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CONCURRENT SCHEDULES: A QUANTITATIVE RELATION BETWEEN CHANGEOVER BEHAVIOR AND ITS CONSEQUENCES

D. ALAN STUBBS,[1] STANLEY S. PLISKOFF, AND HOWARD M. REID

UNIVERSITY OF MAINE, ORONO

Data from several published experiments on concurrent variable-interval schedules were analyzed with respect to the effects of changeover delay on the time spent responding on a schedule before changing to an alternate schedule: *i.e.*, the interchangeover time. Interchangeover time increases as the duration of the changeover delay increases, and the present analysis shows that a power function describes the relation. The power relation applied in spite of numerous differences in the experiments: different variable-interval schedules for the concurrent pairs; equal or unequal reinforcement rates for the schedules of the concurrent pairs; different durations of the changeover delay; response-dependent or response-independent reinforcers; pigeons or rats as subjects; different reinforcers. A power function also described the data in experiments where the changeover incurred a timeout, where a fixed ratio was required to changeover, and also when asymmetrical changeover delays were used.

Key words: concurrent schedule, changeover delay, power function, variable interval, timing behavior, pigeons, rats

Concurrent schedules of reinforcement involve two or more independent schedules functioning simultaneously, each schedule controlling a separate operant. In the typical procedure (Catania, 1966), responses on one operandum produce reinforcers according to one schedule and responses on a second operandum produce reinforcers according to a second schedule. A variant of this procedure (the changeover-key procedure) assigns both schedules to the same key (main key); each schedule is associated with a different stimulus. Responses on a second key (changeover key) alternate the stimulus-schedule assignment to the main key. Both schedules operate continuously, but responses on the main key produce reinforcers only according to the schedule whose stimulus is present. Reinforcers arranged by the second schedule may be produced only if a changeover first occurs, and the subject responds on the main key then associated with the second stimulus-schedule pair.

Among all reinforcement analyses, concurrent schedules and their variant, concurrent chained schedules, have stimulated by far the largest number of quantitative accounts. Most of the work has dealt with or started from the findings on concurrent variable-interval (VI) schedules (see Catania, 1966; Rachlin, 1971; and Herrnstein, 1970, for general discussions). Many experiments have reported "matching" between relative reinforcement rate and relative aspects of behavior, such as response rate and time proportions (*e.g.*, Baum and Rachlin, 1969; Catania, 1966; Rachlin, 1971). Reinforcement conditions can be related not only to relative but also to absolute aspects of behavior. While the precise quantitative statement may be questioned (Catania, 1973; Herrnstein, 1970, 1974), the evidence is clear that response rate on one variable-interval schedule of a concurrent pair is affected in precise ways by the conditions of reinforcement (*e.g.*, rate, amount, delay) for that response and also for alternative responses. Response rate on a schedule increases as rate or amount of reinforcement increases for that response. But response rate decreases as the rate or amount of reinforcement increases for an alternative response.

The present paper deals quantitatively with a different set of relations found with concurrent schedules, *i.e.*, relations between changeover behavior and its consequences. Animals

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typically respond first on one schedule and then on the other, each alternation being a changeover. In the two-key procedure, a changeover occurs whenever the animal switches from Key A to Key B, or *vice versa.* In the changeover-key procedure, the changeover response is made explicit, since each response on the changeover key alternates the stimulus-schedule pair on the main key. The changeover delay requires that a specified duration must elapse after a changeover before a main-key response can be reinforced. The changeover delay is widely used to eliminate rapid switching patterns that could develop if a response immediately following a changeover were occasionally reinforced (Herrnstein, 1961). Parametric research has shown that increases in the duration of the changeover delay reduce the rate of changeovers (*e.g.*, Shull and Pliskoff, 1967). The reduced changeover rate necessarily means that the subject spends a longer average time on a schedule before changing to the alternate schedule (interchangeover time). So, increased changeover-delay requirements produce increased average interchangeover times. Data already published are examined below, and they suggest a more specific statement about the relation between changeover delay and interchangeover time: the relation is a power function.

BASIC EXPERIMENTS: EFFECTS OF CHANGEOVER DELAY ON INTERCHANGEOVER TIME

METHOD

Experimental Procedures

Six published studies were examined and the data re-analyzed. A seventh (Allison and Lloyd, 1971) was not used because of a lack of tabular data for analysis. Since detailed procedures may be found in the original reports, only the salient procedural features are presented here.

Shull and Pliskoff (1967) reinforced rats' lever-press responses with brain stimulation according to concurrent variable-interval variable-interval schedules. A changeover-key procedure was used. Two rats were exposed to *conc* VI 1-min VI 3-min schedules and two others were exposed to *conc* VI 1.5-min VI 1.5-min schedules. Changeover-delay (COD) values ranged from 0 to 20 sec. Each delay was timed from a response on the changeover key. (The specific durations of the changeover delay for this and the other studies are shown in Figure 1.) The changeover delay was first increased from low to high durations and then decreased; each delay was in effect for five sessions.

All the other studies differed from that by Shull and Pliskoff in three main ways: all used pigeons rather than rats, all used food as the reinforcer rather than brain stimulation, and all exposed the subjects to each changeover delay for more sessions (typically 15 to 30 sessions).

Brownstein and Pliskoff (1968) used concurrent variable-time variable-time (*conc* VT VT) schedules. With a variable-time schedule, reinforcers are delivered aperiodically and independently of behavior. For this experiment, responses on a single key (changeover key) alternated the ambient chamber illumination while both variable-time schedules operated simultaneously providing response-independent reinforcers; however, a schedule provided a reinforcer only when the appropriate illumination was present. The specific schedule was *conc* VT 1-min VT 3-min. The changeover-delay values ranged between 0 and 7.5 sec, and each delay was timed from a response on the changeover key.

