CHOICE, RATE OF REINFORCEMENT, AND THE CHANGEOVER DELAY¹

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Pigeons distribute their responses on concurrently available variable-interval schedules in the same proportion as reinforcements are distributed on the two schedules only when a changeover delay is used. The present study shows that this equality between proportions of responses and proportions of reinforcements ("matching") is obtained when the value of the changeover delay is varied. When responses are partitioned into the set of rapid response bursts occurring during the delay interval and the set of responses occurring subsequently, the proportion of neither set of responses matches the proportion of reinforcements. Instead, each set deviates from matching but in opposite directions. Matching on the gross level results from the interaction of two patterns evident in the local response rates: (1) the lengthening of the changeover delay response burst is accompanied by a commensurate decrease in the number of changeovers; (2) the changeover delay response burst is longer than the scheduled delay duration. When delay responses are eliminated by introducing a blackout during the delay interval, response matching is eliminated; the pigeon, however, continues to match the proportion of time spent responding on a key to the proportion of reinforcements obtained on that key.

In concurrent variable-interval (Conc VI VI) schedules of reinforcement, a single schedule of reinforcement may be associated with each of two response keys. Each schedule comprising a pair is independent of the other in that reinforcements received for responding on one key have no effect upon the assignment of reinforcements on the second key. These schedules have been used to determine the relation between the proportion of responses on one of two keys (responses on a key divided by the response total on both keys) and the proportion of reinforcements (reinforcements on a key divided by the reinforcement total on both keys) available on them. Herrnstein (1961), for example, found that the proportions of pigeons' responses to one of two keys equalled (matched) the proportions of reinforcements obtained on that key, provided that a changeover delay (COD) was employed. The COD used by Herrnstein specified the minimum time during which reinforcement was unavail-

able between a changeover from responding on either key to responding on the other. Suppose that a reinforcement became available on the left key while the pigeon was responding on the right key. The first response on the left key would not be reinforced. To obtain reinforcement on the left key, the pigeon would first have to peck the left key once to initiate the COD interval. After the end of the COD interval, the next response on the left would be reinforced, provided that no intervening responses had been made on the right. If a response were made on the right before reinforcement had been obtained on the left, the COD requirement would have to be satisfied anew on the left.

Previous investigators (*e.g.*, Herrnstein, 1961, and Shull and Pliskoff, 1967) have concentrated on regularities that appear in the overall response rates on a key, even though the patterns and rates of responding generated during COD periods are different from those occurring after the COD has ended (Catania, 1963). By analyzing the effects of the COD upon the rates and patterns of responding both during and after the COD periods, the present series of experiments sought to clarify the role of the COD in choice behavior, particularly its involvement in the linear matching between proportions of reinforcements and proportions of

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Table 1

Order of procedures: number of sessions in each procedure; proportions of reinforcements, of total responses, of COD responses, of post-COD responses, and of time spent on the left key; number of changeovers to the left key; absolute rates of responding (in responses/min).

