

EFFECTS OF SYMMETRICAL AND ASYMMETRICAL CHANGEOVER DELAYS ON CONCURRENT PERFORMANCES¹

STANLEY S. PLISKOFF

UNIVERSITY OF MAINE, ORONO

Two variable-interval 3-min schedules functioned concurrently to arrange reinforcement of a pigeon's pecks on a single key, the main key. Each schedule was associated with a distinct color of the main key; a response on a second key alternated the color and schedule assignment of the main key. A changeover delay, a period of time following schedule and key-color alternation during which reinforcement of responding on the main key could not occur, was arranged with equal or with unequal durations for the two directions of alternation. Durations were varied from 0.33 sec to 27 sec, in addition to no delay. With equal delays for the two directions of alternation, the pigeon alternated the schedules less often the larger the delay duration. When the delays in the two directions of alternation were unequal, it could be shown that alternation of the schedules was reduced both by a delay just incurred by the last alternation and by a delay to be incurred by the next. The latter delay was more potent in reducing the frequency of alternations.

There has been much interest in the study of concurrent performances over the past 10 years. Earlier work was described by Ferster and Skinner (1957), but the major impetus probably comes from an experiment by Herrnstein (1961) and from the work of Catania (1966). Research has focused on concurrent performances as a means for studying the "reinforcement input-response output" relation (Herrnstein, 1961), as a procedural alternative to isolated and multiple schedules for studying variables such as amount of reinforcement (Catania, 1963; Pliskoff and Hawkins, 1967), and as a hope for gaining theoretical generality beyond the study of the single operant (Catania, 1966; Herrnstein, 1970; Pliskoff, Shull, and Gollub, 1968).

Concurrent performances are arranged by two (or more) schedules of reinforcement that operate simultaneously but assign reinforcements independently. When each schedule of a concurrent variable-interval pair is associated with different operanda, the organism typically alternates from responding on one operandum to responding on the other; other-

wise, reinforcers arranged by one of the schedules are not obtained. A sufficiently high rate of alternation, or changeover, as the switch of operanda has come to be called, produces with minimal delays all of the reinforcers assigned by both schedules.

Another method for arranging concurrent schedules employs a single operandum (Findley, 1958). Again, the schedules operate simultaneously and assign reinforcements independently. Each schedule is associated with a distinct exteroceptive stimulus, and only one schedule at a time is assigned to the operandum. A response on a second operandum alternates the schedule assignment and stimulus. A reinforcer arranged by one of the schedules is produced by a response only when the appropriate schedule is assigned to the operandum. The two methods for arranging concurrent schedules are formally equivalent and are often assumed to be functionally equivalent.

A "changeover delay" (Herrnstein, 1961) specifies a minimum delay between a changeover from one schedule to the other and the possibility of reinforcement; effects of that variable on concurrent performances have been studied by Catania (1966), Shull and Pliskoff (1967), Silberberg and Fantino (1970), and Stubbs and Pliskoff (1969). In each of those experiments, symmetrical delays were

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arranged, *i.e.*, delays of equal duration for changeovers in either direction, from schedule A to schedule B and from schedule B to schedule A. It has been found without exception that the frequency or rate of changeovers decreases with increasing duration of the changeover delay. An experiment briefly described by Catania (1966) arranged asymmetrical changeover delays; the durations studied were brief, and the pigeons emitted more responses on the schedule associated with the briefer changeover delay.

The present experiment employed concurrent variable-interval 3-min schedules of reinforcement in conjunction with both symmetrical and asymmetrical changeover delays.

METHOD

Subjects

A single male White Carneaux pigeon was maintained at about 80% of its free-feeding weight throughout the experiment. This bird had an extensive experimental history before the present research. Its immediately preceding experiment (by another experimenter) involved ratio schedules of several types.

Apparatus

The experiment was performed with a modified Lehigh Valley pigeon box fitted with two Gerbrands keys centrally mounted on the front wall, with centers 2.5 in. (6.35 cm) apart and 8.5 in. (21.6 cm) above the mesh floor. Each of the keys could be transilluminated from behind by colored light. A peck of about 15 g (0.147N) force was required to operate a key, and each operation produced a sharp, feedback click from a relay mounted behind the front wall. Routine electromagnetic equipment was employed throughout.