Stubbs and Pliskoff (1969), using a changeover-key procedure, studied performance on nonindependent concurrent schedules. Responses on the changeover key alternated the color of the main key. Responses on the main key produced food according to a single VI 1.5-min schedule subject to the following restrictions: the color of the main key for the next reinforced response was established by a stepping switch from reinforcement to reinforcement. Thus, it was possible to specify and fix that 75% of the reinforcers would occur for red-key responses, and 25% for green-key responses. The schedule is like *conc* VI 2-min VI 6-min schedules, except that the usual concurrent schedules are independent. Changeover-delay requirements were 0 to 32 sec, with each changeover delay timed from a response on the changeover key.

Silberberg and Fantino (1970; Experiment 2) employed a two-key procedure. Two pigeons were exposed to each of the three following concurrent pairs: *conc* VI 7.5-min VI 1.88-min;

conc VI 2.25-min VI 4.5-min; *conc* VI 1.69-min VI 13.5-min. Each pigeon was exposed to changeover delays of 0.88, 1.75, and 3.5 sec. The changeover delays began with the first peck on a key following pecks on the alternate key.

Pliskoff (1971), as part of an experiment on asymmetrical changeover delays, studied performance of one pigeon under *conc* VI 3-min VI 3-min schedules. The pigeon was exposed to changeover delays ranging from 0 to 27 sec. A changeover-key procedure was used. The delay was timed from the first main-key response after a changeover, rather than from the changeover response itself, which is the more-usual procedure.

Silberberg and Schrot (1974) used a changeover-key procedure with two pigeons, and a two-key procedure with another two. The schedules were nonindependent concurrent schedules and were arranged like those of Stubbs and Pliskoff (1968). The schedule was similar to standard *conc* VI 2.14-min VI 5-min schedules. Changeover delays ranged from 0 to 30 sec. For the two subjects with the changeover-key procedure, the delay was timed from each response on the changeover key. For the subjects with the two-key procedure, the delay began with the first response on a key following a response on the alternate key.

Analysis

Interchangeover times are the primary data of interest in this paper. Interchangeover times were evaluated from the tabular data in the several published experiments and were calculated separately for each schedule of a concurrent pair. If, for example, the schedules were VI 1-min and VI 3-min, interchangeover times were obtained separately for the VI 1-min schedule and the VI 3-min schedule:

$$\text{Interchangeover time (Sched. A)} = \frac{\text{Time (Sched. A)}}{\text{Changeovers (Sched. A)}}$$

Changeovers (Schedule A) are those changeovers emitted with Schedule A in effect, thereby instituting Schedule B.

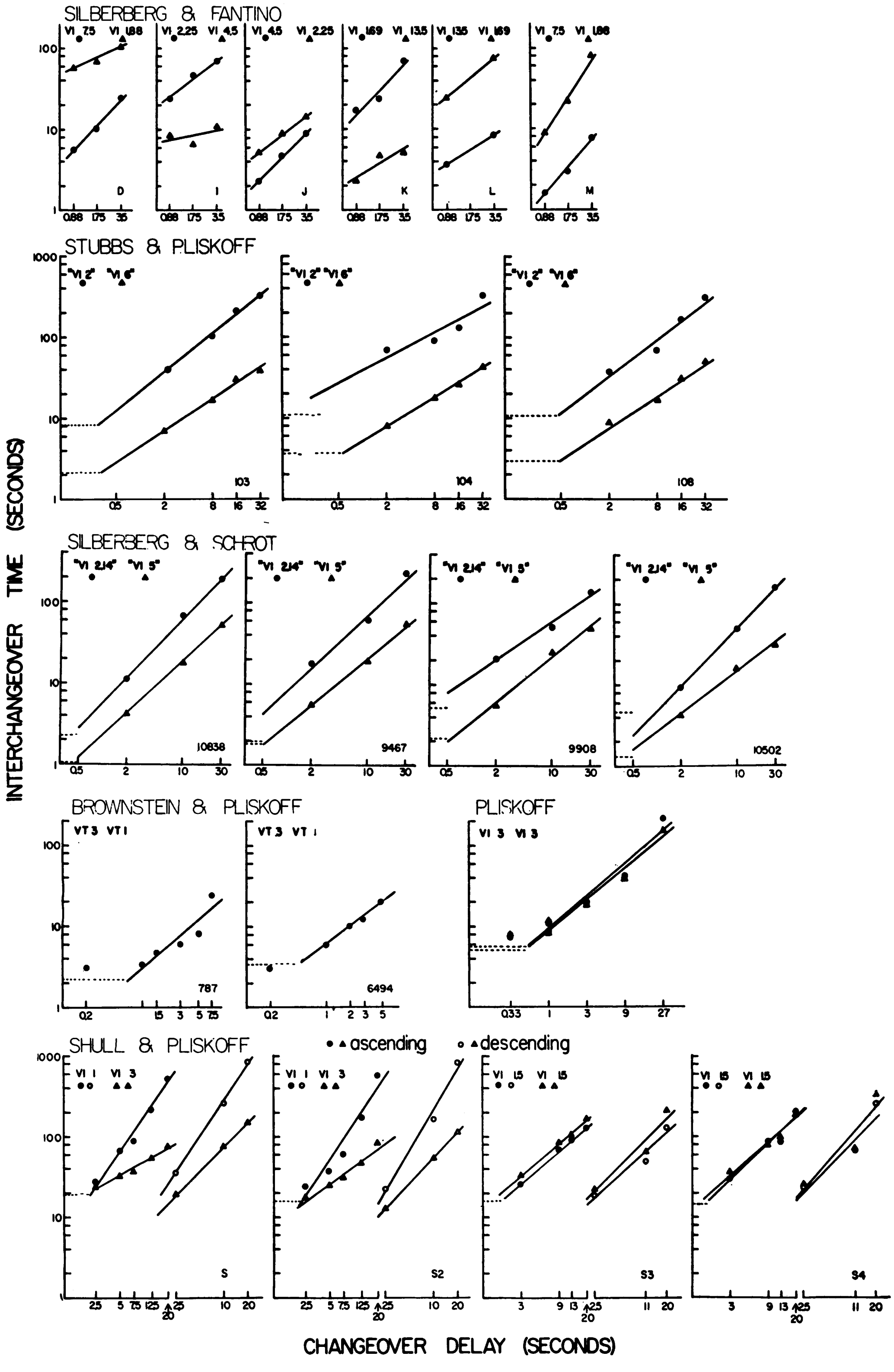
In three of the studies (Shull and Pliskoff, 1967; Stubbs and Pliskoff, 1969; Pliskoff, 1971) calculations came directly from the published tables. In the study by Silberberg and Schrot, times cumulated on each schedule were reported but only the total number of changeovers was published; accordingly, the total was divided by two to obtain the number of changeovers for each schedule. In the study by Silberberg and Fantino, the number of changeovers had to be obtained in a similar way. Additionally, time cumulated on each schedule was not reported. Session time was estimated to be 90 min, based on the values of the two VI schedules. With that estimate of session time, time cumulated on each schedule was calculated from the table, which showed the proportional amount of time for each schedule.

