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Concurrent procedures, changeover delay and the choice behavior of rats

Procedimientos concurrentes, demora de cambio y la conducta de elección de ratas[1]

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ABSTRACT

A three-operanda procedure was used to study the behavior of rats on concurrent variable-interval, variable-interval schedules. In Experiment 1 this new procedure was compared to the known "two-bar" and "changeover bar" procedures when the length of a changeover delay was varied. In Experiment 2 the three-operanda procedure was used, without a changeover delay, and different pairs of concurrent schedules were used in six experimental conditions. The absence of a changeover delay did not preclude the observation of lawful relationships between behavior and consequences. Results indicated that with a procedure in which each schedule is associated with a different operandum, and changeovers are topographically different from concurrent operants, relative behavior measures are sensitive to relative reinforcement rate, even with rats as subjects.

DESCRIPTORS: matching, changeover delay, concurrent procedures, chain pull, bar press, rats.

RESUMEN

Se utilizó un procedimiento de tres operandos en el estudio de la conducta de ratas en programas concurrentes intervalo-variable, intervalo-variable. En el Experimento 1 se comparó este nuevo procedimiento con los procedimientos conocidos como de "dos palancas" y de "palanca de cambio", variándose la duración de demora del reforzamiento contingente a las respuestas de cambio. En el Experimento 2 se utilizó el procedimiento de tres palancas, sin contingencia de demora de cambio, y se utilizaron diferentes pares de programas concurrentes en seis condiciones experimentales. La ausencia de la demora de cambio no impidió la observación de relaciones ordenadas entre la conducta y sus consecuencias. Los resultados indicaron que al utilizar un procedimiento de una palanca

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asociada a cada programa de intervalo variable y una tercera, con topografía distinta, asociada a las respuestas de cambio, las medidas relativas de conducta son sensibles a tasas relativas de reforzamiento, incluso con ratas como sujetos experimentales.

DESCRIPTORES: igualación, demora de cambio, procedimientos concurrentes, cadena de jalar, presión de palanca, ratas.

Quantitative studies of choice behavior represent a considerable proportion of the literature on the experimental analysis of behavior over the last two decades, especially after the contributions of Catania (1966) and Herrnstein (1961). Typically, concurrent schedules are employed in studies of continuous choice: "Two or more responses, of different topography at least with respect to locus, capable of being executed with little mutual interference at the same time or in rapid alternation, under the control of separate programming devices" (Ferster and Skinner, 1957, p. 724). Since procedures which permit the simultaneous ocurrence of concurrent operants complicate the analysis of choice (cf. Catania, 1966, pp. 214-215), investigations of behavior maintained by concurrent schedules usually select incompatible operants, different with respect to locus (Skinner, 1950) or discriminative stimuli which set the occasion for its occurrence (Findley, 1958). In the first case, two manipulanda are used, each associated with a different schedule of the concurrent pair. In the Findley procedure responses in one manipulandum alternate discriminative stimuli in the presence of which responses in the second manipulandum are reinforced according to different schedules. Both procedures have been assumed to generate comparable data in quantitative studies of choice behavior and/or preference for consequent events (cf. de Villiers, 1977).

A rapid pattern of alternation between the schedules will develop when equal reinforcement frequencies are programmed by the concurrent pair (Skinner, 1950). Changing over decreases as a function of the dissimilarity between schedules (Catania, 1966). It has been assumed that the pattern of rapid alternation may result in part from the accidental pairing in time of responses in one schedule and reinforcements provided by the other schedule (de Villiers, 1977). "Thus, when concurrent operants are incompatible in the first place, it is often necessary to program concurrent schedules in such a way that the operants become even more incompatible, at least with respect to their relationship to their separate schedules of reinforcement" (Catania, 1966, p. 216). The procedural artifact most used to diminish the rapid alternation pattern has been a changeover delay, COD (Herrnstein, 1961; Sidman, 1958; Findley, 1958). The COD is an added contingency which specifies a minimum time interval between responding in one schedule and reinforcement for responding in the other schedule.

As an added contingency, the COD produces its own effects on behavior maintained by concurrent schedules. Manipulations of COD length systematically affect rate of changeovers (Shull and Pliskoff, 1967; Stubbs, Pliskoff and Reid, 1977), the distribution of responses and of obtained reinforcements between the schedules (Shull and Pliskoff, 1967), and response patterns in each schedule (Silberberg and Fantino, 1970).