The variable-interval schedules of reinforcement described below were arranged by means of Gerbrands tape pullers that operated at 1 mm per second. The sequences of intervals, specified as averaged minimum interreinforcement durations, were arithmetic with the interval of longest duration equal to twice the average. One sequence consisted of 11 intervals, the other, 12.

Procedure

Following a single session during which each peck on the right key (the left key was dark-

ened and inactive) operated the feeder and alternated the key color between red and green, the bird was placed on a multiple schedule of reinforcement. Responding was reinforced on variable-interval 3-min (VI 3-min) schedules of reinforcement. After 26 sessions on the above procedure, the bird was placed on concurrent VI 3-min schedules of reinforcement.

Both VI 3-min schedules functioned simultaneously; each arranged reinforcers independently and each was associated with a particular color (red or green) of the right-hand (main) key. Only when the main key was appropriately colored could a peck produce a reinforcer assigned by the associated VI schedule; a single peck on the left-hand (changeover) key, which was transilluminated by white light throughout the experiment, alternated the color and schedule assignment for the main key. A reinforcement arranged by the schedule not assigned to the main key was held until the schedule assignment was alternated by a changeover. For the first 10 sessions of the procedure employing concurrent schedules, no changeover delay was used, *i.e.*, the first peck on the main key following a changeover could be reinforced. From the eleventh session on, except for the next to last condition of the experiment, a changeover delay was employed.

The changeover delay when scheduled was initiated by the first peck on the main key following a changeover.² Neither that first peck nor responding during the delay could be re-

²Using the changeover-key procedure, the delay incurred by a changeover from schedule A to schedule B may start with the last response on schedule A, the response on the changeover key, or the first response on schedule B. The first procedure has not been used, the second is most common, and the third is the one employed in this experiment, for two reasons. The experiment was performed before the second procedure had been so often reported in the literature and also because it seemed more analogous to the changeover delay most often used with the two-key procedure (*e.g.*, Herrnstein, 1961), where the first response on schedule B initiates the delay. An advantage of the procedure used in this experiment as compared with the most common procedure is that the delay is more exactly arranged, since when the changeover initiates the delay, the first response on schedule B may or may not be reinforced, depending on how much time is taken to move from the changeover key to the main key (and the availability of reinforcement).

inforced. A reinforcer arranged before the changeover, or arranged during the changeover delay, was produced by the first peck after the changeover delay expired. Following a changeover, the changeover key was darkened and inactivated until the first peck on the main key. If another changeover occurred during a changeover delay, the delay began anew.

The experimental variable consisted of various durations of the changeover delay, including no changeover delay. Both symmetrical and asymmetrical combinations of the changeover delay were studied. A symmetrical combination involved delays of equal duration following changeovers in either direction, from one VI schedule to the other and *vice versa*. An asymmetrical combination involved delays of unequal duration following changeovers in the two directions. The first column of Table 1 shows the various combinations of the changeover delay (COD); G and R refer to green and red, and the durations (in seconds) shown under each are the delays incurred by the first peck on a key of that color following a changeover. The second column of Table 1 shows the number of sessions devoted to each combination.

Experimental sessions were conducted daily, and each session was terminated after 60 reinforcements. The reinforcer was mixed grain, and the duration of a feeder operation was 4 sec, with small variations depending on weight trends. When the feeder was raised, the grain was illuminated by white light, while the rest of the chamber was darkened.

RESULTS

Table 1 contains summary data for the entire experiment. Both the total number of responses during each session in addition to only those responses that occurred during the changeover delays were recorded, and the third and fourth columns show those data averaged over the final five sessions of each condition. The fifth column shows the averaged elapsed time in seconds, less total feeder time but including changeover delay times, spent in the presence of each key color. The next to last column on the right shows the averaged number of reinforcers produced by pecking on the green key; subtraction from 60 yields the equivalent datum for the red key. The final

column shows the averaged number of changeovers that were initiated in the presence of each key color. All of the figures described below in connection with this experiment were prepared with calculations made from the data in Table 1. (Calculations were made separately for each of the two conditions involving changeover delays of 1 sec in either direction. The points plotted in the figures for that condition were obtained by averaging the separate calculations.)