Subject	(a)		(b)	(c)	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii
	Left Key	Right Key	COD (in Sec)	No. of Sessions	Prop. of Reinforcements	Prop. of Re- sponses	Prop. of COD Re- sponses	Prop. of Post- COD Re- sponses	Prop. of Time Spent	Number of Change- overs	Rate of Respond- ing Left	Rate of Respond- ing Right	Rate of COD Re- spond- ing Left	Rate of COD Re- spond- ing Right	Rate of Post- COD Respond- ing Left	Rate of Post- COD Respond- ing Right
A	2.25	4.5	0.88	45	0.68	0.60	0.58	0.61	0.52	739	139.5	103.7	257.9	188.6	107.2	77.4
	13.5	1.69	0.88	45	0.12	0.17	0.55	0.09	0.10	271	176.0	96.3	261.4	213.9	122.1	90.9
	1.88	7.5	0.88	45	0.80	0.72	0.50	0.85	0.69	580	135.4	112.7	250.5	254.7	115.6	53.9
B	4.5	2.25	1.75	75	0.33	0.35	0.62	0.23	0.23	129	59.3	33.0	182.2	109.5	33.9	28.9
	7.5	1.88	1.75	58	0.20	0.18	0.41	0.11	0.18	167	109.2	107.9	187.1	233.4	77.8	99.6
	13.5	1.69	1.75	45	0.11	0.20	0.50	0.11	0.12	146	108.9	57.9	177.2	175.2	70.0	51.9
C	2.25	4.5	1.75	80	0.67	0.62	0.26	0.84	0.81	174	32.7	83.5	78.6	221.5	29.5	30.2
	1.88	7.5	1.75	45	0.80	0.90	0.37	0.95	0.78	69	67.6	26.5	75.8	129.2	67.4	12.6
	1.69	13.5	1.75	45	0.88	0.84	0.35	0.94	0.90	104	51.4	86.8	104.0	192.9	49.6	37.9
E	4.5	2.25	0.88	65	0.36	0.38	0.49	0.30	0.35	358	83.6	73.8	326.8	344.2	43.8	51.4
	7.5	1.88	0.88	45	0.20	0.22	0.56	0.11	0.10	196	168.8	68.5	370.7	294.1	86.5	60.8
	1.69	13.5	0.88	58	0.88	0.80	0.61	0.88	0.83	253	64.9	77.7	321.7	206.5	53.2	43.3
G	2.25	4.5	3.5	80	0.63	0.55	0.51	0.66	0.57	369	93.6	104.6	171.8	168.3	48.6	42.9
	13.5	1.69	3.5	45	0.12	0.19	0.53	0.06	0.09	107	126.7	54.1	146.6	108.8	89.0	50.0
	7.5	1.88	3.5	59	0.19	0.28	0.61	0.11	0.21	152	129.7	87.9	231.0	148.9	44.7	79.7
H	2.25	4.5	3.5	70	0.63	0.69	0.70	0.68	0.50	173	108.3	49.4	184.5	75.4	90.0	43.3
	1.69	13.5	3.5	45	0.91	0.93	0.36	0.97	0.95	25	46.6	72.9	88.2	164.1	4.6	38.9
	7.5	1.88	3.5	45	0.20	0.32	0.72	0.13	0.17	126	91.6	39.8	163.4	64.3	41.1	37.5

EXPERI-
MENT 1

Subject	VI Values Left Key	(a) (in Min) Right Key	(b) COD (in Sec)	(c) No. of Sessions	i Prop. of Retin- force- mentis	ii Prop. of Re- sponses	iii Prop. of COD Re- sponses	iv Prop. of Post- COD Re- sponses	v Prop. of Time Spent	vi Number of Change- overs	vii Rate of Respond- ing Left	viii Rate of Respond- ing Right	ix Rate of COD Re- sponding Left	x Rate of COD Re- sponding Right	xi Rate of Post-COD Respond- ing Left	xii Rate of Post-COD Respond- ing Right
EXPERI- MENT 2																
D	7.5	1.88	3.5	64	0.17	0.11	0.74	0.03	0.19	42	33.9	63.4	199.0	67.0	9.2	63.3
	7.5	1.88	0.88	47	0.20	0.12	0.62	0.04	0.09	86	66.1	47.7	306.1	191.3	24.1	45.5
	7.5	1.88	1.75	45	0.20	0.13	0.66	0.05	0.13	68	49.1	50.5	229.5	116.5	18.1	49.0
I	2.25	4.5	1.75	45	0.70	0.89	0.44	0.96	0.88	101	78.8	68.8	156.6	199.0	76.3	31.2
	2.25	4.5	3.5	45	0.67	0.90	0.42	0.97	0.86	68	106.4	70.3	145.6	200.4	104.6	23.6
	2.25	4.5	0.88	49	0.65	0.83	0.49	0.91	0.74	163	123.3	71.9	213.5	225.4	116.9	37.3
J	4.5	2.25	0.88	45	0.35	0.48	0.59	0.39	0.30	718	176.0	80.0	273.2	193.7	121.0	59.8
	4.5	2.25	3.5	45	0.36	0.35	0.51	0.28	0.38	228	52.6	60.2	66.5	64.3	41.7	59.1
	4.5	2.25	1.75	45	0.35	0.33	0.28	0.40	0.35	403	71.7	79.4	112.5	288.5	52.9	33.4
K	1.69	13.5	1.75	45	0.89	0.82	0.49	0.90	0.83	190	69.0	74.3	111.9	115.4	65.9	52.5
	1.69	13.5	3.5	45	0.90	0.89	0.37	0.97	0.93	72	61.6	93.8	66.4	115.8	61.4	62.1
	1.69	13.5	0.88	47	0.89	0.86	0.41	0.93	0.88	283	41.1	47.2	54.0	79.0	40.4	20.0
L	13.5	1.69	3.5	45	0.09	0.11	0.70	0.06	0.10	64	86.2	74.4	133.4	56.9	59.6	75.2
	13.5	1.69	0.88	45	0.12	0.16	0.57	0.07	0.13	190	58.8	48.1	119.0	91.2	26.0	42.6
	13.5	1.69	1.75	(beak injury)			(beak injury)						(beak injury)			
M	7.5	1.88	1.75	45	0.20	0.20	0.55	0.09	0.12	216	180.6	100.6	214.8	172.3	139.5	94.7
	7.5	1.88	0.88	46	0.21	0.30	0.46	0.23	0.15	521	226.7	92.3	195.9	227.9	259.2	101.4
	7.5	1.88	3.5	45	0.19	0.11	0.55	0.04	0.10	69	132.2	116.0	199.4	162.2	81.1	163.7