Quantitative studies of operant behavior involved in continuous choice procedures have generated not only information about variables involved in behavior-environment intercations (cf. Myers and Myers, 1977; de Villiers, 1977), but also some theoretical contributions to behavior analysis (e.g., Herrnstein, 1961; Baum, 1973; Rachlin, 1978; Prelec and Herrnstein, 1978; Myerson and Miezin, 1980). Baum (1974) suggested that the equation

$$\frac{R_1}{R_2} = k\left(\frac{r_1}{r_2}\right)^a \tag{1}$$

would describe data from studies of performance maintained by concurrent schedules. In Equation (1), the generalized matching law, *R* and *r* represent responses and reinforcements, respectively; *k*, is a bias toward one of the schedules due to uncontrolled variables (cf. de Villiers, 1977); *a* is a measure of the sensitivity of responding to changes in reinforcement distribution between the schedules (Baum, 1974); and subscripts denote the schedules of the concurrent pair. A similar equation is suggested for the distribution of session time between the schedules:

According to Baum (1974) and de

$$\frac{T_1}{T_2} = k\left(\frac{r_1}{r_2}\right)^a \tag{2}$$

Villiers (1977), in controlled experiments with concurrent variable-interval, variable-interval (*conc* VI VI) schedules, both *k* and *a* should equal unity. In such a case, of Herrnstein's (1961) matching law. The controversy about

$$\frac{R_1}{r_2} = \frac{T_1}{T_2} = \frac{r_1}{r_2} \tag{3}$$

interpretations of values of *a* different from one have generated much discussion over the last years (*e.g.*, Myers and Myers, 1977, de Villiers, 1977; Lobb and Davison, 1975; Baum, 1979). In studies of operant behavior of rats, agreement on the interpretation of results has been difficult, specially for the scarcity of published experiments.

The purpose of the present investigation was (*a*) to compare the effects of manipulations of COD length on behavior maintained by concurrent schedules when different procedures for programming the concurrent pair are used; and (*b*) to study the concurrent performance of rats with a procedure which facilitates the discrimination of the schedules of the concurrent pair, without a changeover delay.

EXPERIMENT 1

In the procedures developed by Skinner (1950) and Findley (1958) only two operanda are used. The procedures differ as to the function ascribed to those operanda. The purpose of this experiment was to verify how a new procedure would affect the concurrent performance of rats. This new procedure was developed so that is includes the characteristics of Skinners's (1950) two-key procedure and Findley's (1958) changeover-key procedure. The experiment was designed to provide a comparison of the effects of manipulations of COD duration on the behavior of subjects submitted to those three procedures.

METHOD

Subjects

Nine male rats, eight Long Evans and one Wistar, served. Subjects were approximately 100 days old at the beginning of the experiment, and were submitted to a 23-hour water deprivation schedule, with free access to water for 25 min after daily sessions. Food was always available at their individual home-cages. Animals were randomly assigned to three groups of three subjects each.

Apparatus

A BRS (USA) operant conditioning chamber for rats, model RG-004, was used. Two retractible levers (BRS RRI 001) were separated by 12 cm. A chain was added to the chamber, pending from the ceiling, with a length of 14 cm and a ring of 2 cm in diameter attached to its loose end. The ring was 14 cm from the floor and 12 cm from each lever. White noise and a fan were continuously on inside the chamber during sessions. Illumination was provided by a 6 W DC light bulb. Events were scheduled and recorded by solid state equipment.

Procedure

Group "CO chain". A variable-interval l-min (VI 1) schedule was associated with the left bar, and a variable-interval 3-min schedule (VI3) with the right bar. Only one bar was inside the chamber and operating at a time. A chain pull would retract a bar and insert the other in the chamber. The first bar press after a chain pull would turn on a light above that bar. After a changeover, the chain was operative again only after a press on the inserted bar.

Group "two bars". A VI 1-min schedule was associated with the left bar, and a VI-3 min with the right bar. Both bars were inserted in the chamber, and the chain was unoperative. A first response in one bar would turn on a light above that bar and turn off the light above the other bar.