Tabular data were not presented in the study by Brownstein and Pliskoff. However, their Figure 3 shows total changeover rate, which is the reciprocal of average interchangeover time. The figure was enlarged and projected on graph paper. Estimates of interchangeover times were made from the enlargement.

RESULTS

Figure 1 shows interchangeover time as a function of changeover delay for the six experiments. Both the horizontal and vertical axes are logarithmic. Figure 1 shows that in all cases, interchangeover time increased as the changeover delay increased. "Best-fit" straight lines were fitted to the points by the least-squares method. Lines were fit for each subject for each schedule of a concurrent pair, with the exception of the study by Brownstein and Pliskoff, where the available data were presented in combined form.

The straight-line functions provide a suitable description of the data in the different experiments. The functions describe the data when the changeover delay ranged between 0.88 and 32 sec. The dashed horizontal lines show interchangeover times when there was a 0-sec changeover delay, and they indicate that there was not a simple alternation from schedule to schedule; rather, the animals spent some time on a schedule before changing (*e.g.*, an average interchangeover time of 6 sec for the pigeon in the study by Pliskoff). In two experiments (Brownstein and Pliskoff, 1968; Pliskoff, 1971) very brief changeover delays (0.2 and 0.33 sec) were used, and the data were similar to those with a 0-sec changeover delay. In both experiments, a changeover-key procedure was employed with delays timed from a


SILBERBERG & FANTINO
VI 7.5 VI 18.8
VI 2.25 VI 4.5
VI 4.5 VI 2.25
VI 16.9 VI 13.5
VI 13.5 VI 16.9
VI 7.5 VI 18.8
D
I
J
K
L
M
0.88 1.75 3.5
STUBBS & PLISKOFF
"VI 2" "VI 6"
103
104
108
0.5 2 8 16 32
SILBERBERG & SCHROT
"VI 2.14" "VI 5"
10838
9467
9908
10502
0.5 2 10 30
BROWNSTEIN & PLISKOFF
VT 3 VT 1
787
6494
0.2 1.5 3 5 7.5
0.2 1 2 3 5
PLISKOFF
VI 3 VI 3
0.33 1 3 9 27
SHULL & PLISKOFF
● ▲ ascending
○ △ descending
VI 1 VI 3
VI 15 VI 15
S
S2
S3
S4
2.5 5 7.5 12.5 ^25 20 10 20
3 9 13 ^25 20 11 20
1
10
100
1000
INTERCHANGEOVER TIME (SECONDS)
CHANGEOVER DELAY (SECONDS)

response on the changeover key. With this arrangement, a very brief changeover delay might easily not make contact with behavior, since it takes time for a subject to emit a changeover response and then return to the main key. Too brief a delay could elapse before the subject is able to respond again on the main key. The straight-line functions intersect the dashed lines at changeover delays of 0.5 to 0.75 sec for pigeons and 1 to 2 sec for rats. The points of intersection suggest a limit below which the changeover delay would be minimally or not at all effective.[2] Accordingly, data at 0.2-sec and 0.33-sec changeover delays were not included in fitting the straight lines.

The straight-line functions on logarithmic coordinates indicate a power relation of the form $T = kt^n$ with arithmetic coordinates, where T is interchangeover time, t is the duration of the changeover delay, and k and n are constants. In the figure, n gives the slope of the line while the value of k indicates the Y-intercept of the line.

A primary determinant of k was the relative reinforcement rate. Both Y-intercepts for a subject were nearly the same when both schedules of a concurrent pair arranged an equal reinforcement rate (*e.g.*, VI 3-min VI 3-min in the study by Pliskoff). However, the Y intercepts were different with differences in reinforcement rate for the two schedules (*e.g.*, Stubbs and Pliskoff). Changes in k correlate with changes in the relative time spent on a schedule. Where both schedules arrange an equal rate of reinforcement, the animal spends an equal amount of time with each schedule, producing equal interchangeover times. When 75% of the reinforcers are provided by one schedule, however, the subject spends approximately 75% of the time with that schedule. Such an increase in cumulated time implies an increase in interchangeover time.

