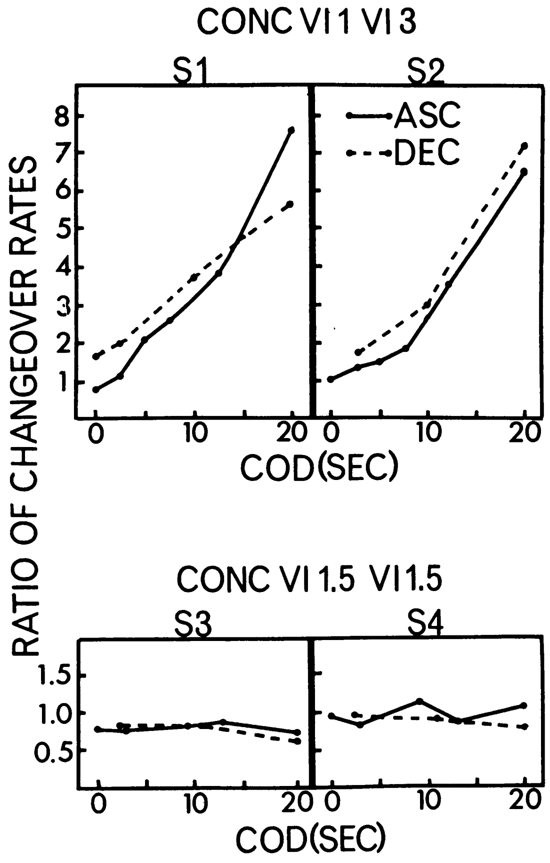

Fig. 5. Ratios of median changeover rates plotted against the duration of the COD. In the upper half of the figure, the schedules were Conc VI 1-min VI 3-min and the changeover rate for the VI 3-min schedule was divided by the changeover rate for the VI 1-min schedule. In the lower half of the figure the schedules were Conc VI 1.5-min VI 1.5-min, and the changeover rate for the VI 1.5-min schedule correlated with the click stimulus was divided by the changeover rate for the VI 1.5-min schedule correlated with the tone stimulus.