Group "CO bar". Both VI schedules were arranged on the left bar, each associated with a different discriminative stimulus. The light above the left bar would have its intensity changed by a changeover response. A VI 1-min schedule was associated with the lower light intensity and VI 3-min with the higher intensity. A bar press on the right bar (Changeover bar) would turn off the light over the left bar (main bar). The first response on the left bar after a press on the changeover bar would turn the light on again, with its intensity changed.

For all groups, the variable interval tape programmers run concurrently, reinforcements being independently assigned. Each VI tape had 20 intervals, arranged according to prescriptions made by Catania and Reynolds (1968, p. 381). A reinforcement was the presentation of approximately 0.2 cm^3 of water through a dipper.

In all experimental conditions and for all subjects a changeover delay (COD) was in effect (Herrnstein, 1961). A COD would begin with the first response on a bar after a changeover: only a second response on a bar could eventually be reinforced. Throughout the experiment the COD duration was manipulated, and 0–, 1–, 2–, 4–, 8–, and 16-sec were the values utilized. A 0-sec COD was the initial condition for all rats. The sequency of experimental conditions is shown in Table 1.

At least 14 daily sessions were conducted under each experimental condition. When the proportions of responses associated with each VI schedule revealed no ascending or descending trends during the last five of these 14 sessions, another COD duration was introduced. If more than 20 sessions were conducted without reaching this criterion, the last 10 sessions were taken into consideration. When there was no trend in proportions of responses on these 10 sessions, the experimental condition was changed (Todorov, 1971; 1977). Absence of a trend was defined as a slope lower than 0.009 for best linear fit to the data of the last five or 10 sessions, determined by the least squares method.

RESULTS

Results are summarized in Table 1. Ratios of reinforcements, responses and time refer to data from the last five or 10 sessions included in the stability criterion, as indicated. Table 1 also shows the total number of sessions per experimental condition, for all subjects.

When comparing the ratios of obtained reinforcements (r_1/r_2) for each COD>0 condition to ratios observed in the previous baseline (0-sec COD) condition, it can be seen no systematic effect of increases in COD lenght. For the three groups, increases and decreases in reinforcement ratios are no different from chance fluctuations (sign test). The groups differ in the effect of

Table 1

Orden of experimental conditions, number of sessions, number of sessions considered for data analysis (in parenthesis), ratios of obtained reinforcement (r_1/r_2), response (R_1/R_2) and time spent responding in each schedule (T_1/T_2), for all groups and subjects. Subscripts 1 and 2 indicate VI 1 min and VI 3-min schedules, respectively.