The constant n is the exponent of the power function and gives the slope of the line. Figure 1 shows that the straight-line functions are in many cases similar across the various studies, and that in many comparisons for individual subjects, the straight lines are roughly parallel. Figure 2 shows the frequencies of different exponents (values of n) for all subjects. The approximate normal distribution of exponents had a median and mode occurring at the 0.80 to 0.89 class; approximately half of the exponents were between 0.70 and 0.99. Figures 1 and 2 raise two questions. First, why did some exponents diverge from the median value as much as they did? Second, why were the straight-line functions parallel for some subjects but not for others? Figure 3 provides an answer by showing an additional factor that affects changeover behavior.

As part of the experiment by Stubbs and Pliskoff, relative reinforcement rate was manipulated while the changeover delay was constant at 2 sec. Figure 3 shows the relative reinforcement rates used (expressed as reinforcement ratios) and the results of the manipulation on interchangeover time. The data indicate that interchangeover times change as a function of reinforcement ratio, even with the same changeover-delay requirement. Interchangeover time increased as reinforcement ratio increased. For example, interchangeover time for red increased from 39 to 52 sec for Pigeon 103 as the reinforcement ratio increased from 3 to 9. Thus, interchangeover time is a function not only of the changeover-delay value but also of reinforcement ratio.

Changes in the reinforcement ratio appear to have produced some of the exponent differences shown in Figure 1. In the study by Shull and Pliskoff, for example, the *conc* VI 1-min VI 3-min pair arranged three times the

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[2] At short COD values, the effect of the COD probably depends on the way it is scheduled. With a changeover-key procedure, where the COD is timed from each changeover response, a 0-sec or brief COD would be functionally equivalent to having no COD. In contrast, with a two-key procedure, the COD typically is timed from the first response on a key following a response on the alternate key. Thus, the first response is not reinforced but simply starts the COD. Even with a 0-sec COD, the first response is not reinforced.

Fig. 1. Interchangeover time as a function of changeover delay. Both axes are scaled logarithmically. The schedules (in minutes) for each concurrent pair are shown for each subject. Quotes have been placed around the schedule values for two of the studies. In these studies, nonindependent concurrent schedules were used; the values shown are the equivalents that would have been arranged in the usual procedure employing independent VI schedules. (See procedure section for details.) Straight lines through points were fit by the method of least squares. Horizontal dashed lines indicate interchangeover times when the changeover delay was 0 sec.

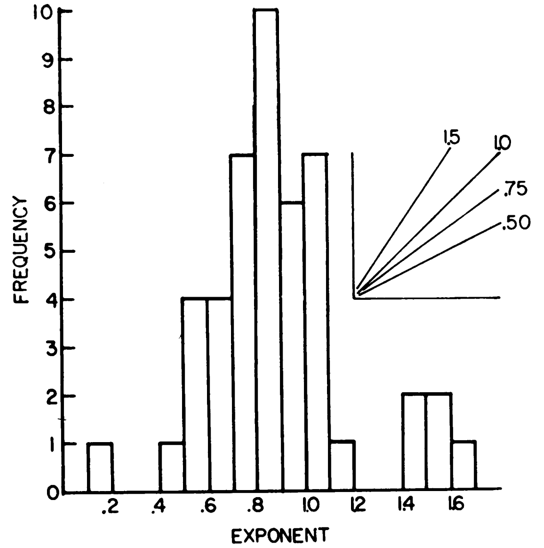

Fig. 2. Frequency of exponents for the power functions shown in Figure 1. The exponents are the values of n in the formula $T = kt^n$. The insert in the upper-right portion shows the lines generated by power functions with different exponents. (See text for additional details.)

reinforcers for the VI 1-min schedule as for the VI 3-min schedule. As the changeover delay was increased to 20 sec, the animals spent more and more time on the VI 1-min schedule, until the observed reinforcement ratio had changed from 3 to 1 to approximately 9 to 1 with regard to that schedule. So, data obtained by Shull and Pliskoff are the result of the combined effects of increasing changeover-delay and increasing reinforcement ratio. The combination of both factors would be expected to make the slope of the line representing VI 1-min behavior relatively steep. A similar logic suggests that the combined effects of increasing changeover delay and decreasing relative reinforcement rate should produce smaller exponents for the VI 3-min schedule. Thus, it would appear that changes in reinforcement ratio can, and in some cases did, complicate the effects of changeover delay. Changes in reinforcement ratio can change the results by altering the functions or even perhaps producing divergence from linearity.

In contrast, the straight-line functions in the studies by Stubbs and Pliskoff and by Silberberg and Schrot were parallel for each subject, and in most cases the exponents were less than 1.0. In both experiments, the procedure guaranteed a fixed reinforcement ratio. The effects were thus effects of changeover delay uncomplicated by changing reinforcement ratio.

EXTENSIONS: ASYMMETRICAL CHANGEOVER-DELAY, TIMEOUT, AND FIXED-RATIO REQUIREMENTS FOR A CHANGEOVER

A power relation described the effects of a symmetrical changeover delay on interchangeover time. This section deals with asymmetrical changeover delays, the timeout changeover requirement, and the fixed-ratio changeover requirement.

