*CONCURRENT PERFORMANCES: SYNTHESIZING RATE
CONSTANCIES BY MANIPULATING
CONTINGENCIES FOR A SINGLE RESPONSE¹*

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An earlier experiment scheduled variable-interval reinforcement for pigeons' pecks on one key, and variable-interval reinforcement alternating with extinction, in a multiple schedule, for pecks on a second key. During the second key's extinction component, first-key pecking was relatively slow and continuous, rarely interrupted by second-key pecking; during the variable-interval component, first-key pecking was frequently interrupted by second-key pecking. When changeover delays operated, so that reinforced pecks on one key could not follow closely upon changeovers from the other key, rapid first-key pecking between interruptions compensated sufficiently for the time lost in second-key pecking that the overall rate of first-key pecking remained roughly constant across the alternating multiple-schedule components. The present experiments duplicated, on a single key, the temporal pattern of first-key pecking generated in the earlier experiments: components of continuous key availability were alternated with components of interrupted key availability. Approximately constant overall rates of responding were observed with a single-key equivalent of a changeover delay scheduled after interruptions and with manipulations of the on-off durations of the interruption cycle. Rate constancies in the original concurrent situation presumably depended on analogous contingencies that operated upon the concurrent responses, rather than on any constant "reserve" of responses.

Previous research (Catania, 1961, 1962) examined conditions under which the rate of responding maintained by variable-interval (VI) reinforcement is independent of changes in the rate of other, concurrently reinforced responses. For example, when a pigeon's pecks on one key are reinforced according to a VI schedule, and pecks on a second key are reinforced according to a multiple schedule in which VI reinforcement alternates with extinction (EXT), the rate of first-key pecking may remain invariant across the alternating second-key components.

This invariance and other properties of this type of performance are illustrated in the top frame of Figure 1. On Key A, a VI schedule operates continuously; on Key B, a multiple schedule operates, in which EXT in the presence of one stimulus alternates with VI rein-

forcement in the presence of a second stimulus. During the EXT component on Key B, pecks occur only on Key A and their distribution over the available time is fairly uniform. During the VI component on Key B, however, pecks occur on both keys, and Key-A pecking is therefore frequently interrupted by periods of Key-B pecking. But the higher momentary rate of Key-A pecking during Key B's VI component in this example sufficiently compensates for the interruptions that the overall rate of Key-A pecking remains roughly constant: about as many Key-A pecks are emitted during the EXT component of Key B as during the VI component of Key B. (The compatibility of such rate constancy with another phenomenon, reinforcement interaction in concurrent performances, has been treated elsewhere: Catania, 1966, pp. 252-253.)

Rate constancy similar to that illustrated in Figure 1 has been demonstrated with pigeons, rats, and squirrel monkeys, with responses of different topographies, and with variations in reinforcement schedules (Catania, 1966; Catania and Dobson, 1971). A critical feature in some of the procedures is the operation of a changeover delay (COD: Herrnstein, 1961), which prevents one response from coming

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Fig. 1. Illustration of rate constancy in a concurrent performance (top frame) and procedure for synthesizing constancy on a single key (bottom frame). In the top frame, vertical lines represent pecks; Key-A pecks are emitted at a moderate and relatively steady rate during the Key-B extinction component (EXT), but are emitted in short bursts at a higher rate during the Key-B variable-interval component (VI). In the bottom frame, this temporal pattern of Key-A pecking is duplicated on a single key by alternating a period of continuous key-availability with a period of interrupted key-availability. Details in text.

under the control of reinforcers scheduled for other, concurrent responses. After a change-over from one response to another, the COD prevents responses from being reinforced until some minimum time has elapsed. For example, if a COD operated during the performance illustrated in Figure 1, the first peck on one key after a peck on the other, and all subsequent pecks within the specified time interval, would be ineligible for reinforcement.

The present experiment examined the variables operating in concurrent performance by synthesizing the conditions for rate constancy on a single key. The lower frame of Figure 1 illustrates the basic procedure. The key is made unavailable, by turning off its light and making pecks on it ineffective, during periods of time that correspond to Key-B pecking in the concurrent performance. In the illustration, one component (continuous) corresponds to the relatively steady and uninterrupted Key-A pecking during Key B's EXT component; the other component (interrupted) corresponds to the interrupted Key-A pecking during Key B's VI component. Just as the VI schedule in the concurrent performance operates at all times, including periods of Key-B pecking, the VI schedule for the single key operates at all times, including key-off periods in the interrupted component. But just as Key-A reinforcement cannot occur during Key-

B pecking in the concurrent performance, reinforcement cannot occur in the single-key procedure when the key is off.