responses. The effects of the COD upon other performance measures, including the proportions of time spent responding on each key, were also examined.

METHOD

Subjects

Twelve male adult White Carneaux and King pigeons were maintained at approximately 80% of free-feeding body weights (determined during free access to grain). Six had been used in a prior study, without CODs, and six were experimentally naive.

Apparatus

The two identical experimental chambers used were modified picnic ice chests (Ferster and Skinner, 1957), each containing two translucent (Gerbrands) response keys mounted 9 in. (22.8 cm) above the floor. The left key was transilluminated by green light, the right key by red light. Transillumination was accomplished by stimulus lights mounted behind the response keys. A minimum force of 16 g (0.14 N) was required to operate each response key. Each response produced auditory feedback by operating a 110-v ac relay. The chamber also contained a solenoid-operated hopper that occasionally presented grain to the pigeon for 4 sec (reinforcement) and two 6-w lamps for general illumination. During reinforcement, the stimulus lights and the general illumination were turned off and the food hopper was illuminated.

Standard scheduling and recording equipment were housed in another room.

Procedure

After the naive pigeons received initial training with the food magazine and the response keys, all pigeons were exposed to five sessions of 30 reinforcements each with no COD. In these sessions, all changeovers from one key to the other key were reinforced; no other responses were reinforced. By the end of this training each pigeon had adopted a pattern of responding in rapid alternation between the two response keys.

In the first experiment, six pigeons were exposed to each of three variations in the relative frequency of reinforcement (Conc VI 2.25-min VI 4.50-min; Conc VI 1.88-min VI 7.50-min; and Conc VI 1.68-min VI 13.50-min) at a

single COD value (for two pigeons 0.875 sec, for two pigeons 1.75 sec, and for two pigeons 3.5 sec).²

In the second experiment, the duration of the COD was systematically varied. Each of six different pigeons was exposed to all three COD values and only one pair of the concurrent schedules listed above (two pigeons were exposed to each pair). Table I (columns a and b) indicates the order of presentation of COD intervals and concurrent schedules for each pigeon.

All data were tabulated from daily sessions, each of which ended after 60 reinforcements. Each pigeon in the first two experiments was maintained in a given experimental condition for a minimum of 45 sessions and until its response pattern was stable for the terminal five (consecutive) sessions. The stability criterion stipulated that the proportion of responses made to one key in each of the five sessions must be within 5% of the mean proportion for all five sessions. The number of sessions required in each condition is listed in Table 1 (column c).