	GROUP CO CHAIN				GROUP TWO BARS				GROUP CO BAR			
COD (seg)	Sessions	r_1/r_2	R_1/R_2	T_1/T_2	Sessions	r_1/r_2	R_1/R_2	T_1/T_2	Sessions	r_1/r_2	R_1/R_2	T_1/T_2
	Rat 7				Rat 10				Rat 14			
0	26 (10)	4.1	3.8	3.0	25 (10)	3.9	3.3	2.8	25 (10)	3.7	1.8	1.9
1	20 (10)	3.8	3.7	3.2	21 (10)	3.7	2.2	2.0	20 (10)	3.2	1.7	1.8
0	14 (5)	2.9	2.7	1.7	14 (5)	2.7	1.5	1.8	14 (5)	3.0	1.4	1.6
2	20 (10)	3.0	3.5	1.8	20 (10)	2.9	2.2	2.5	20 (10)	3.0	1.4	1.5
0	14 (5)	3.2	4.3	2.0	20 (10)	2.8	1.5	1.4	20 (10)	2.6	1.2	1.3
4	14 (5)	3.4	2.9	2.7	20 (10)	3.4	2.3	2.3	22 (10)	3.2	1.5	1.7
0	14 (5)	3.4	4.3	1.7	14 (5)	3.4	2.2	1.9	14 (5)	3.2	1.9	2.0
8	20 (10)	3.2	2.5	1.6	14 (5)	4.1	2.7	3.2	20 (10)	3.7	2.8	3.0
0	20 (10)	3.2	9.4	2.1	14 (5)	3.6	2.0	1.6	21 (10)	3.2	1.8	1.9
16	20 (10)	3.0	5.8	2.0	20 (10)	5.1	3.8	4.3	20 (10)	7.3	6.7	5.7
	Rat 8				Rat 11				Rat 15			
0	28 (10)	4.1	11.8	6.1	25 (10)	3.5	1.1	1.7	24 (10)	4.6	1.7	2.2
8	20 (10)	9.8	19.0	11.2	20 (10)	3.2	2.2	2.1	20 (10)	3.3	1.8	2.3
0	22 (10)	3.5	9.2	4.2	20 (10)	2.5	1.3	1.2	14 (5)	2.7	1.2	1.4
4	14 (5)	3.6	9.0	5.7	24 (10)	2.8	1.8	1.9	20 (10)	2.8	1.4	1.7
0	14 (5)	2.9	5.9	3.7	20 (10)	2.6	1.2	1.1	14 (5)	2.8	1.1	1.1
2	14 (5)	3.9	9.6	6.2	20 (10)	2.9	1.6	1.7	20 (10)	3.0	1.2	1.3
0	14 (5)	3.9	7.9	3.8	20 (10)	3.1	1.3	1.3	14 (5)	2.8	1.6	1.6
1	14 (5)	2.9	9.9	3.0	20 (10)	3.1	1.6	1.6	14 (5)	2.9	1.5	1.4
0	14 (5)	3.2	9.4	3.5	*	+	+	+	14 (5)	3.0	1.5	1.3
16	14 (5)	6.4	22.3	6.9	*	+	+	+	20 (10)	4.1	2.6	2.5
	Rat 9				Rat 12				Rat 16			
0	25 (10)	3.5	2.9	2.6	25 (10)	3.1	1.7	1.8	14 (5)	2.9	1.2	1.2
4	20 (10)	3.1	3.6	2.6	25 (10)	3.0	1.8	1.9	20 (10)	2.8	1.5	1.6
1	20 (10)	2.7	2.7	2.2	14 (5)	2.6	1.6	1.9	20 (10)	2.8	1.2	1.3
0	14 (5)	2.9	3.5	2.7	14 (5)	2.6	1.4	1.7	14 (5)	3.0	1.2	1.5
8	14 (5)	3.0	4.2	3.0	++	++	++	++	14 (5)	4.3	4.3	4.6
0	21 (10)	3.4	5.4	2.8	++	++	++	++	14 (5)	3.1	1.4	1.5
2	14 (5)	3.2	3.9	2.3	++	++	++	++	14 (5)	3.0	1.4	1.5
0	20 (10)	2.7	4.3	2.9	++	++	++	++	+++	+++	+++	+++
16	14 (5)	8.1	6.6	6.1	++	++	++	++	+++	+++	+++	+++

*Rats 11. 12 and 16 died during the 9th, 6th, and 9th experimental conditions, respectively.

COD duration on response and time ratios: for group "CO chain" changes in response or time ratios were not related to changes in COD duration. For the other two groups increases in COD length generally increased response ratios ($p=0.006$ for group "two bars"; $p=0.033$ for group "CO bar") and time ratios ($p=0.033$ for group "two bars"; $p=0.046$ for group "CO bar").

The "CO chain group" also differed from the other groups on response and time ratios observed in the five baseline conditions (0–sec. COD). Tests of significance of the difference between group means show that the "two bars" procedure did not produce data different from the "CO bar" procedure. Both groups, however, generated data on response and time ratios in baseline conditions that are significantly different ($t = 3.788$, $p < 0.01$, 6 df for response ratios; $t = 3.1619$, $p < 0.02$, 6 df, for time ratios) from results of the "CO chain" group. For the "CO chain" procedure, both response and time ratios are generally close to or are greater than reinforcement ratios. For the other groups both relative performance measures are lower than reinforcement ratios.

Figure 1 shows interchangeover time as a function of COD length for groups "CO chain" (left graphs) and "CO bar" (right graphs). The upper graphs show interchangeover times in the VI 3-min schedule (T_2/CO); lower graphs refer to data of VI1-min schedules (T_1/CO). A power function provides a good description of the relationship between interchangeover times in VI 1-min and COD lenght for the "CO bar" group (r^2=0,92); it provides also a reasonable fit for the data on VI 3-min for that group (r^2=0,68). Poor fittings were obtained from data referring to the "CO chain" group. Data from the "two bars" group are not shown in Fig. 1 since two of the subjects died in the middle of the experiment and the parameters of the power function would be determined mostly by the results of only one rat.