The key-off periods in the single-key procedure correspond to periods of Key-B pecking in the concurrent performance. Thus, a single-key equivalent of a COD can be scheduled by making the first peck in each key-on period, and all pecks that follow it within a specified time interval, ineligible for reinforcement. The present experiments examined performances maintained by this single-key procedure both with and without a COD-equivalent, and, guided by data on the temporal spacing of responses in concurrent performances, with various combinations of on- and off-durations in the interrupted component.

METHOD

Subjects

Four adult, male, White Carneaux pigeons were maintained at about 80% of free-feeding body weight. Pigeon 36 was about 9 yr old and Pigeons 92, 97, and 93 were each about 1.5 yr old at the start of the present experiments. Each pigeon had a history of key pecking in an undergraduate laboratory course in operant behavior and in exploratory procedures that preceded the present experiments.

Apparatus

A standard single-key pigeon chamber (Ferster and Skinner, 1957) included a house-light, a masking-noise source, a dc relay for providing feedback clicks, and a Gerbrands feeder for presenting mixed grain. During the 4-sec operation and illumination of the feeder, when all other lights in the chamber were off, the timing of other events in the chamber (*e.g.*, component durations) was discontinued. The Gerbrands key, which operated at a minimum force of 15 g (0.14 N), could be illuminated from behind by two green 6-w lamps. Key pecks produced feedback clicks only when the key was lighted. Events in the chamber were controlled and recorded by standard electro-mechanical equipment located in a separate room.

Procedure

Table 1 summarizes the sequence of procedures. The sequence of and duration of exposure to successive conditions were based on

detailed examination of individual performances, as discussed in Results. Each daily session consisted of alternating continuous and interrupted components, as illustrated in the bottom frame of Figure 1. During each component, an independent VI 180-sec schedule of reinforcement, designed according to the specifications of Catania and Reynolds (1968, Appendix II), operated for pecks on the lighted key. Scheduled reinforcements that remained available when a component ended were cancelled.

Both the houselight and key light were on and the VI schedule operated throughout continuous components. The houselight was on and the VI schedule operated throughout interrupted components, but the keylight was on (S^D) or off (S^A) according to a scheduled cycle of interruption. Each session began with a continuous component and ended with an interrupted component, and each interrupted component began with the keylight off and ended with the keylight on.

During Conditions 1 and 2 of Table 1, sessions consisted of sixty 120-sec components (120 min). Thereafter, sessions consisted of fifty 120-sec components (100 min), except that when the interruption cycle was 6-sec on and 3-sec off (Conditions 9, 10, and 11), sessions consisted of forty four 135-sec components (99 min). Thus, the number of interruption cycles in each interrupted component varied

with the on- and off-durations: 20 cycles with 3-sec on and 3-sec off and with 4-sec on and 2-sec off; 15 cycles with 4-sec on and 4-sec off; 10 cycles with 5-sec on and 5-sec off; and 15 cycles (in 135-sec components) with 6-sec on and 3-sec off.

During key-on periods in interrupted components when no COD-equivalent was scheduled, each key peck was eligible for reinforcement. Thus, if a VI reinforcement had been scheduled during the preceding key-off period, the first peck after the key lighted would be reinforced. When a COD-equivalent was scheduled, however, this peck was not eligible for reinforcement, and initiated a delay, as specified in Table 1, during which subsequent pecks were ineligible for reinforcement; only the first peck after this delay could be reinforced. Thus, a minimum of two pecks in each key-on period was required for reinforcement when a COD-equivalent was scheduled during interrupted components.

Pecks during key-off periods were ineligible for reinforcement. During preliminary studies, all key-off pecks reset the timing of key-off periods and cancelled any VI reinforcements that had been scheduled. This procedure, which reduced key-off pecking to negligible levels, was maintained throughout the present experiments.