Pigeons G, H, and I were studied in a third experimental procedure for 30 sessions subsequent to those listed in Table 1. Pigeons G and H continued on Conc VI 7.5-min VI 1.88-min with a COD value of 3.5 sec; Pigeon I was continued on Conc VI 2.25-min VI 4.5-min with a COD of 0.875 sec. During each COD interval, however, the keylights and general illumination were turned off. All responses that occurred during the blackout were recorded and received auditory feedback. In all other respects this "COD blackout" procedure was identical to that in effect in the first two experiments.

RESULTS

The data for each pigeon, averaged over the last five sessions in each of the first two experiments are presented in Table I (columns i through xii). Column (i) lists the proportion of reinforcements obtained on the left key, *i.e.*,

²The VI schedules each contained 10 interreinforcement intervals and were constructed according to Segal's (1964) procedure for generating random reinforcement intervals. The CODs were of the type used by Herrnstein (1961) and described in the introduction of the present manuscript. Two ATCOTROL timers were used to schedule the COD.

the number of reinforcements obtained on the left key divided by 60, the total number of reinforcements. Column (ii) presents the proportion of responses made on the left key, *i.e.*, the total number of left-key responses divided by the total number of responses on both keys. Column (iii) indicates the proportion of responses when only responses made during the COD are considered, *i.e.*, the number of responses during the left COD divided by the total number of responses made during the left and right CODs. Column (iv) presents the analogous proportions when responses during the COD are excluded, *i.e.*, the number of post-COD responses made on the left key divided by the total number of post-COD responses made on both keys. Column (v) presents the proportion of time spent responding on the left key. The times from which these latter proportions were calculated were recorded, for each session, in the following manner: the first response on a key started a running-time meter that operated until a response was made on the other key; thus the sum of the times for the two keys equalled the duration of the session. The number of alter-

nations or changeovers to the left key per session are listed in column (vi).

The marked difference between the proportions in columns (iii) and (iv) for birds in the first and second experiments shows that the proportion of responses on a key depended critically on whether responding was during or after the COD. Figure 1 presents typical cumulative records illustrating this effect. Responding on the key that provides the higher rate of reinforcement is sustained at a high rate. Responding on the other key, however, produces a stepwise pattern of (1) responding at a high rate during and immediately after the COD on this key and (2) no responding for a subsequent period. Moreover, the proportion of COD responses on the key providing the lower rate of reinforcement was higher than the proportion of COD responses on the key providing the higher rate of reinforcement for 26 of the 35 comparisons in Exp. 1 and 2 listed in Table I. This is in marked contrast to the proportion of post-COD responses: for each of the 35 comparisons, these proportions were above 0.50 on the key providing more frequent reinforcements.

Fig. 1. Sample cumulative records for each of three pigeons. The records are for Conc VI 13.5-min VI 1.68-min with COD = 0.875 sec (Pigeon A), Conc VI 7.5-min VI 1.88-min with COD = 1.75 sec (Pigeon D) and Conc VI 2.25-min VI 4.5-min with COD = 3.5 sec (Pigeon I). Downward deflections of the pen indicate reinforcements. For each record, note the stepwise pattern of responding on the key providing the lower rate of reinforcement. The length of the rapid bursts of responding ("COD bursts") on this key was a function of scheduled COD duration; this was true both within and across pigeons. Pigeon I did not match its proportion of responses to reinforcements. In the present procedure, for example, it obtained 67% of its reinforcements on the left, yet distributed 90% of its responses on the left. This was the largest deviation from matching observed in this study.