(a) Symmetrical Changeover Delays

Figure 1 shows the number of changeovers per hour (unbroken line) and the number of main-key responses per changeover (dashed line) as a function of the changeover delay. Data are included only for the conditions involving delays of equal duration for changeovers in either direction.

The points plotted above N on the horizontal axis are for the condition involving no changeover delay, *i.e.*, the first response on the main key following a changeover could be reinforced. The points through which the graph lines are drawn were computed from data combined for the two key colors; the unfilled circles are points for the green key alone, and

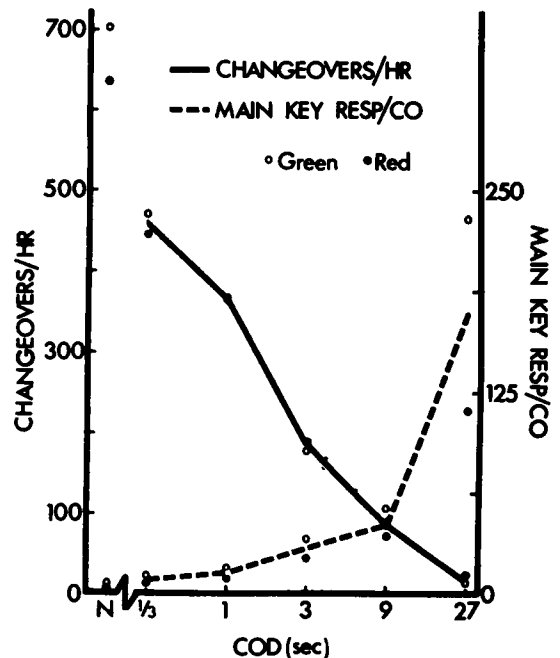


Fig. 1. Changeovers per hour and main-key responses per changeover (CO) as a function of the delay variable. The horizontal axis is logarithmic.

Table 1

Summary data for the experiment. The entries in columns three through seven are averages over the last five sessions of each of the experimental conditions shown in the first column. Ave cum = average cumulated, G = green, R = red, CO = changeover, COD = changeover delays. See text for further details.

Duration COD (sec)		No. of Sessions	Ave Cum Resp : Total		Ave Cum Resp : COD		Ave Cum Time : Total		Ave Reinf G	Ave COs	
G	R		G	R	G	R	G	R		G	R
1	1	64	5180	3660	1930	1550	2890	2830	30.8	325	325
3	3	21	5280	3500	2260	1310	2970	2850	31.4	149	149
9	9	10	4030	2610	1440	934	3080	3070	31.0	74.8	74.2
9	3	18	3290	2300	1470	651	2370	3690	29.4	82.8	83.0
3	9	18	3850	1380	374	635	4970	1570	35.6	49.4	49.2
9	1	21	2410	2250	1510	321	1590	5080	25.4	110	110
1	9	19	4020	1440	291	840	4710	1600	34.0	81.8	82.1
3	1	18	3640	2680	1250	625	2130	3640	29.6	146	146
1	3	18	3900	2230	520	895	3410	2360	31.4	167	167
1	1	12	4250	2450	1080	751	2840	2910	30.6	258	258
27	27	36	4870	2370	1010	994	4500	3240	33.4	20.8	20.6
27	3	20	300	7270	198	131	376	9670	7.0	12	12
3	27	19	7150	569	206	431	7940	693	48.2	26.2	26.0
27	9	19	2570	4690	709	492	2880	4440	26.4	30.0	29.6
9	27	18	6580	2070	567	661	5170	2340	38.4	30.2	30.2
27	1	18	671	8450	526	102	698	9080	11.4	28.6	28.6
1	27	20	8930	968	234	721	7360	1020	46.6	41.8	41.6
1	1	1	—	—	—	—	—	—	—	—	—
None	None	18	2930	2200	0	0	2830	3130	30.8	553	553
0.33	0.33	18	3590	3250	335	375	2780	2930	31.0	364	364

the filled circles, for the red key. In each instance, both data points are close to the curve except where the ordinate values are largest.

