**CONCURRENT SCHEDULES OF REINFORCEMENT:
EFFECTS OF GRADUAL AND ABRUPT INCREASES
IN CHANGEOVER DELAY¹**

TOM S. ALLISON AND KENNETH E. LLOYD

WASHINGTON STATE UNIVERSITY

Pigeons' pecks were maintained on concurrent variable-interval 1-min variable-interval 3-min schedules of reinforcement, with a changeover delay of 2 sec. When changeover delay was increased successively to 5.0, 7.5, and 12.5 sec (Exp. I) the actual relative rate of reinforcement for the variable-interval 3-min key decreased progressively for two birds, abruptly for two other birds, and the subjects devoted proportionately less of their time and responding to that key. However, the relative performance measures (relative time and relative responding) approximated the actual relative rate of reinforcement, with a maximum discrepancy of 11%, over all changeover delay values investigated. Experiment II attempted to lengthen response-run durations on the variable-interval 3-min key so that they were long enough to meet the changeover delay requirement at each new changeover delay value, by progressively increasing the changeover delay by 0.5-sec increments. With this procedure the actual relative rate of reinforcement approximated more closely the scheduled relative rate as changeover delay increased. As in Exp. I, relative performance measures approximated the actual relative reinforcement rate (maximum discrepancy 17%).

When concurrent variable-interval (VI) schedules are arranged with a changeover delay (COD), the relative response rate and relative time on a given schedule tend to approximate the relative reinforcement rate provided by that schedule (Findley, 1958; Herrnstein, 1961; Catania, 1963, 1966; Brownstein and Pliskoff, 1968; Baum and Rachlin, 1969; Schroeder and Holland, 1969). Shull and Pliskoff (1967), using brain stimulation as a reinforcer, and a switching-key concurrent scheduling procedure, found that with unequal concurrent VI VI schedules, rats directed proportionately more of their time and responding to the schedule with the higher frequency of reinforcement as COD increased. However, the correspondence between relative reinforcement rate and relative performance measures was essentially maintained in the Shull and Pliskoff study, since the proportion of rein-

forcement actually produced by the key with the higher frequency of reinforcement also increased as COD increased. Similar results were obtained by Silberberg and Fantino (1970) using pigeons, grain reinforcement, and a two-key concurrent scheduling procedure. However, the latter study examined the effects of a relatively narrow range of COD values (0.88, 1.75, and 3.5 sec).

The present experiments examined further the relationships between relative reinforcement, and a two-key concurrent scheduling relative time on a given schedule, as a function of COD, in unequal concurrent VI VI schedules. The purpose of Exp. I was to examine the degree of correspondence between relative reinforcement rate and relative performance measures as a function of a wider range of COD values, using pigeons, grain reinforcement, and a two-key concurrent scheduling procedure. The purpose of Exp. II was to determine whether the effects associated with increases in COD obtained in Exp. I were attributable to increased COD *per se*, or to the method of increasing COD. The method of increasing COD in Exp. I essentially followed the method used by Shull and Pliskoff (1967), in that COD increases were made abruptly rather than gradually. In Exp. II, the COD was always increased by 0.5-sec increments.

¹This research was supported in part by USPHS Grant M5936(A), and in part by the Washington State University Research Fund (K. E. Lloyd, principal investigator). During the research, the first author was supported by a research traineeship from the National Aeronautics and Space Administration. Portions of the present paper were submitted at Washington State University in partial fulfillment of requirements for the Ph.D. degree. Reprints may be obtained from T. S. Allison, Institute of Psychiatric Research, Indiana University School of Medicine, 1100 West Michigan Street, Indianapolis, Indiana 46202.

EXPERIMENT I

METHOD

Subjects

Four male naive 2-yr-old White Carneaux pigeons were maintained at 80% of their free-feeding weights during the experimental period.

Apparatus

A Grason Stadler experimental chamber for pigeons, with a three-key pigeon response panel, was modified by covering the center key so that only two end keys were exposed. The separation between keys was 8.0 in. (20.3 cm) center to center. Each translucent plastic key was illuminated from behind by a 10-w red (right key) or white (left key) light. The chamber was illuminated by a 10-w light except during presentation of the reinforcer (5-sec access to grain) when the keylights and house-light were out and the grain magazine was illuminated by a 10-w light. Data were collected on magnetic counters and cumulative recorders. The force required to operate each key was 10 g (0.098 N).