Because VI reinforcement could be scheduled but pecks were ineligible for reinforcement

Table 1

Conditions and data (arithmetic means across the last five sessions). On-Off—Interruption cycle in sec; COD-equiv—Changeover-delay equivalent in sec; R_c and R_i —Responses per minute during continuous and interrupted components, respectively. The order of conditions is shown in parentheses:

Sessions	On-Off	COD-equiv	Pigeon 36			Pigeon 92			Pigeon 97			Pigeon 93		
			R_c	R_i	R_i/R_c	R_c	R_i	R_i/R_c	R_c	R_i	R_i/R_c	R_c	R_i	R_i/R_c
62 (7)	3-3	None	54	24	0.44	115	60	0.52	61	43	0.71	73	51	0.70
28 (5)	3-3	1.2	83	61	0.74	122	82	0.67	74	92	1.26	70	63	0.91
8 (6)	3-3	1.5	79	65	0.82	120	85	0.71	74	91	1.23	72	67	0.93
15 (4)	4-4	0.6	69	50	0.73	122	88	0.69	87	62	0.70	99	72	0.73
10 (3)	4-4	1.2	87	66	0.75	136	82	0.61	92	79	0.86	92	59	0.64
13 (8)	5-5	None	50	18	0.36	116	56	0.48	91	52	0.57	65	37	0.56
68 (1)	5-5	0.6	73	54	0.74	134	83	0.62	73	56	0.77	90	73	0.82
16 (2)	5-5	1.2	86	66	0.77	155	85	0.55	90	64	0.71	102	76	0.74
41 (11)	6-3	None	57	44	0.77	105	79	0.75	64	42	0.71	72	62	0.86
17 (9)*	6-3	1.5	68	57	0.83	104	96	0.93	76	71	0.93	60	60	1.01
11 (10)	6-3	3.0	62	56	0.91	97	89	0.91	75	72	0.95	89	70	0.78
8 (12)	4-2	None	57	46	0.81	113	77	0.68	68	46	0.67	68	52	0.78
33 (13)	4-2	1.0	63	44	0.71	117	97	0.82	65	54	0.84	59	59	1.00
28 (14)	4-2	2.0	85	64	0.74	119	97	0.82	87	66	0.90	79	68	0.92

*Other procedures intervened for 91 sessions between Conditions 8 and 9.

ment during key-off periods in interrupted components, actual interreinforcement intervals in the continuous and interrupted components were not identical. For example, with an interruption cycle of 5-sec on and 5-sec off, half the reinforcements, on the average, were scheduled during key-off periods and, on the assumption that their scheduling was uniformly distributed within these 5-sec periods, at least 2.5 sec was added during which pecks were ineligible for reinforcement. The net effect of 2.5 sec added to half the intervals was a nominal VI schedule of 181.25 sec. No attempt was made to correct for this effect, because of its small magnitude and its correspondence to the effect of interrupted pecking in the concurrent performances upon which the procedure was based.

RESULTS

Some properties of the single-key performances of the present experiments are illustrated in Figure 2, which shows sample cumulative records for Pigeon 92. The recorder operated throughout both continuous and interrupted components. Thus, records ob-

Fig. 2. Sample cumulative records for Pigeon 92. Continuous and interrupted components alternate, with the pen displaced downwards during interrupted components; pips represent reinforced pecks. Relatively steady pecking during continuous components alternated with bursts of pecks separated by pauses during interrupted components. With on- and off-periods of 3 sec and no changeover-delay equivalent (COD equiv), about half as many pecks were emitted during interrupted components as during continuous components (left records). Adding a 1.5-sec COD-equivalent increased pecking during interrupted components, but the total pecking remained less than during continuous components (middle records). With on-periods of 6 sec and off-periods of 3 sec, approximate rate constancy was obtained; roughly the same number of pecks was emitted during interrupted components as during continuous components (right records).

tained during continuous components show relatively steady, uninterrupted responding; records obtained during interrupted components, however, show a steplike grain, corresponding to alternations between responding during key-on periods and pauses during key-off periods.