When a changeover did not incur a delay in either direction of changeover, the rate of changeovers was maximal, averaging 669 per hour for both key colors combined and 636 per hour for the red key alone. Correlated with those changeover rates, the number of main-key responses per changeover averaged slightly fewer than five; *i.e.*, the bird pecked the main key about five times between successive changeovers. When a 0.33-sec changeover delay prevailed, the average changeover rate fell to 459 per hour, and the average number of main-key responses preceding a changeover increased to about 10. Figure 1 shows the effects of additional increases in the size of the delay; both functions are monotonic. At the largest changeover delay studied, the changeover rate averaged just under 20 per hour, and the average number of main-key responses per changeover was 175, with 234 pecks preceding a changeover from the green key.

Figure 2 shows the rate of responding on the main key in thousands of responses per

hour. The horizontal axis is the same as that of Fig. 1. Two functions are shown. The unbroken line is the rate of responding for the duration of the changeover delay; the dashed function shows the rate of responding calculated for other times, *i.e.*, after the delay was

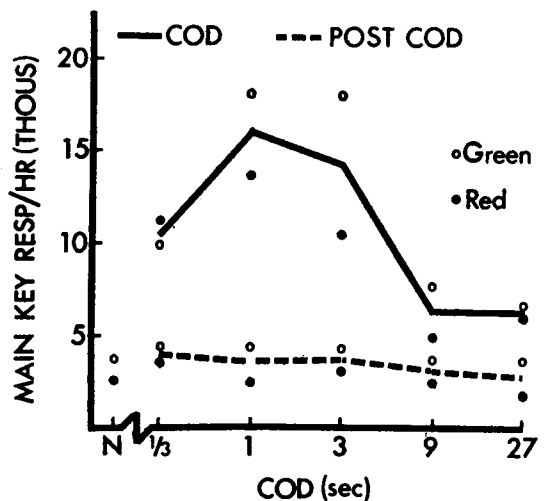


Fig. 2. Main-key responses per hour during (COD) and after (post COD) the duration of the changeover delay as a function of the delay variable. The horizontal axis is logarithmic.

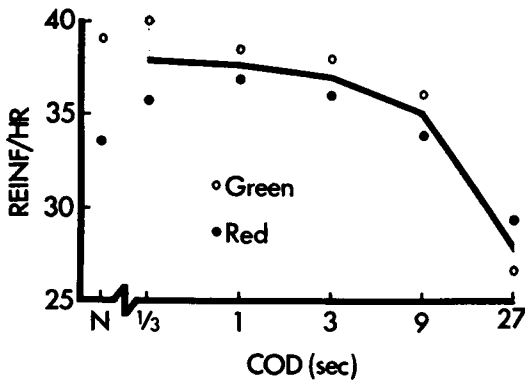


Fig. 3. Reinforcements per hour as a function of the delay variable. The horizontal axis is logarithmic.

completed (post COD). The two curves do not overlap, and a delay as brief as 0.33 sec produced a distinct difference in delay and post-delay response rates. The response rate during the delay passed through a maximum in the range from 1 to 3 sec, while post-delay response rate was relatively steady, although a distinct rise is evident at the 0.33-sec delay as compared with no delay (N).

Figure 3 shows the reinforcement rate as a function of the delay condition. The use of a 0.33-sec delay increased slightly the number of reinforcements per hour for each key color, while further increases in the duration of the changeover delay resulted in an accelerating decrease in the average reinforcement rate. The decrease from the 9-sec delay to the 27-sec delay amounted to 7.2 reinforcements per hour.