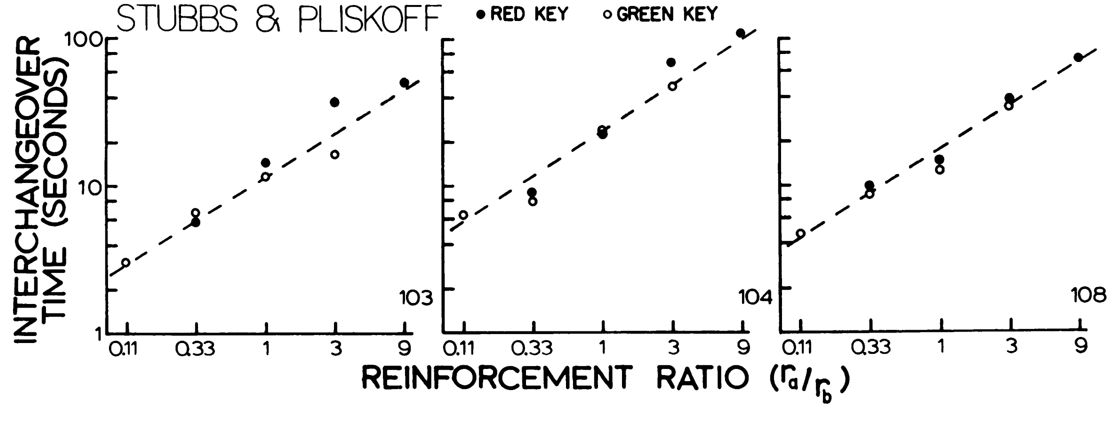

Fig. 3. Interchangeover times as a function of reinforcement ratio. Both axes are scaled logarithmically. The dashed lines were fit by eye. The changeover delay was 2 sec across all conditions. The reinforcement ratios correspond to relative reinforcement rates $[r_a/(r_a + r_b)]$ of 0.10, 0.25, 0.50, 0.75, and 0.90.

ASYMMETRICAL CHANGEOVER DELAY

METHOD

Pliskoff (*1971*) examined the effects of asymmetrical changeover delays on concurrent performances. The behavior of one pigeon was studied with a standard procedure involving *conc* VI 3-min VI 3-min schedules. Changeover delays of 1, 3, 9, and 27 sec were used. The procedure differed from the usual: one delay (*e.g.*, 1 sec) occurred when the subject changed from Schedule A to Schedule B, a second delay (*e.g.*, 9 sec) occurred when the subject changed from Schedule B to Schedule A. Also, the delay was timed from the first main-key response after a changeover, rather than from the changeover response itself (see Pliskoff's comments on ways of arranging changeover delays). Every delay combination was studied for each schedule: the changeover delay for Schedule A was 1 sec and the delays for Schedule B were 1, 3, 9, and 27 sec; the delay for A was 3 sec and the delays for B were 1, 3, 9, and 27 sec; *etc.*

RESULTS

Figure 4 shows the effects of asymmetrical changeover consequences on interchangeover time. (Data were calculated directly from Pliskoff's study.) Consider the left panel first. Here, a changeover to one schedule resulted in a 1-sec changeover delay; changeover to the alternate schedule resulted in changeover delays of 1, 3, 9, and 27 sec across conditions. The circles indicate interchangeover times when the pigeon was responding on the schedule with the 1-sec delay; therefore, another changeover would be "from 1 sec", and would produce the schedule with one of the delays indicated on the horizontal axis. The triangles show interchangeover times when the animal was responding on the schedule with the 3-, 9-, or 27-sec delay; therefore, another changeover would be "to 1 sec". The squares represent the condition where the changeover delay was symmetrical, here 1 sec. (The different points represent different determinations.) The other panels are analogous; in the second, the circles show behavior on the schedule with the 3-sec delay; triangles show behavior on the schedule with one of the varying delays. Again, the squares represent the symmetrical delays, 3 sec in this case.

The circles and squares (across panels) indicate increasing functions, while the triangles show functions that are almost horizontal. Thus, changing "from 1 sec" in the first panel, "from 3 sec" in the second, *etc.*, to one of the four changeover delays produced an in-

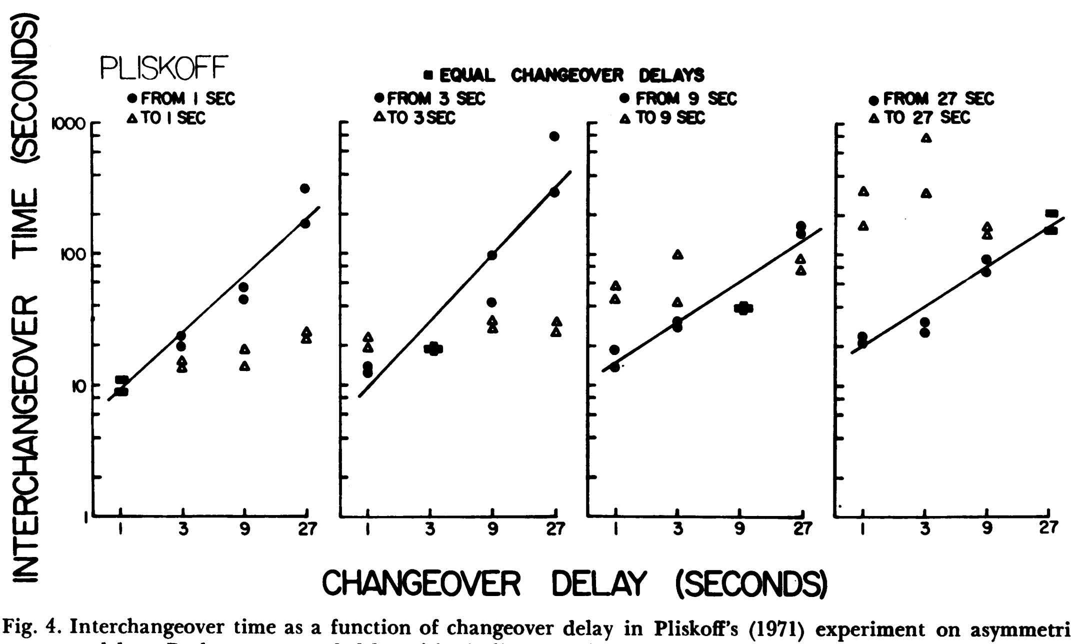

Fig. 4. Interchangeover time as a function of changeover delay in Pliskoff's (1971) experiment on asymmetrical changeover delays. Both axes are scaled logarithmically. Straight lines through the points were fit by the method of least squares. (See text for additional details.)

creasing function. However, changing from one of the four delays always "to 1 sec", always "to 3 sec" and so on, did not.