With equal key-on and key-off periods of 3 sec each and with no COD-equivalent in interrupted components, the momentary rate of responding during key-on periods was about equal to the rate during continuous components. Thus, because the key was on only half the time during interrupted components, the overall rate of responding during interrupted components was about half that during continuous components. This lower overall rate is shown by the slope of the interrupted components in the left-hand records of Figure 2; in this instance, the overall rate, taken over both key-on and key-off periods, is the appropriate measure, because it corresponds to the rate measure that would be taken for a response in a concurrent performance (*e.g.*, Key A of Figure 1, top frame). Interruption of VI responding by EXT components often generates higher momentary rates of responding than when VI responding is uninterrupted (*i.e.*, the phenomenon called behavioral contrast: Reynolds, 1961); the failure to obtain such a difference in momentary rates between the present interrupted and continuous components may have come about because these conditions alternated within individual sessions, or because the duration of key-on (S^D) and key-off (S^A) periods in interrupted components was relatively short (*cf.* Shimp and Wheatley, 1971).

When a 1.5-sec COD-equivalent was added to interrupted components with 3-sec key-on and key-off periods for Pigeon 92, the momentary rate of responding during key-on periods increased, but not sufficiently to compensate fully for the time lost during key-off periods; as shown in the middle records, the overall rate of responding during interrupted components remained lower than that during continuous components. The change from interrupted to continuous components had effective control over momentary rate of responding, even though the same key color was correlated with each component; examination of cumulative records showed that the higher momentary rate after the last key-off period

of interrupted components extended only briefly into the beginning of the next continuous component.

Detailed analysis of the relative times spent pecking each key in performances in which rate constancies had been obtained (Catania, 1961, Figures 5 and 6) showed that considerably more time was spent changing over to and pecking the key with the constantly operating VI schedule than changing over to and pecking the key with the multiple VI EXT schedule (*i.e.*, during Key B's component in Figure 1, Keys A and B respectively). The pigeon determines the time spent on a key in the concurrent performance, but the experimenter does so in the single-key procedure. Thus, to make the procedure more analogous to actual concurrent performance, the present experiments scheduled interrupted components with key-on periods longer than key-off periods. With 6-sec key-on periods and 3-sec key-off periods for Pigeon 92, the increased momentary rate produced by the 1.5-sec COD-equivalent resulted in an overall rate during interrupted components that approximated the rate during continuous components, as illustrated in the right-hand records of Figure 2.

The data for each pigeon under each condition are summarized in Table 1, which presents overall rates in both continuous and interrupted components, and the ratio of the interrupted-component rate to the continuous-component rate. When momentary rates during key-on periods are equal to rates during continuous components, this ratio equals the proportion of time the key is available during interrupted components; when rate constancy is approximated, this ratio approaches 1.0. Since the proportion of key availability is 0.50 with equal key-on and key-off periods, and 0.67 with key-on periods twice the duration of key-off periods, approximations to constancy measured in terms of this ratio cannot strictly be compared across these two procedures. The present analysis, however, does not justify a more complex statistic.

The pattern of results was idiosyncratic for individual pigeons. For the group as a whole, close approximations to rate constancy were obtained with an interruption cycle of 6-sec on and 3-sec off and COD-equivalents of 1.5 sec and 3.0 sec. But approximations to rate constancy were also obtained for Pigeons 97 and 93 with an interruption cycle of 3-sec on

and 3-sec off and COD-equivalents of 1.2 sec and 1.5 sec. For each pigeon, the introduction of a COD-equivalent often produced rate increases in both continuous and interrupted components.

The sequence and duration of exposure of the pigeons to the various conditions was in part determined by a detailed analysis of the properties of each pigeon's performance: latency from the onset of a key-on period to the first response; persistence of responding through the key-on period; and proportion of key-on periods in which no responses occurred. Across conditions, mean latencies (seconds) over the last five sessions ranged from 0.9 to 1.5 for Pigeon 36, 0.4 to 0.8 for Pigeon 92, and 0.6 to 1.4 for both Pigeon 97 and Pigeon 92, except that longer mean latencies were obtained from each pigeon in Condition 10. Some pigeons tended occasionally to stop pecking during the last 1 or 2 sec of key-on periods with key-on durations of 5 sec and 6 sec. Proportion of key-on periods in which no peck occurred was usually less than 3% and never more than 5% for all pigeons in Conditions 1 through 8, except for Pigeon 97 in Condition 6, when it was 9%; the proportion in Conditions 9 through 14 ranged from 1 to 7% for Pigeon 36, 2 to 9% for Pigeon 92, 7 to 13% for Pigeon 97, and 2 to 10% for Pigeon 93. No systematic relationships of these data to the interruption-cycle and COD-parameters were obtained across pigeons. For example, when a COD-equivalent increased the overall rate of responding in the interrupted component for two pigeons in a given condition, it sometimes did so by decreasing the first-response latency for one pigeon and by increasing the momentary rate of responding for the other.