The amount of time a subject spent on a given key was measured by accumulating 1-sec timing intervals on magnetic counters. Time accumulated for a given key from the first peck on that key to the first peck on the opposite key. Thus, this measure included time when the subject was not actually responding, including time spent in changing between keys.

Preliminary Training

The pigeons were trained to peck a single response key. Both keys were illuminated by 10-w white lights during this phase of training. After key pecking was established, the birds were trained to peck a second key with the first key covered. Both keys were then exposed, and reinforcement was produced by a peck on either key only if the preceding reinforcement was of a peck to the opposite key. When simple alternation between keys was established, both keys were transilluminated with 10-w red lights until it was clear that the birds would respond reliably to both left and right keys of that color. The left key was then transilluminated with white light, and the right key with

red light for the remainder of the experiment. The schedule of reinforcement on each key was then changed from continuous reinforcement to VI 30-sec, the alternation requirement was dropped, and a 0.5-sec COD, timed from the first response on a key after changing over, was imposed between keys. When at least 25 responses had been reinforced on each key under this condition the reinforcement schedules were changed to concurrent VI 1-min VI 1-min. This condition was maintained for 15 sessions, and then the schedule on the right key was changed to VI 3-min. After seven sessions, the COD duration was increased to 2 sec.

Procedure

The experimental procedure consisted of increasing the COD duration with the concurrent VI 1-min VI 3-min schedules in effect. Successive COD values were 2.0, 5.0, 7.5, and 12.5 sec. Each COD value remained in effect for a minimum of five sessions (*cf.*, Shull and Pliskoff, 1967). A session lasted until 60 reinforcers were delivered. With frequent alternation between keys there were 45 reinforcers (75%) arranged by the VI 1-min key, and 15 (25%) by the VI 3-min key. No further COD increase was attempted for any bird if the number of reinforcers actually obtained on the VI 1-min key by that bird was 48 (80%) or more for five successive sessions. This criterion was adopted because it was felt that this reliable (though small) discrepancy between the frequency of reinforcement scheduled for the VI 1-min key, and the frequency actually produced by pecks on that key, might reflect poor experimental control (*i.e.*, COD increases too abrupt), and therefore, a need for a different method of increasing the COD (Exp. II).

RESULTS

A median based upon the last five sessions under each COD was obtained for (1) relative response rate (responses on one key/responses on both keys), (2) relative time (1-sec timing intervals accumulated on the counter associated with one key/total session time in seconds), and (3) relative reinforcement rate (number of reinforcers received on one key/total reinforcers received on both keys), with respect to the VI 3-min key (Fig. 1).

The maximum discrepancy between relative reinforcement and relative responding at any

Fig. 1. Relative time, relative responding, and relative reinforcement rate on the VI 3-min key, as a function of COD duration. The broken line at 0.25 represents the relative frequency of reinforcement scheduled for the VI 3-min key.

COD was 11%. The degree of correspondence between relative reinforcement rate and relative time was slightly better (maximum discrepancy of 7%). Increased COD did not appear to have any clear systematic effects on the degree of correspondence between relative reinforcement rate and the relative performance measures.

It can be seen that the degree of correspondence between relative reinforcement rate scheduled for the VI 3-min key, and the relative reinforcement rate actually produced on that key, decreased gradually as COD increased for Birds 6479 and 1864. The decrease in correspondence was more abrupt for Birds 6311 and 6862 (25% discrepancy at COD 5-sec). Table 1 shows the original data used to

calculate the median relative values and the number of sessions run with each COD.

EXPERIMENT II

In Exp. I, increasing COD did not appear to have any systematic effects on the degree of correspondence (matching) between relative performance and actual relative reinforcement rate. However, relative responding, relative time, and actual relative reinforcement rate for the VI 3-min key decreased as COD increased especially for Birds 6311 and 6862. It is not clear whether this decrease was a result of increased COD *per se*, or of the method of increasing COD. It is possible that the rate of increase resulted in subjects not producing all of the scheduled reinforcers on the VI 3-min key at the new COD value. This could happen when a subject's duration of responding on the VI 3-min key after a changeover was shorter than the new COD. In an attempt to ensure that the subjects would continue to contact the scheduled reinforcers on the VI 3-min key at each successive COD, COD was increased by 0.5-sec increments in Exp. II.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as those used in Exp. I.