Straight lines were fit to the data represented by circles and squares for each panel. The straight-line functions (all with exponents less than 1.0) provide a reasonable description of the data, though the fits are not as close as those shown in Figure 1. Both variable-interval schedules were 3-min. This arrangement normally allows 50% of the reinforcers for each schedule, with 50% of the animal's time spent responding on each. When the asymmetrical delays were 1 sec and 27 sec, however, the animal spent approximately 90% of the time responding on the schedule with the 1-sec delay, and produced approximately 80% of the reinforcers on this schedule. In spite of the variability and the more complicated delay arrangement, the functions are similar to those shown in Figure 1, and the exponents are similar to those shown in Figure 2.

TIMEOUT CHANGEOVER REQUIREMENT

METHOD

Todorov (*1971*) reinforced pigeons' responses according to a *conc* VI 1-min VI 3-min procedure. Each changeover produced a timeout period, during which all lights were off and all schedule functions stopped. The timeout procedure is like a changeover-delay procedure, insofar as a changeover response postpones the delivery of a reinforcer by a fixed period of time. However, with the changeover delay, the schedules operate during the delay and responses may occur; with the timeout procedure, the schedules do not operate and responses have no scheduled consequence.

RESULTS

Figure 5 shows the effects of timeout duration on interchangeover time. (Data points were calculated from Todorov's table.) Interchangeover times increased as a function of timeout duration. Straight-line functions are a good description of the data, indicating a power relation between timeout duration and interchangeover time. The functions for the VI 1-min and VI 3-min schedules are not quite parallel for the three pigeons, and they are less steep than those found when a changeover produces a delay rather than a timeout. Exponents here were 0.41 and 0.26 for Pigeon P 12, 0.64 and 0.30 for Pigeon P 13, and 0.59 and 0.20 for Pigeon P 15.

FIXED-RATIO CHANGEOVER REQUIREMENT

METHOD

Pliskoff examined the effects of a fixed-ratio changeover requirement on concurrent performance. Since this study has not been published, more details of the procedure are presented than for the other experiments.

The subjects were three naive Silver King pigeons maintained at 80% of their free-feeding weights throughout the experiment. The apparatus was a two-key pigeon chamber like that described by Stubbs and Pliskoff (1969).

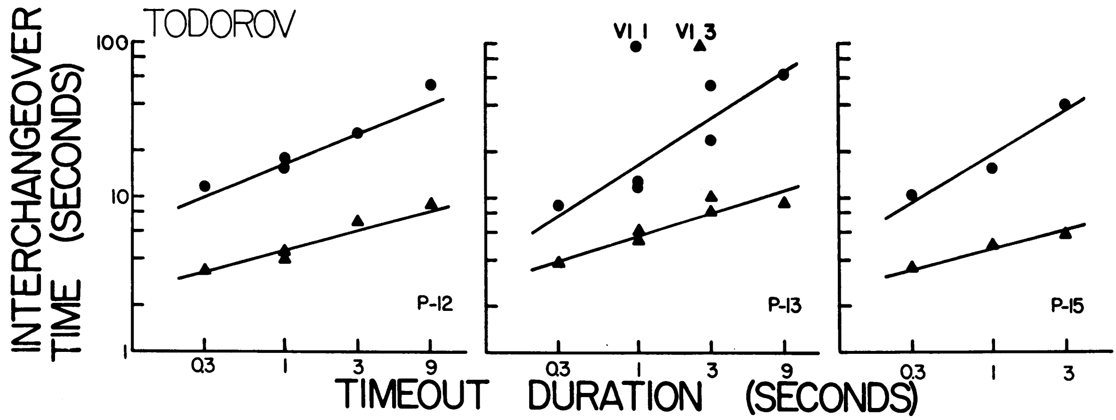

Fig. 5. Interchangeover time as a function of timeout duration in Todorov's (1971) experiment. Both axes are scaled logarithmically. Straight lines through the points were fit by the method of least squares.

Table 1

Data from Pliskoff's experiment, averaged across the last five sessions of each condition. Responses were averaged to the nearest response and time was averaged to the nearest tenth of a minute. Each condition was in effect for between 20 and 30 sessions.