DISCUSSION

It is well established in the literature concerning concurrent variable-interval, variable interval schedules that the absence of a changeover delay (COD), or the use of a COD of short duration, results in short interchangeover times and in response and time distribution between the schedules which undermatch reinforcement distribution (cf. Catania, 1966; de Villiers, 1977). As COD length is incresased, interchangeover times increase (cf.Shull and Pliskoff, 1967; Stubbs, Pliskoff and Reid, 1977) and response and time ratios tend to match reinforcement ratios (cf. de Villiers, 1977). Thus, a comparison among the procedures for programming concurrent schedules can be made based on such established findings.

In the present investigation, the data referring to groups "two bars" and "CO bar" replicate observations on the effects of COD, lenght on changeovers and on response and time ratios. For 0-sec COD, interchangeover times were generally short and response and time ratios were lower than reinfor-

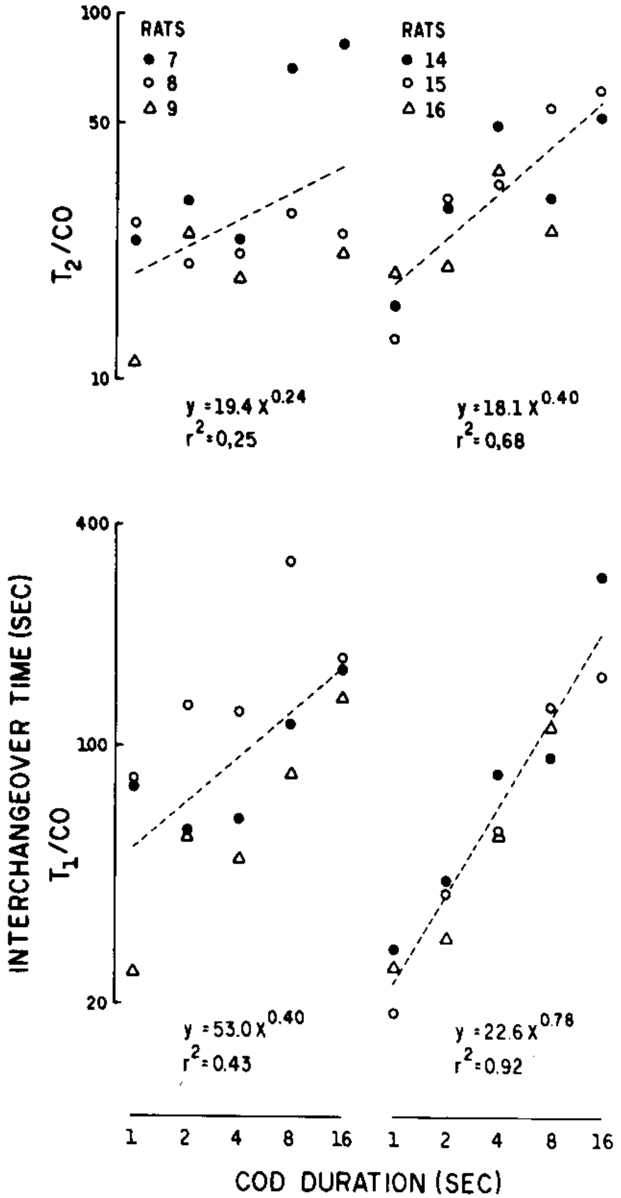

Fig. 1. Interchangeover time in sec as a function of COD duration (sec) for the "CO chain" group (left) and the "CO bar" group (right). Individual data are identified on top of figure. Equations refer to group data. (Experiment 1).

cement ratios (cf. de Villiers, 1977). The data from the "CO chain" group, however, show that, with this procedure, the matching of response and time ratios to reinforcement ratios can be obtained even with a 0-sec COD, and that manipulations of COD duration have no systematic effects on interchangeover times and on response and time ratios.

The results from the present experiment indicate that the use of a changeover response which is topographically different from responses associated with reinforcement provided by the concurrent schedules helped in the establishment of differential responding to different sources of reinforcement. Approximations to the matching of response and time ratios to reinforcement ratios were obtained even with a 0-sec COD, a finding not reported in the literature on studies of concurrent schedules with rats (cf. de Villiers, 1977).