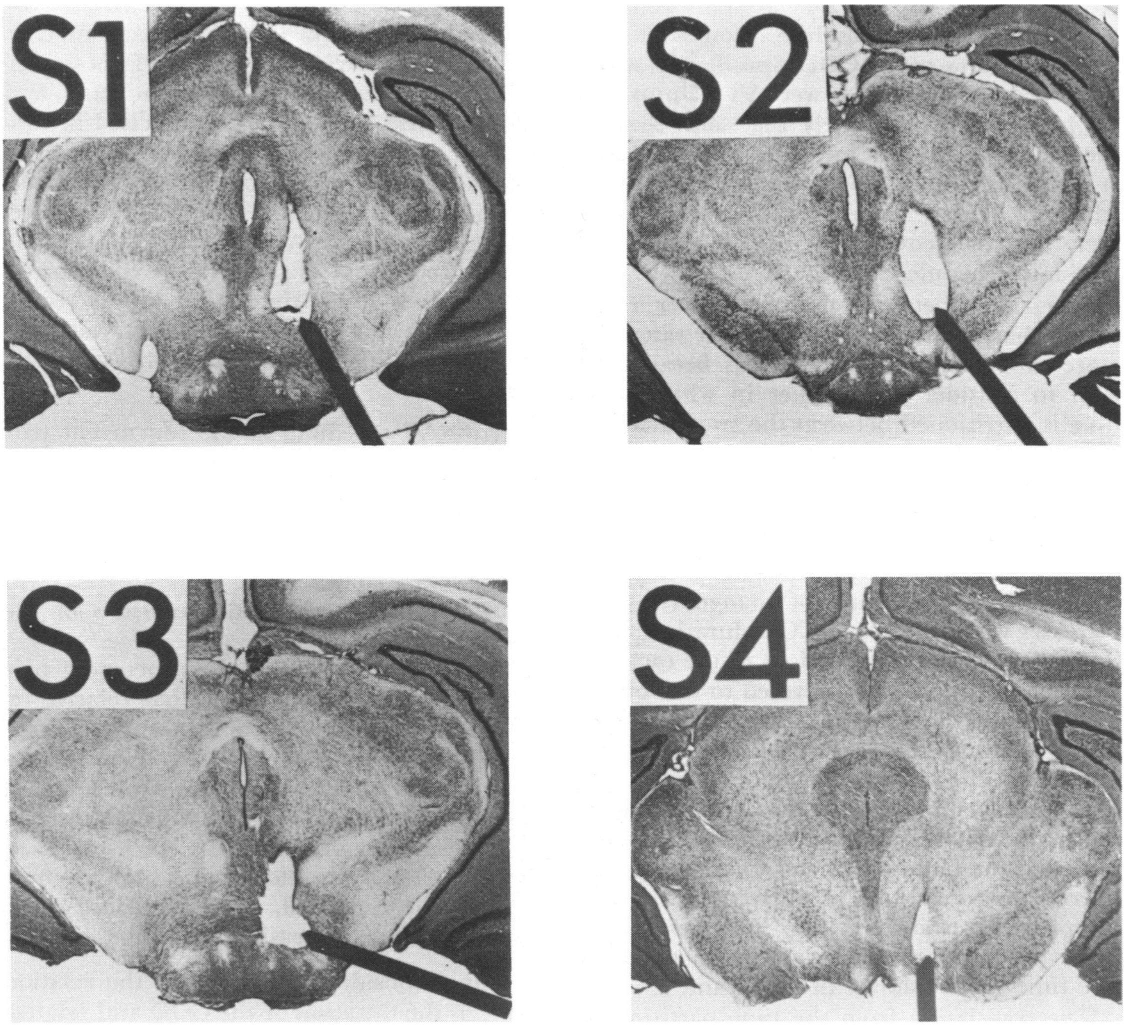

Fig. 6. Photomicrographs showing the electrode tracks. See text.

DISCUSSION

The purpose of the present experiment was to examine the effect(s) of COD duration on relative response rate and on changeover rate. The data showed that relative response rate depended on the duration of the COD when the VI schedules of the concurrent pair were VI 1-min and VI 3-min, but that relative response rate was independent of COD duration when the VI schedules of the concurrent pair were VI 1.5-min and VI 1.5-min. The findings were similar with the relative time statistic. Further, relative reinforcement rate was invariant with respect to COD duration when the VI schedules of the concurrent pair were VI 1.5-min and VI 1.5-min. However, when the VI schedules were VI 1-min and VI 3-min, relative reinforcement rate approximated the value 0.75 for COD durations from 0 to 7.5 sec; above 7.5 sec, the relative reinforcement rate rose, eventually attaining values about 0.90 at a COD duration of 20 sec.

That the COD is a programmed consequence of a changeover may suggest that the effects on relative response rate resulted indirectly from effects on changeover responding. Herrnstein (1961) showed with pigeons that the absolute number of changeovers per session was smaller with a 1.5-sec COD than with no COD. Our results with rats confirm Herrnstein's finding and extend it by revealing (a) a decreasing, concave upward function relating absolute changeover rate and COD duration, and, (b) the role of reinforcement rate in determining absolute changeover rate at a given value of the COD. Specifically, when the concurrent schedules were VI 1.5-min and VI 1.5-min, approximately the same changeover rate was observed for the two VI schedules at each COD duration; when the concurrent schedules were VI 1-min and VI 3-min, however, the changeover rate was higher on the VI 3-min schedule.

The ratios between the changeover rates, rather than the absolute changeover rates, are more interesting for our analysis because we wish to consider the manner in which total time is partitioned between the two VI schedules of the concurrent pair as the COD is varied. Total time will be evenly partitioned, for example, whether the absolute changeover rates are high or low, provided the changeover rates are equal or, stated differently, their ratio is unity. If the ratio of changeover rates increases with changes in COD duration, then increasingly larger proportions of the total experimental time will be devoted to one of the VI schedules. The results shown in Fig. 5 illustrate both relationships between COD duration and the ratios of changeover rates, the former when the VI schedules of the concurrent pair delivered reinforcements at the same rate, and the latter when the VI schedules delivered reinforcements at different rates. The computations shown in Fig. 5, therefore, explain (in fact, are redundant with) the relative time graphs shown in Fig. 1 and 2.