(b) Asymmetrical Changeover Delays

Figure 4 shows some of the results obtained with asymmetrical changeover delays. Delays of 1, 3, 9, and 27 sec had been compared with each other, with a given delay duration assigned once to the red key and once to the green key. Only the data from conditions involving a 1-sec delay for either (or both) color(s) have been graphed. The figure consists of two functions. The unbroken line shows results calculated on the condition that the pigeon had just changed over so as to incur a 1-sec delay; therefore, another changeover would be "from 1 sec", as noted on the figure, and incur one of the delays shown on the horizontal axis. The dashed graph shows results calculated on the condition that the pigeon had just changed over so as to incur

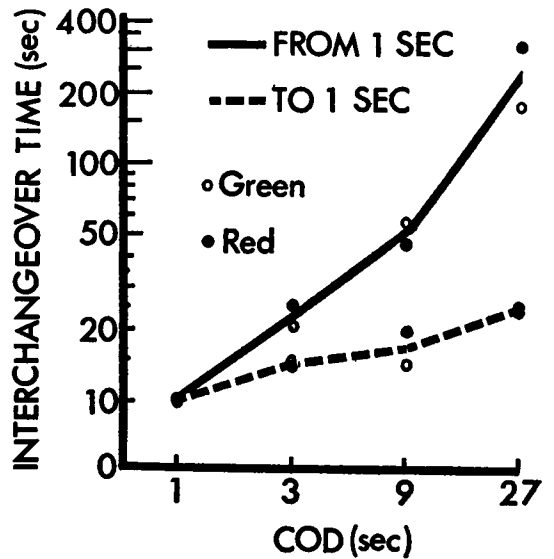


Fig. 4. Elapsed time (interchangeover time) between successive changeovers as a function of asymmetrical changeover delays. Both axes are logarithmic. (See text for explanation of the figure.)

one of the delays shown on the horizontal axis; another changeover would, therefore, be "to 1 sec" and incur a 1-sec delay in each case. The vertical axis shows the average elapsed times between successive changeovers, or interchangeover times.

The time that elapsed between successive changeovers depended on the delay conditions that prevailed as a consequence of the prior changeover and also as a consequence of the delay conditions that would have prevailed should another changeover have occurred. When the prior changeover produced one of the delays shown on the horizontal axis and another would have produced a 1-sec delay (dashed curve), the time that elapsed before another changeover exceeded the current delay for delays of 1, 3, and 9 sec. The interchangeover time at 1 sec was 9.83 sec; at 3 sec, 14.4 sec; at 9 sec, 16.6 sec. When the current delay was 27 sec, the interchangeover time was 24.5 sec. That the mean interchangeover time was smaller than the current delay indicates that a changeover that incurred a 27-sec delay was often followed by another changeover sooner than the minimum time necessary for a response on the main key to produce an already scheduled reinforcer.

The unbroken graph describes the case where a 1-sec delay had just been incurred,

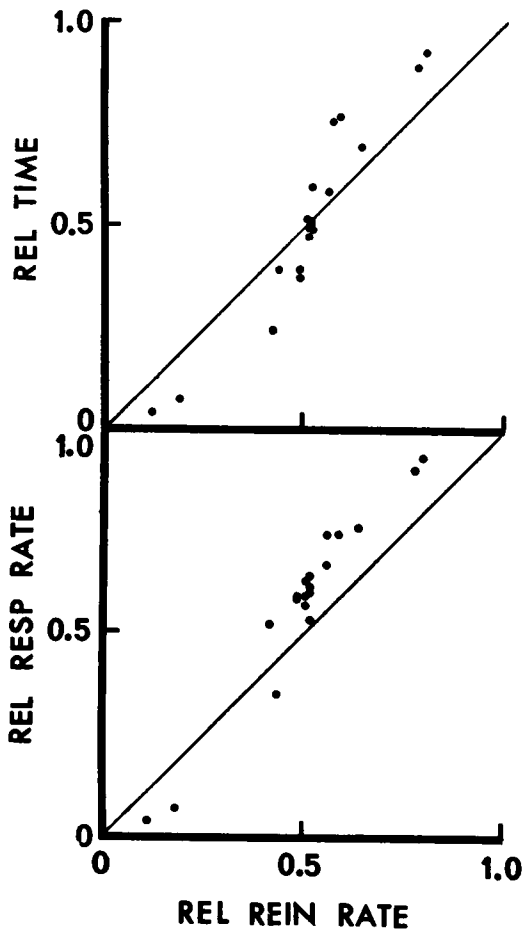


Fig. 5. Relative overall response rate (bottom panel) and relative elapsed time as functions of relative overall reinforcement rate.