EXPERIMENT 2

There are only two experiments in the literature in which the behavior of individual rats was studied under different pairs of concurrent schedules. Baum (1976) found, for five rats, values of *a* in Equation 1 ranging from 0.79 to 1.01 (reported in Baum, 1979, p. 271), and *k* from 0.76 to 1.05. Norman and McSweeney (1978), using five rats also, found values of *a* ranging from 0.78 to 1.17, and values of *k* from 0.66 to 1.23. In both experiments a changeover delay (COD; Herrnstein, 1961) was utilized. A COD stipulates a time that has to elapse after a changeover before a response can be reinforced; it separates in time responses in one schedule from reinforcements provided for responding in the other schedule of the concurrent pair. Baum (1976) used a COD of 7.5 sec, Norman and McSweeney fixed a duration of 5 sec; de Villiers (1977, p. 243) argues that a COD between 5 and 10 sec is necessary for rats before they discriminate the two reinforcement schedules of the concurrent pair.

Evidence that Equation 3 does not hold for rats as subjects and COD values lower than 5 sec come from experiments from Shull and Pliskoff (1967) and de Villiers and Millenson (1972), but in both cases only one pair of schedules was used. There is no experiment in the literature in which reinforcement distribution between the schedules was manipulated in the absence of a COD or with COD duration lower than 5 sec.

METHOD

Subjects

Six male rats served. Subjects were approximately 100 days old at the beginning of the experiment, and were submitted to a 23 hour water deprivation schedule, with free access to water for 25 min after daily sessions. Food was always available at their individual home-cages.

Apparatus

A BRS operant conditioning chamber for rats, model RG-004, was used. Two retractible levers (BRS PRI 001) were separated by 12 cm. A chain was added to the chamber, pending from the ceiling, with a length of 14 cm and a ring of 2 cm in diameter attached to its loose end. The ring was 14 cm from the floor and 12 cm from each lever. White noise and a fan were continuously on inside the chamber during sessions. Illumination was provided by a 6 w DC light bulb. Events were scheduled and recorded by solid state equipment.

Procedure

Variable interval schedules were associated with the levers. Only one lever was inside the chamber and operating at a time. A chain pull would retract a lever and insert the other in the chamber. The first lever press after a chain pull would turn on a light above that lever. After a changeover, the chain was operative again only after a press on the inserted lever.

Table 1 shows pairs of concurrent schedules associated, in different experimental conditions, with the levers. Tape programmers run simultaneous and independently. Each VI schedule had 20 intervals, randomly distributed according to prescriptions made by Catania and Reynolds (1968, p. 381). A programmer would stop when a reinforcement was scheduled. A reinforcement was the presentation of approximately 0.2 cm^3 of water throught a dipper. During reinforcements a light was over the dipper opening for 10 sec, and all programming and recording devices were off. Daily sessions ended after 40 reinforcements.

Changes of experimental conditions occurred whenever a stability criterion described by Norman and McSweeney (1978) was reached: 'Responding under each concurrent schedule was considered to be stable when the overall rates of responding emitted during the last five sessions fell within the range of rates of responding set by the earlier sessions" (Norman and McSweeney, 1978, p. 455).

RESULTS

The sums of reinforcements, responses, and times over the last 5 days of each experimental condition, and the number of sessions per condition, are presented in Table 2.

Figure 2 shows local changeover rates as a function of reinforcement rates. Local changeover rates on each lever were obtained by dividing the number of changeovers on a lever by the time spent on that lever (Table 2). Reinforcement rates were obtained by dividing number of reinforcements on a lever by total time. For all subjects, local changeover rates generally decreased with increases in rates of reinforcement provided by each lever.

Tabla 2

Sequence of experimental conditions, number of sessions, and sum of number of obtained reinforcements, responses, time spent (sec) and changeover responses (CO) on each lever, of the last five sessions of the condition, for each subject.