This analysis indicates that frequency of reinforcement had opposing effects upon the distribution of COD and post-COD responses. This can be seen as well in Fig. 2 and 3. Figure 2 shows the proportions of COD responses as a function of reinforcements (delivered, of course, for post-COD responses) for the first and second experiments. These data do not fit the locus of perfect matching represented by the diagonal. For both experiments, in fact, the proportion of COD responses tends to vary inversely with the rate of reinforcement: the

bulk of the data lies in the top-left or bottom-right quadrants of the figures. Figure 3 presents the data for the post-COD responding. Here, a clear, positive relation is indicated and each point falls in either the bottom-left or top-right quadrant of the figure. The data appear to differ systematically from the locus of perfect matching, however: for 29 of the 35 points of Exp. 1 and 2, more post-COD responses are made on the key providing more reinforcement than would be expected by

Fig. 2. Percent of COD responses on left key as a function of percent of reinforcements on left key for the first and second experiments. Each point represents the performance of a single pigeon averaged over the last five sessions on a single procedure. The 45° diagonal represents the locus of perfect matching.

Fig. 3. Percent of non-COD (*i.e.*, post-COD) responses on left key as a function of percent of reinforcements on left key for the first and second experiments. Each point represents the performance of a single pigeon averaged over the last five sessions on a single procedure. The 45° diagonal represents the locus of perfect matching.

matching. Hence, a total of only three points in the bottom-left quadrant are above the locus of perfect matching and only one in the top-right quadrant is below this locus (two other points fall on the locus).

The above data have been presented in terms of proportions of responses. Columns (vii) and (viii) present additional data for absolute rates of responding on each key, defined as the number of responses made on a key divided by the time in minutes spent on that key. If responding occurred at a uniform rate under either schedule, a possibility raised by Catania (1966, p. 241) and by Shull and Pliskoff (1967), these rates should be equal for both keys. Columns (vii) and (viii) show that they are generally not equal; moreover, the higher rates are sometimes associated with the key providing more reinforcements and sometimes with the key providing fewer reinforcements. The data from procedures in which the concurrent VIs were most discrepant, however, are consistent: for each of the 11 comparisons obtained with the Conc VI 13.5-min VI 1.68-min schedules, the rate of responding was higher on the VI 13.5-min, that is to say on the schedule providing the lower rate of reinforcement.

Columns (ix) and (x) present the response rates during the COD computed as the number of responses made during the COD divided by the time in minutes spent in the COD interval. These data are consistent with those of column (iii): rates of COD responding, as well as proportions of COD responses, were generally higher on the key providing fewer reinforcements. Columns (xi) and (xii) list response rates for post-COD periods and are presented for the sake of completeness. These values were defined as responses made on a key after the COD had terminated divided by the post-COD time, in minutes, spent on that key. For the key providing fewer reinforcements, almost all post-COD responding resulted from the continuation of the COD burst; hence, these values are high.

Figure 4 presents the results in the conventional manner (*e.g.*, Herrnstein, 1961) with no distinction between COD and post-COD responses. This is a plot of the proportion of all responses on a key against the proportion of reinforcements on that key for Exp. 1 and 2. In this case, the locus of perfect matching provides a reasonable description of the data. An

Fig. 4. Percent of total responses on left key as a function of percent of reinforcements on left key for the first and second experiments. Each point represents the performance of a single pigeon averaged over the last five sessions on a single procedure. The 45° diagonal represents the locus of perfect matching.

equally good approximation to matching is obtained when the proportion of time spent on a key is plotted on the ordinate. This plot is presented for each experiment in Fig. 5. The mean of the absolute deviations from matching is 0.07 for Fig. 4 and 0.06 for Fig. 5 (maximum deviations: 0.23 for Fig. 4, 0.19 for Fig. 5; in each case for Pigeon I with COD = 3.5 sec). There is no apparent reason for the consistently large deviations evinced by Pigeon I.

Despite the fact that COD length did not systematically affect the absolute deviations from matching (which may be readily com-

Fig. 5. Percent of time spent responding on left key as a function of percent of reinforcements on left key for the first and second experiments. Each point represents the performance of a single pigeon averaged over the last five sessions on a single procedure. The 45° diagonal represents the locus of perfect matching.

puted from Table I), COD length clearly affected changeover behavior. For each of the six pigeons exposed to different COD lengths (Exp. 2), Fig. 6 shows that the number of changeovers was an inverse monotonic function of COD length.