and another changeover would have incurred one of the delays shown on the horizontal axis. While a 1-sec delay produced a 9.83-sec interchangeover time, a 3-sec delay resulted in an interchangeover time of 22.7 sec, and a 9-sec delay, 51.9 sec—almost 1 min. The average interchangeover time when another changeover would have produced a 27 sec delay was 246 sec—4 min. A comparison between the mean interchangeover time produced by a 27 sec delay that had just *been* incurred, 24.5 sec, and one that would have been incurred, 246 sec, suggests clearly a dual role for the delay in the control of changeover frequency.

Figure 5 shows the relative overall rate of responding on the green key and the relative-elapsed time in the presence of the green key as a function of the relative overall reinforcement rate for the green key (Catania, 1966).

The diagonals represent the theoretical distribution of data points that exactly satisfy the matching relationship between the relative dependent variables and relative reinforcement rate (Herrnstein, 1961). The plotted data points, however, indicate a systematic deviation from the theoretical distribution. The functions are S-shaped, suggesting that the pigeon emitted more responses on and spent more time in the presence of the key color associated with the briefer changeover delay than would have been predicted on the basis only of the reinforcement advantage provided by responding on that key.

DISCUSSION

Analyses of concurrent performances often relate a relative dependent variable to a relative independent variable. Relative response rate has been related to relative reinforcement rate (Herrnstein, 1961; Catania, 1966), to relative duration of reinforcement (Catania, 1963), and to relative immediacy of reinforcement (Chung and Herrnstein, 1967). It has been related also to a multiplicative combination of reinforcement rate and duration (Ten Eyck, 1970; see also Premack, 1965). Relative time devoted to one or two concurrent schedules has been studied when main-key responses produced the reinforcer (Catania, 1966; Shull and Pliskoff, 1967), when no main key was present, and the feeder operated on variable-time schedules (Brownstein and Pliskoff, 1968), and when pigeons moved from one side to the other of a shuttle-type box (Baum and Rachlin, 1969). Baum and Rachlin suggested a relation between relative time and a combination of relative reinforcement rate, duration and immediacy; the suggested relation was stated in utility terms, and the authors concluded that "... pigeons allocate time to any given pair of activities in such a way that the ratio of the times allocated equals the ratio of the values of the activities" (p. 870).

Regardless of whether one favors laws of response distribution or of time allocation as basic to understanding concurrent performances, the fact remains that responses are distributed and times are allocated, both of which are correlated with the temporal distribution of changeovers. One may ask whether changeover responding is a byproduct of response distribution and/or time alloca-

tion or whether the latter are byproducts of changeover responding. It may be that the two ways of describing concurrent performances are equivalent. The changeover model more easily employs the language of response and consequence common to behavior analysis, and to that extent, it enjoys an advantage over the response distribution and time allocation models. Shull and Pliskoff (1967), for example, analyzed their data in terms of the joint effect of the changeover delay and relative reinforcement rate in determining changeover rates for each schedule of a concurrent pair. The ratios of the changeover rates were transformed into time allocations, and the authors assumed a constant rate of responding to yield response distributions.

The present experiment was not undertaken especially to examine further the changeover model as it applies to the relationship between relative reinforcement and response rates. Instead, the concern was primarily with the dependence of changeovers on an immediate consequence, the changeover delay.