The translation from the time partition to the response partition, *i.e.*, from relative time to relative response rate, is suggested by an examination of Fig. 1 and 2, where there appears to be an isomorphism between the relative response rate and relative time functions. An isomorphism in detail between the relative response rate and relative time functions suggests that the manner in which responses are partitioned between the two VI schedules of a concurrent pair, *i.e.*, $R_t/R_t + R_c$, is determined by the time partition, $T_t/T_t + T_c$. Stated otherwise, responses on the main lever occur at a roughly uniform rate throughout the experimental session, and those responses are assigned to one or the other VI schedule as a consequence of the distribution in time of changeovers. This analysis is identical with that suggested by Catania (1966, p. 241), although he was concerned primarily with the control over the time partition exercised by manipulations of relative reinforcement rate. It is entirely likely that the COD is as important as relative reinforcement rate, and that the effect of the COD is exercised in conjunction with relative reinforcement rate by determining the changeover rates, the ratios of which determine the time and, hence, response partitions. In brief, and under the present conditions of rats as the experimental subjects and brain stimulation in the region of the posterior hypothalamus as the reinforcer, the following conclusions are warranted:

1. If the VI schedules of the concurrent pair are equal, so that relative reinforcement rate approximates 0.50 at a 0-sec COD, then the ratio of changeover rates approximates unity at larger durations of the COD, with the result that relative response rate will approximate 0.50 at all durations of the COD.
2. If the VI schedules of the concurrent pair are sufficiently unequal so that relative reinforcement rate differs substantially from 0.50 at a 0-sec COD (*e.g.*, 0.75, as in the present experiment), then the ratio of changeover rates increases with increases in the duration of the COD. As a result of the increase in the ratio of changeover rates, the time and, hence, response partitions become increasingly extreme.

A final consideration concerns the relation between the duration of the COD and relative reinforcement rate. The analysis in the case of Conc VI 1.5-min VI 1.5-min is straightforward. Since relative time approximated 0.50 at all durations of the COD, it follows that roughly equal numbers of reinforcements should have been obtained from each of the VI schedules at all durations of the COD studied. That result is illustrated in Fig. 2; relative reinforcement rate approximated 0.50 at all values of the COD. The analysis in the case of Conc VI 1-min VI 3-min is slightly more involved. At the 0-sec COD, absolute changeover rates were sufficiently high that reinforcements were produced almost as soon as each VI schedule assigned them. Since the VI 1-min could assign reinforcements about three times as often as the VI 3-min, the relative reinforcement rate computed with respect to the VI 1-min was close to 0.75.

Even moderate increases in the duration of the COD served to decrease absolute changeover rates and to increase the ratio between the changeover rates. The decrease in absolute changeover rates increased the probability that a reinforcement would be programmed by the VI schedule not assigned to the main lever, and those reinforcements were "held" for periods of time before they were obtained. The "hold" time consisted of the time between the assignment of the reinforcement and the occurrence of a changeover plus the duration of the COD incurred by the changeover. Not all reinforcements were produced after "hold" time, since many reinforcements were programmed and produced without the intervention of a changeover. The VI 1-min schedule assigned more reinforcements than the VI 3-min, and more of those reinforcements were produced without the intervention of a changeover, since the time partition favored the VI 1-min schedule. In short, "held" reinforcements were distributed about evenly between the VI 1-min and VI 3-min schedules at moderate durations of the COD, with the result that the relative reinforcement rate remained at about 0.75. The relatively flat portions in the relative reinforcement rate curves (ascending) from COD = 0 sec to COD = 7.5 sec shown in Fig. 1 illustrate that effect particularly well. Had COD = 7.5 sec been reexamined during the descending series, the same result might have been clear during the descending series for Rat S1. Even so, it was illustrated rather well during the descending series for Rat S2.

At the larger durations of the COD, the relative reinforcement rates rose to 0.90. That effect resulted most probably from the increasingly extreme time partitions at the larger values of the COD. At extreme values of the time partition, the rats spent relatively little time in the presence of the VI 3-min schedule, and the probability was greater than at smaller durations of the COD that reinforcements were assigned by the VI 3-min schedule during the time that that schedule was not in effect on the main lever. The reinforcements so assigned were subject to "hold" time, during which reinforcements were produced on the VI 1-min schedule almost immediately after assignment. As accumulated "hold" time became large, fewer than 25% of the total number of reinforcements were provided by the VI 3-min schedule, with the result that relative reinforcement rate with respect to the VI 1-min schedule increased to the values observed at the longest durations of the COD.

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