Preliminary Training

Because concurrent performance was disrupted by the increased COD in Exp. I, it was necessary to retrain the subjects before manipulating COD in Exp. II. This was accomplished for Birds 6311 and 6862 by returning to COD 2-sec under concurrent VI 1-min VI 1-min schedules, until the rate of changing over between keys had increased enough to ensure that the birds would contact the contingencies of reinforcement on the right key when the VI 3-min schedule was reinstated on that key. Birds 6479 and 1864 received one session on forced alternation training before the concurrent VI 1-min VI 1-min COD 2-sec condition, and Bird 6479 was given two sessions with the VI 1-min and VI 3-min schedules reversed on the keys. These manipulations were necessary to reestablish a high rate of changing over between keys within a reasonable period of time. After this training, all

Table 1

The Original Data from Which the Medians Shown in Fig. 1 Were Calculated and the Number of Sessions at Each COD (Exp. I)

COD	Responses		Time		Reinforcements		Session
	VI 3-min	VI 1-min	VI 3-min	VI 3-min	VI 3-min	VI 1-min	
BIRD 6311							
2.0	1463	3917	824	2212	14	46	7
5.0	90	5082	125	3554	1	59	5
BIRD 6479							
2.0	1390	2723	710	2307	15	45	7
5.0	806	1870	412	2249	14	46	15
7.5	681	2165	309	2623	10	50	8
BIRD 6862							
2.0	931	1817	581	2585	14	46	15
5.0	38	2303	23	3719	0	60	5
BIRD 1864							
2.0	1433	3355	994	2193	15	45	10
5.0	1461	2772	749	2208	14	46	14
7.5	1551	3088	591	2338	13	47	7
12.5	979	2836	363	2659	10	50	10

birds were returned to concurrent VI 1-min (left key) VI 3-min (right key) COD 2-sec, the first condition of Exp. II.

Procedure

The procedure was the same as in Exp. I, except that COD was always increased by 0.5 sec.

RESULTS

The calculation of relative response rate, relative time, and relative reinforcement rate, (Fig. 2) was the same as in Exp. I. The maximum discrepancy between relative reinforcement rate and relative responding was 17%. The maximum discrepancy between relative reinforcement rate and relative time was 11%. There was a slight (9%) systematic decrease in correspondence between relative reinforcement rate and relative time for Bird 6311 as COD increased. However, there did not appear to be any other evidence of systematic effects of COD on the degree of correspondence between relative reinforcement rate and relative responding or relative time for any of the birds in Exp. II.

The degree of correspondence between scheduled and actual reinforcement rates decreased progressively as COD increased. However, the abrupt decreases in correspondence for Birds 6311 and 6862 did not occur in Exp. II as they did in Exp. I. The discrepancy between scheduled and actual reinforcement

rates at COD 5-sec for Birds 6311 and 6862 was 2% and 5%, respectively, in Exp II, compared to 23% and 25% at the same COD value in Exp. I.

The original data used to calculate the median relative response rate, relative time, and relative reinforcement rate, are shown in Table 2. Table 2 also shows the number of sessions conducted with each COD.

There was seldom any evidence of within-condition trends during the first five days at a new COD. The median values for relative reinforcement rate, relative responding, and relative time were as likely to be drawn from the first as from the last session. More than five sessions were conducted at some COD durations for different birds, to determine whether there might be trends beginning after the first five sessions. There did not appear to be any further systematic changes in performance after the first five sessions.

DISCUSSION

The results of both Exp. I and II indicate that the degree of correspondence (matching) between relative reinforcement rate and relative performance measures is essentially unaffected by COD duration within the range examined. However, the results do suggest that a more gradual increase in COD duration does help maintain a greater degree of correspondence between the scheduled relative rate of

Fig. 2. Relative time, relative responding and relative reinforcement rate on the VI 3-min key, as a function of COD duration. The broken line at 0.25 represents the relative frequency of reinforcement scheduled for the VI 3-min key.