As a (most often) brief delay incurred by a changeover, the changeover delay has been found to reduce changeover rate; the larger the duration of the delay, the larger the decrement in changeover rate. The data obtained with the use of symmetrical delays replicate earlier findings on this point (see introduction). Figure 1 shows also the not surprising increase in the number of main-key responses per changeover with increasing duration of the delay. The data in the second figure replicate the finding by Silberberg and Fantino (1970), who showed that the main-key response rate is higher during the changeover delay than after. They employed delays of 0.88, 1.75, and 3.50 sec, and their data suggest that response rate was highest during the 0.88-sec delay. Figure 2 shows that main-key response rate during the 1-sec delay was higher than during the 3-sec delay, which replicates the result by Silberberg and Fantino.

It is not known why the response rate during the changeover delay is greater than after the changeover delay. Catania (1962) speculated that the elevated response rate might be compensatory. He hypothesized that a particular variable-interval schedule calls for a fixed number of responses during a given period of time. Time for responding is lost, however, when the organism changes over to

a second schedule—thus, the response rate is elevated upon returning to the first schedule in order to “make up the lost time” and approximate the required response output. Both Catania (1962) and Silberberg and Fantino (1970) suggest a second possibility, *viz.*, the elevated response rate following a changeover might reflect an increased local probability of reinforcement. Since the probability of reinforcement in a variable-interval schedule increases as a function of time, it follows that a response on the first schedule is more likely to be reinforced following a period of time during which the organism is responding elsewhere. Still a third possibility was suggested by Stubbs and Pliskoff (1969), who pointed to the complex contingencies existing immediately after a changeover. A changeover delay is a brief fixed interval initiated by a response—a tandem fixed-ratio one fixed-interval x -sec schedule. The tandem schedule is itself conjunctive with a variable-interval schedule, and the probability of reinforcement at the expiration of the changeover delay depends upon (a) the duration of the specific VI interval timing, (b) the duration of the changeover delay, and (c) the duration of the immediately preceding interchangeover time. A schedule so complex has not been synthesized to determine its effect on response rate, but an elevated response rate is as likely an expectation as any.

The unique feature of the present experiment was a design that permitted the separation of the effects of a contemporary delay, *i.e.*, a delay incurred by an immediately prior changeover, and one that will be the consequence of the next changeover. Interchangeover times (Fig. 4) show a double role for the changeover delay. First, a changeover requires that another changeover not occur for at least the duration of a contemporary delay if an available reinforcer is to be produced by a response. That the bird was sensitive to that requirement is clear from the results (dashed graph) described in conjunction with Fig. 4. Second, as a consequence of the next changeover, the changeover delay is a period of time during which a main-key response will not be reinforced. That delays of increasingly larger duration produce larger decrements in changeover rate (unbroken graph) suggests that the changeover delay functionally punishes changeovers, permitting an analogy between the duration of the changeover delay

and the intensity of electric shock (Azrin and Holz, 1966).³ Further, the two functions in Fig. 4 show that interchangeover time is increased more by a delay that will be incurred by the next changeover than by an equal delay incurred by the last changeover. In terms of the double role of the changeover delay, the second effect, punishment, is more potent in decreasing changeover frequency than the first effect, "waiting out" the delay.

The changeover delay also suits the classical paradigm for delay of reinforcement (e.g., Perin, 1943). The decrease in frequency of changeovers with increasing duration of the delay follows the delay model if changeovers are maintained by a next reinforcer produced by responding on the main key.

It is clear that the total overall rate of reinforcement is maximized by an optimal changeover rate. Too high a rate incurs too many changeover delays; too low a rate leaves waiting already available reinforcers arranged by the VI schedules when not assigned to the main key. Yet, rate of reinforcement does not easily fit a delay of reinforcement model, which identifies a discrete, temporally circumscribed event, the reinforcer. But the first reinforcement following a changeover occurs with a knowable delay, as do subsequent reinforcements. The sum of these delays translates into a rate of reinforcement. Thus, while the two models are related, the delay model places overwhelming if not exclusive importance on the first reinforcement after a changeover, while the rate of reinforcement model implicates all of the reinforcements that occur over an extended period of time.

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³Todorov (1971) reported experiments in which the changeover delay was, in fact, replaced by a brief electric shock. His results are largely in accord with prior research on the effects of the changeover delay on concurrent performances.