		Responses		*Time (min)*		
Pigeon No.	*CO REQ*	*Red*	*Green*	*Red*	*Green*	*Total Changeovers*
51	FR 1	752	719	42.4	45.9	1275
	FR 5	560	644	43.8	46.5	1005
	FR 2	1048	1129	46.7	44.0	1696
	FR 10	747	827	42.1	48.4	345
	FR 20	1292	1610	44.5	57.0	60
	FR 1	939	1015	47.3	39.7	1169
	FR 10	1222	1233	42.3	46.8	234
52	FR 1	1300	1557	48.2	42.8	1724
	FR 5	1083	1315	44.7	43.7	646
	FR 2	1477	1422	44.9	44.4	1189
	FR 10	1247	1076	51.1	39.7	234
	FR 20	1149	938	60.5	37.8	72
	FR 1	1536	1259	46.5	40.5	1207
	FR10	1060	951	48.8	42.3	187
53	FR 1	886	855	46.0	43.2	1359
	FR 5	893	683	49.5	38.6	479
	FR 2	1141	1118	46.3	45.4	1999
	FR 10	917	803	46.7	43.6	452
	FR 20	1572	1037	53.9	44.5	75
	FR 1	840	962	62.5	61.0	1498
	FR 10	835	781	44.2	44.0	316

The birds were trained to peck and then placed on variable-interval schedules for six to eight sessions, followed by *conc* VI 3-min VI 3-min schedules. Both variable-interval schedules contained 17 intervals, drawn from an arithmetic sequence. A changeover-key procedure was used. The right key (main key) could be lit red or green, with each color associated with one of the schedules. The left key (changeover key) was yellow, and responses on this key alternated the stimulus-schedule pair on the main key. A fixed ratio was required to change the main-key color; across conditions: 1, 2, 5, 10, or 20 responses constituted the ratio. When a pigeon responded on the changeover key, the first response darkened the main key, inactivated it, and stopped both VI tapes. Thus, the animal was functionally removed from the concurrent schedules until the changeover requirement was completed. Completion of the fixed ratio illuminated and reactivated the main key and started the VI tapes. Following the changeover sequence, the changeover key was inactivated until the first response was emitted on the main key.

Table 1 shows the order of experimental conditions and the summary data.

RESULTS

Figure 6 shows the effects of a fixed-ratio changeover requirement on interchangeover time. A power function describes the relation between fixed-ratio size (excluding the one- and two-response conditions) and interchangeover time. The dashed lines are for two determinations of the "FR 1", where each changeover response simply alternated the key color and schedule. The points at FR 2 produced similar interchangeover times, indicating that small FR requirements were functionally equivalent to having no changeover requirement (except for the changeover response itself). The straight-line functions are steep for all three pigeons. The exponents were 2.04 and 2.18 for Pigeon 51, 1.79 and 1.47 for Pigeon 52, and 1.40 and 1.44 for Pigeon 53.

GENERAL DISCUSSION

The first section of the paper showed that a power relation described the effects of the changeover-delay on interchangeover time. The power relation provided a satisfactory description of the data in spite of the many

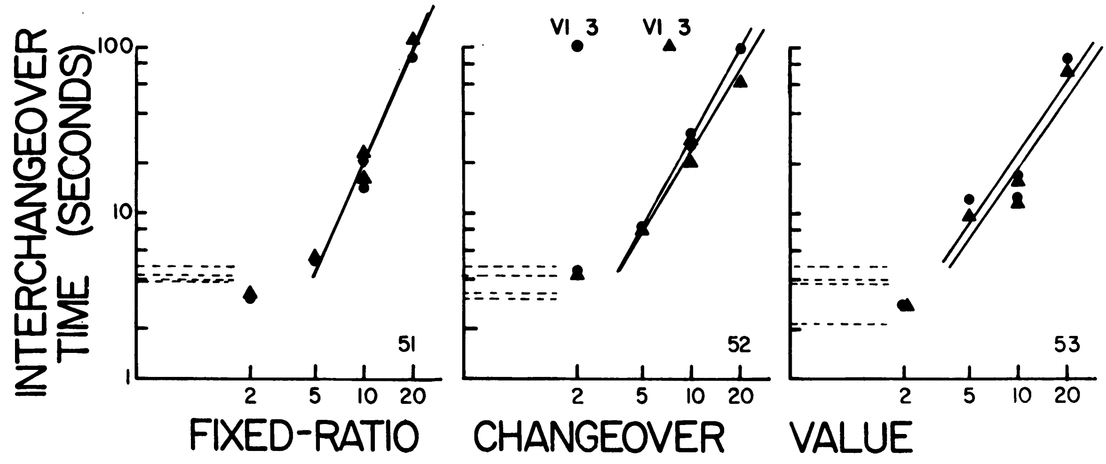

Fig. 6. Interchangeover time as a function of fixed-ratio size. Both axes are scaled logarithmically. Straight lines through the points were fit by the method of least squares. Horizontal dashed lines indicate interchangeover times when each key peck changed the stimulus-schedule pair (FR 1).

differences in the various experiments: (1) equal or unequal reinforcement rates for both schedules of a concurrent pair; (2) independent or nonindependent concurrent schedules; (3) response-dependent or response-independent delivery of the reinforcer; (4) different reinforcers (food and brain stimulation); and (5) different species (rats and pigeons). Not only did a power relation describe the data from all of the experiments examined, but also the exponents tended to be slightly less than 1.0 (see Figure 2). Changes in relative reinforcement rates affected changeover performance, and hence affected slopes in some of the experiments.

The second section of the paper showed that a power function is not limited to the case involving symmetrical changeover delays. Power relations held in other cases also: asymmetrical changeover delay, timeout, and fixed-ratio requirements. The exponents of the functions differed, however. Thus, it would appear that a power function is a general relation that describes changeover behavior. But while the power relation might be general, the specific coefficients and exponents can differ depending on the specific consequences. Consequences other than those studied might produce power functions with still different exponents. For example, varying force requirement on the changeover key might produce a power function relating force and interchangeover with an exponent different from any of those observed here.