Table II presents the proportion of reinforcements, responses, and times for each of the three pigeons observed in the third experimental procedure in which darkness accompanied each COD period. For each pigeon, responding during the COD was effectively eliminated. In addition, for each pigeon, the

Fig. 6. Number of changeovers to the left key per session as a function of COD length for each of the six pigeons exposed to different CODs (Exp. 2). The data are averaged over the last five sessions on each procedure.

proportion of post-COD responding on the less-preferred key was reduced from what it had been in the previous procedure (*cf.* Table I). The proportions of times, however, continued to approximate the proportions of reinforcements.

Table 2
Data for "COD Blackout" Procedure

	Proportion of Reinforcements	Proportion of Time Spent	Proportion of Responses
Pigeon G	0.19	0.16	0.02
Pigeon H	0.19	0.15	0.07
Pigeon I	0.37	0.32	0.07

DISCUSSION

Herrnstein's (1961) experiment showed that the COD can have profound effects upon choice behavior. Specifically, he showed: (1) the matching function between proportions of responses and proportions of reinforcements was obtained only when a COD was employed; (2) the COD reduced changeovers between keys. Shull and Pliskoff (1967) performed a more extensive investigation of the effects of the COD, which is discussed below. Neither of these studies, however, analyzed differences in responding during and after the COD period.

The present study demonstrated that a more complete picture of the effects of the COD upon concurrent performance is obtained when responses are partitioned into COD responses and post-COD responses. Figures 2 and 3 and Table I demonstrate that only for post-COD responding, is the proportion of responses on a key a positive function of the proportion of reinforcements obtained on that key. Responding during the COD is at a relatively high rate on each key; there was a tendency, however, for these response rates to be higher on the key providing fewer reinforcements, despite the fact that the probability of a reinforcement for the first response after the COD was generally higher for the key providing more reinforcements. Thus, this tendency cannot be explained simply by recourse to the local probabilities of reinforcement.

The high COD rates on both keys may, however, be explained by the higher probability of reinforcement of a response immediately following the COD than of subsequent (post-COD) responses. This results from the continued operation of the VI timer associated with one key while the organism is responding on the other key and during the subsequent period when it is satisfying the COD period on the first key. If the VI timer were stopped during these periods, the COD rates might be reduced to the post-COD level; this hypothesis was not tested in the present study.

Despite the clear effects of COD length upon responding, Fig. 4 and Table I indicate that approximate matching was obtained regardless of the COD value in effect. A descriptive account of how matching was achieved is straightforward: as the COD length increased, the length of the COD burst pictured in Fig. 1 increased but was accompanied by a commensurate decrease in the number of changeover responses.

Figures 2 and 3 and Table I demonstrate that only for post-COD responding is the distribution of responses a positive function of the distribution of reinforcements. Furthermore, Fig. 3 indicates that the proportion of post-COD responses made on a key does not match the proportion of reinforcements: more post-COD responses are systematically made on the key providing more reinforcements than would be predicted by matching. These opposite tendencies, depicted in Fig. 2 and 3, combine to produce the better approximation

to matching seen in Fig. 4 when COD and post-COD responses are added together. In sum, matching occurs on a gross level although it does not occur for either COD or post-COD responses.

Up to now, a dichotomy has been maintained between COD and post-COD responses. There is a sense in which this partition is artificial, however: the COD response burst typically continued into the post-COD period. Thus, the post-COD response totals include some responses made at the higher COD response rate. Figure 1 indicates that virtually all responses on the key providing fewer reinforcements occurred as part of the COD burst. This suggests that a measure of responding that totally excluded the COD burst would produce a different picture than that of Fig. 3. In particular, the deviations from the locus of perfect matching should be accentuated if the post-COD responses were uncontaminated by the perseveration of COD responding; the data points should be lower in the bottom-left and higher in the top-right quadrants of Fig. 3. The data for Pigeons G, H, and I in the third experimental condition, which eliminated COD responding, support this prediction. For the two pigeons with a COD of 3.5 sec the proportion of post-COD responses on the non-preferred key was sharply reduced when COD responses were eliminated. A smaller reduction occurred for Pigeon I, which had a COD of 0.875 sec. As indicated in Table II these three data points differ dramatically from the locus of perfect matching. Thus, the linear matching function between responding and reinforcements obtained by Herrnstein (1961), and in Fig. 4 of the present experiment, depends not only upon the interaction of COD and post-COD response patterns, but also upon the perseveration of the COD response burst into the post-COD period.