Nevertheless, although there were differences from pigeon to pigeon, the performances of each pigeon were consistent throughout extended exposure to a given condition. The rapidity of the effect of introducing a COD-equivalent is illustrated in Table 2, which presents the ratio of interrupted-component rate to continuous-component rate over eight sessions. (For Pigeons 92, 97, and 93, this was the first exposure to COD-equivalents; the data are not presented here in more detail because other procedures were introduced in the sessions immediately following those in the table.) The effects of the COD-equivalent, however,

Table 2

Ratio of pecks during interrupted components to pecks during continuous components in eight 100-min exploratory sessions, with VI 120-sec, 120-sec components, and an interruption cycle of 5-sec on and 5-sec off. In Sessions 5 through 8, a COD-equivalent was scheduled. For Pigeons 92, 97, and 93, these sessions were the first exposure to a COD-equivalent in interrupted components.

Sessions	No COD-equivalent				COD-equivalent 0.6-sec			
	1	2	3	4	5	6	7	8
Pigeon 36	0.51	0.48	0.49	0.50	0.57	0.59	0.62	0.63
92	0.54	0.55	0.56	0.50	0.58	0.70	0.64	0.64
97	0.52	0.53	0.52	0.49	0.54	0.61	0.61	0.60
93	0.63	0.57	0.52	0.64	0.69	0.75	0.72	0.78

tended to persist for some time after its discontinuation (*e.g.*, note the consistent deviation from 0.67 of the interrupted-to-continuous ratio in Condition 11 of Table 1).

DISCUSSION

In summary, the data for individual pigeons showed that rate constancies could be approximated on a single key by appropriate adjustment of COD-equivalent and interruption cycles. In some instances, performance fell somewhat short of constancy (*e.g.*, the highest ratio obtained for Pigeon 36 in Table 1 was 0.91). This finding, however, may be consistent with the temporal properties of the present performances, which did not correspond precisely to those of the concurrent performances upon which they were based: bursts of responses in a concurrent performance begin with the first response, whereas the key-on periods in the present case began with the latency preceding the first response; the correspondence between periods of concurrent responding and key-on periods did not hold in instances when no response occurred in a key-on period; and, periods of concurrent responding vary in duration whereas the key-on periods were of fixed duration. It may also be critical that bursts of concurrent responses are initiated by the pigeon, whereas the key-on periods were not.

The finding that rate constancies in the single-key instance depended on a COD-equivalent confirms the conclusion that a COD is a necessary condition for the rate constancies obtained in concurrent performances. But previous accounts (*e.g.*, Catania 1966) have emphasized the role of the COD in maintaining the independence of the concurrent re-

sponses. The COD, however, also has other effects. When no COD or COD-equivalent operates, the first of a sequence of responses is eligible for reinforcement and therefore can sometimes be reinforced. When a COD or COD-equivalent does operate, the first response of a sequence is no longer eligible for reinforcement, and therefore the response that is reinforced must necessarily be a later response in a sequence. The COD therefore raises response rates because reinforcement of the last of a sequence of responses ordinarily generates more subsequent responding than does reinforcement of a single response (*cf.* Catania, 1971). This interpretation also accounts for the observation that the introduction of a COD-equivalent often raised rates during continuous as well as raising them during interrupted components in the present study.

The present rate constancies also depended on the durations of the key-on and key-off periods in the interruption cycle. These durations are analogous to the time spent at one or the other key in a concurrent performance. Thus, to the extent that rate constancies are consistently generated when a COD is added to the type of concurrent schedule illustrated in Figure 1, a question still remains: what variables determine that the pigeon distributes its time on the concurrent keys in such a way that rate constancies are generated? Whatever the answer to this question, it appears reasonable to conclude that rate constancies come about as a consequence of the operation of specific contingencies on each of the concurrent responses, and not as a consequence of response reserves (*cf.* Skinner, 1938; Catania, 1962) generated by the concurrent schedules of reinforcement.

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