Shock is another consequence that can be, and in fact has been, made dependent on changeover responses (Todorov, 1971). Unfortunately, the data are only suggestive; they do not clearly show whether a power relation is satisfactory. Todorov exposed pigeons to concurrent schedules in which each changeover produced no shock or shocks ranging from 4 to 16 mA across conditions. In general, interchangeover time increased as a function of shock intensity. Power functions with lines of steep slope describe the data for two subjects (P2 and P3), but the results are ambiguous for the remaining two subjects. For example, P1 showed similar interchangeover times when the shock intensity was 0, 4, or 7 mA; then, interchangeover time increased at 10 and 16 mA. Thus, 4- and 7-mA shock intensities appeared functionally the same as no shock for this pigeon. Todorov's data are suggestive, but more research is necessary using a larger number of shock intensities.

The paper has dealt with two factors that affect changeover behavior: changeover consequences and relative reinforcement rate. Not presented were data relating changeover behavior to other manipulations with concurrent schedules, such as changes in overall reinforcement rate. The relevant experiments have not been published or, when published, they have not included changeover data. For example, one question that can be raised is the relation between overall reinforcement rate and changeover rate. Response rate declines on concurrent schedules as total reinforcement rate decreases (Catania, 1966; Fantino, Squires, Delbruck, and Peterson, 1972). But what of changeover rate? Some data suggest that changeover rate also declines (Baum and Rachlin, 1969; A. D. Potthoff, *personal communication* 1976). More data are necessary, however, before a firm conclusion can be stated.

The changeover delay is a time-based contingency and as such is related to other schedule contingencies. Catania (1970) reviewed the literature on a wide variety of time-based schedules and pointed out some interesting similarities—similarities that may be extended to the present data. In one experiment, Catania reinforced pigeon's responses in a trials procedure only if the response latency exceeded a minimum latency. The minimum reinforced latency was varied across conditions, and the average latency tended to approximate the minimum reinforced latency. More specific and more important, a power function described the data for all subjects, and the power function had an exponent of slightly less than 1.0 for each pigeon. Catania reviewed research on differential-reinforcement-of-low-rate schedules (DRL) and found a similar result: power functions with exponents less than 1.0 described the relation between average interresponse times and DRL values. Similarly, a power function described the relation between average interresponse times and response-shock intervals on free-operant avoidance schedules (see also Sidman, 1953). Finally, power functions described the relation between various response measures and stimulus duration in "time perception" experiments with human subjects. Since the publication of Catania's review, several papers have supported and extended the analysis by demonstrating that a power function obtains when response duration is differentially reinforced (Ferraro and Grilly, 1970; Kuch, 1974; Platt, Kuch, and Bitgood, 1973), and when the time to complete a fixed-ratio requirement is differentially reinforced (DeCasper and Zeiler, 1974). Thus, across a wide variety of experiments, temporal response measures relate to the temporal properties of the environment in a similar way.

The effects of the changeover delay on behavior appear congruent with and related to the research on "temporal judgments". The changeover delay may be viewed as involving "time estimation", or the situation may be viewed as a complex situation that involves, in part, the effects of temporal properties of the environment on the temporal aspects of behavior. The temporal power law appears to go beyond the individual experiments dealing with temporal contingencies; it appears to extend to other contingencies that involve time only because events occur in time.

REFERENCES

Allison, T. S. and Lloyd, K. E. Concurrent schedules of reinforcement: effects of gradual and abrupt increases in changeover delay. *Journal of the Experimental Analysis of Behavior,* 1971, **16,** 67-73.

Baum, W. M. and Rachlin, H. C. 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 operants. In W. K. Honig (Ed.), *Operant behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 213-270.

Catania, A. C. Reinforcement schedules and psychophysical judgments: a study of some temporal properties of behavior. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules.* New York: Appleton-Century-Crofts, 1970. Pp. 1-42.

Catania, A. C. Self-inhibiting effects of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 517-526.

DeCasper, A. J. and Zeiler, M. D. Time limits for completing fixed ratios. III. stimulus variables. *Journal of the Experimental Analysis of Behavior,* 1974, **22,** 285-300.

Fantino, E., Squires, N., Delbruck, N., and Peterson, C. Choice behavior and the accessibility of the reinforcer. *Journal of the Experimental Analysis of Behavior,* 1972, **18,** 35-43.

Ferraro, D. P. and Grilly, D. M. Response differentiation: a psychophysical method for response produced stimuli. *Perception and Psychophysics,* 1970, **7,** 206-208.

Herrnstein, R. J. Relative and absolute strength of response as a function of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 267-272.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 243-266.

Herrnstein, R. J. Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 159-164.

Kuch, D. O. Differentiation of press durations with upper and lower limits on reinforced judgments of time. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 239-250.

Platt, J. R., Kuch, D. O., and Bitgood, S. C. Rats' lever-press durations as psychophysical judgments of time. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 239-250.

Pliskoff, S. S. Effects of symmetrical and asymmetrical changeover delays on concurrent performances. *Journal of the Experimental Analysis of Behavior,* 1971, **16,** 249-256.

Rachlin, H. On the tautology of the matching law. *Journal of the Experimental Analysis of Behavior,* 1971, **15,** 249-251.

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.

Sidman, M. Two temporal parameters of the maintenance of avoidance behavior by the white rat. *Journal of Comparative and Physiological Psychology,* 1953, **46,** 253-261.

Silberberg, A. and Fantino, E. Choice, rate of reinforcement, and the changeover delay. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 187-197.

Silberberg, A. and Schrot, J. A yoked-chamber comparison of concurrent and multiple schedules: the relationship between component duration and responding. *Journal of the Experimental Analysis of Behavior,* 1974, **22,** 21-30.

Stubbs, D. A. and Pliskoff, S. S. Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 887-895.

Todorov, J. C. Concurrent performances: effect of punishment contingent on the switching response. *Journal of the Experimental Analysis of Behavior,* 1971, **16,** 51-66.

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