Table 2

The Original Data from Which the Medians Shown in Fig. 2 Were Calculated and the Number of Sessions at Each COD (Exp. II)

COD	Responses		Time		Reinforcements		Sessions
	VI 3-min	VI 1-min	VI 3-min	VI 1-min	VI 3-min	VI 3-min	
BIRD 6311							
2.0	1400	2700	724	2933	15	45	5
2.5	1412	2380	759	1950	16	44	5
3.0	1854	2405	889	1941	16	44	5
3.5	1302	3038	655	2148	15	45	5
4.0	972	2530	650	2190	15	45	5
4.5	885	2945	415	2314	14	46	10
5.0	853	3485	383	2419	14	46	5
5.5	658	3837	299	2536	12	48	5
6.0	497	3633	258	2558	12	48	5
6.5	583	3693	254	2571	12	48	8
BIRD 6479							
2.0	775	2199	481	2242	15	45	6
2.5	861	2606	467	2171	14	46	5
3.0	687	2224	388	2370	14	46	6
3.5	579	1950	340	2218	14	46	5
4.0	593	2731	339	2447	13	47	5
4.5	617	2366	311	2415	12	48	5
5.0	420	2530	238	2687	10	50	5
BIRD 6862							
2.0	1086	1536	698	1987	16	44	5
2.5	722	1819	390	2323	15	45	14
3.0	623	1697	333	2384	14	46	5
3.5	697	1814	363	2339	14	46	5
4.0	651	1311	312	2407	13	47	5
4.5	569	1507	247	2614	12	48	5
5.0	538	1736	251	2578	12	48	5
5.5	395	1395	181	2776	11	49	5
6.0	495	1572	204	2785	10	50	5
6.5	390	1625	168	2920	7	53	5
BIRD 1864							
2.0	1321	2594	607	1972	16	44	7
2.5	1444	2909	665	2111	16	44	6
3.0	1366	2597	654	2013	15	45	6
3.5	1199	2923	528	2019	16	44	5
4.0	1350	2643	583	2028	15	45	5
4.5	1178	2976	550	2112	14	46	5
5.0	1281	2840	608	2150	15	45	5
5.5	1466	3234	684	1966	14	46	5
6.0	1257	3405	650	2148	14	46	5
6.5	774	2581	451	2304	13	47	7
7.0	982	3394	460	2465	13	47	5
7.5	1277	2808	653	2385	13	47	5
8.0	1020	2410	469	2396	11	49	6
8.5	1131	2231	580	2305	12	48	5
9.0	929	2315	560	2530	11	49	8

reinforcement and the actual relative reinforcement rate with some subjects.

It should be noted, however, that the effectiveness of a gradual increase in COD duration is limited by the interaction of COD with the concurrent schedules of reinforcement. With a COD of 5 sec, for example, 5 sec would have to transpire before reinforcement could occur on the VI 3-min key after a changeover,

assuming a reinforcer was primed for delivery, and 10 sec would have to transpire before reinforcement could occur on the VI 1-min key (5-sec COD in each direction). If the VI 1-min schedule included one interval of 0.0 sec, and one of 10 sec, as in the present experiments, there would be at least one occasion during each cycle of the VI-1min scheduling tape when the subject could receive two

reinforcers in less than 5 sec on the VI 1-min key, and one occasion when two reinforcers could be received in 10 sec. It is expected that this would tend to increase the probability of reinforcement for continued responding on the VI 1-min key, as opposed to changing over to sample the VI 3-min key. With more intervals of 10 sec or less on the VI 1-min schedule, the probability of reinforcement for continued responding on the VI 1-min key, as opposed to changing over, should be even higher, and the subject could be expected to devote more of its responding to that key, and make fewer changeovers. Ultimately, this would reduce the relative rate of reinforcement by the VI 3-min key, because the subject would fail to sample that key on some occasions when reinforcement could occur. The unobtained reinforcers on the VI 3-min key would be "held" until obtained, and such "hold" time would contribute to the intervals between reinforcers for that schedule (*cf.*, Shull and Pliskoff, 1967). Gradual lengthening of the COD could not be expected to maintain correspondence between the scheduled reinforcement frequency and the actual reinforcement frequency under these circumstances.

REFERENCES

- Baum, W. M. and Rachlin, H. O. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.
- Brownstein, A. J. and Pliskoff, S. S. Some effects of relative reinforcement rate and changeover delay in response-independent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 683-688.
- Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 253-263.
- Catania, A. C. Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 213-270.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 123-144.
- Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 267-272.
- Schroeder, S. R. and Holland, J. G. Reinforcement of eye movement with concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 897-903.
- Shull, R. L. and Pliskoff, S. S. Changeover delay and concurrent schedules: some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 517-527.
- Silberberg, A. and Fantino, E. Choice, rate of reinforcement, and changeover delay. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 187-197.

Received 6 August 1970.