Due to the large number of sessions required to satisfy the stability criterion in the present study, and due to the additional manipulation of the relative frequency of reinforcement, only three COD values were chosen. The middle value (1.75 sec) was selected because it was intermediate to those used in two prior studies reporting linear matching: 1.5 sec used by Herrnstein (1961) and 2 sec used by Catania (1963). The other values selected, 0.875 sec and 3.5 sec, were half and twice 1.75 sec respectively. The range of values used was sufficient

to alter sharply the number of changeovers and the length of the COD response burst following a changeover. Nonetheless, linear matching was obtained. With a sufficiently small COD value, of course, matching should not occur; in the extreme case, with no COD, both Herrnstein (1961) and Shull and Pliskoff (1967) failed to obtain matching. It is also clear that with a sufficiently large COD, responding should occur on one key only. This might be expected, for example, when the COD requirement is longer than the mean of the lower VI schedule. In this case, the subject decreases both its local and overall rates of reinforcement by a changeover to the higher VI. Although there are presently no data on this question, support for this hypothesis is obtained from a clear tendency in Shull and Pliskoff's data. They used CODs ranging up to 20 sec in a Conc VI 1-min VI 3-min schedule. When the COD was 20 sec, both of Shull and Pliskoff's rats distributed about 90% of their responses on VI 1-min; with shorter CODs, however, they distributed closer to 75% of their responses on the VI 1-min. Presumably, with CODs considerably larger than 20 sec all responses would occur on VI 1-min.

As indicated, Shull and Pliskoff found that subjects did not match proportions of responses to proportions of scheduled reinforcements when the COD value was 20 sec, or substantially larger than the values used in the present study. Nonetheless, each of their two rats matched proportions of responses to proportions of obtained reinforcements at this point. Indeed, the deviations from matching were smaller for the 20-sec COD points than for most of Shull and Pliskoff's data obtained with shorter COD values. Thus, matching was obtained both in the Shull and Pliskoff study and in the present one. This comparability of results is striking when the procedures in the two experiments are compared. Whereas the present study followed those of previous workers in rewarding pigeons with food, Shull and Pliskoff rewarded rats with brain stimulation. In addition, Shull and Pliskoff generally employed only five sessions per condition, rather than a stability criterion; a large number of sessions was required to achieve stable responding in the present study. Finally, Shull and Pliskoff employed a different method of concurrent scheduling (that of Findley, 1958) than the present one.

In sum, two sharply different experiments have established that the linear matching relation found by Herrnstein (1961) is also obtained when the value of the COD is manipulated. The present study also showed that this relation holds despite sharp differences in the local rates of responding both within and across pigeons and despite the fact that for each pigeon, neither responding during the COD nor responding after the COD matched the proportion of reinforcements on a key. Indeed, the reinforcement variable had opposite effects upon COD and post-COD responding, as shown in Fig. 2 and 3. Furthermore, when responding was reduced by the "COD-blackout" procedure, response proportions no longer matched reinforcement proportions. The time data, however, continue to indicate matching between the proportion of time spent responding on a key and the proportion of reinforcements on that key. Presumably, this time-matching reflects more molecular dynamics of the pigeon's decision-making process. On the basis of the present and previous experiments, however, these dynamics remain poorly understood, although Shimp (1969) has argued that the pigeon chooses the response that maximizes the momentary probability of reinforcement and that matching "results from averaging over many choices, no one of which obeys any matching principle."

The present experiment sought to clarify the role of the COD in choice behavior, particularly its involvement in the linear matching between the distribution of reinforcements and of responses. When the COD was varied, response-matching was still obtained. This occurred because (1) a commensurate decrease in changeovers accompanied the lengthening of the COD burst and (2) the COD burst was somewhat longer than the scheduled COD duration.

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