VI	Schedules (sec) Left	Right	No. of Ses.	Reinf. Left	Rig.	Responses Left	Right	Time Left	Right	CO Left	Right
Rat 1	120	120	33	100	100	1831	2549	6371	6091	595	596
	240	80	28	50	150	1491	3922	4778	8097	471	473
	720	65	23	16	184	906	5053	2570	10339	337	337
	65	720	28	183	17	6971	1200	10397	1945	210	211
	90	180	17	135	65	6958	2443	9186	4644	303	303
	Ext.	60	25	0	200	506	16284	793	11438	104	109
Rat 2	120	120	33	99	101	2489	1858	6780	5982	484	486
	240	80	10	49	151	2216	2878	5910	7005	638	639
	720	65	14	16	184	1549	4171	4290	8276	562	565
	65	720	26	186	14	11074	848	9882	2718	321	318
	90	180	18	140	60	11625	1447	8214	4178	448	449
	Ext.	60	35	0	200	856	7196	1129	10815	129	133
Rat 3	120	120	29	104	96	1872	2081	6976	5468	399	402
	240	80	29	49	151	1220	4068	4436	7720	370	374
	65	720	20	183	17	6887	1674	9852	3182	235	237
	720	65	13	15	185	1117	5641	3242	9809	235	237
	90	180	15	131	69	3876	2681	7531	5557	296	301
	Ext.	60	28	0	200	338	5457	1299	10603	87	92
Rat 4	120	120	17	103	97	1278	1141	6662	5616	350	351
	240	80	19	51	149	1003	2136	5435	8439	440	444
	65	720	20	185	15	5548	753	10458	2780	237	238
	720	65	26	17	183	933	5410	4064	9047	150	153
	90	180	13	131	69	3473	2112	7829	5346	239	241
	Ext.	60	20	0	200	184	8205	1322	10970	71	76
Rat 5	120	120	25	98	102	1541	1315	6435	6297	353	353
	240	80	33	49	151	1066	3738	4614	8611	277	279
	720	65	22	13	187	827	5063	2829	10350	186	189
	65	720	26	187	13	8655	801	11054	2031	138	140
	90	180	22	139	61	8311	1267	9157	3637	198	199
	Ext.	60	29	0	200	363	6873	1033	11141	93	97
Rat 6	120	120	13	100	100	1271	1382	6728	5955	495	497
	240	80	18	48	152	791	3436	4294	8149	449	451
	65	720	22	189	11	4970	1072	10746	2785	317	318
	720	65	16	14	186	792	4777	2490	10598	351	362
	90	180	17	130	70	3547	2208	8297	5053	405	405
	Ext.	60	17	0	200	174	4225	1151	11397	96	101

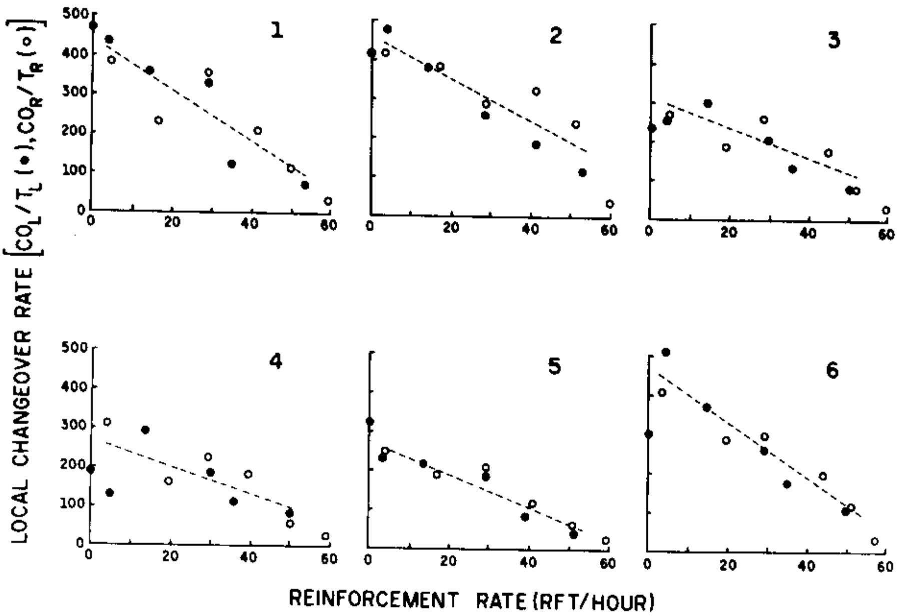

Fig. 2. Local changeover rates as a function of overall reninforcement rates. Filled circles refer to data from the left bar, unfilled circles to data from the right bar. Individual data from six rats are presented.

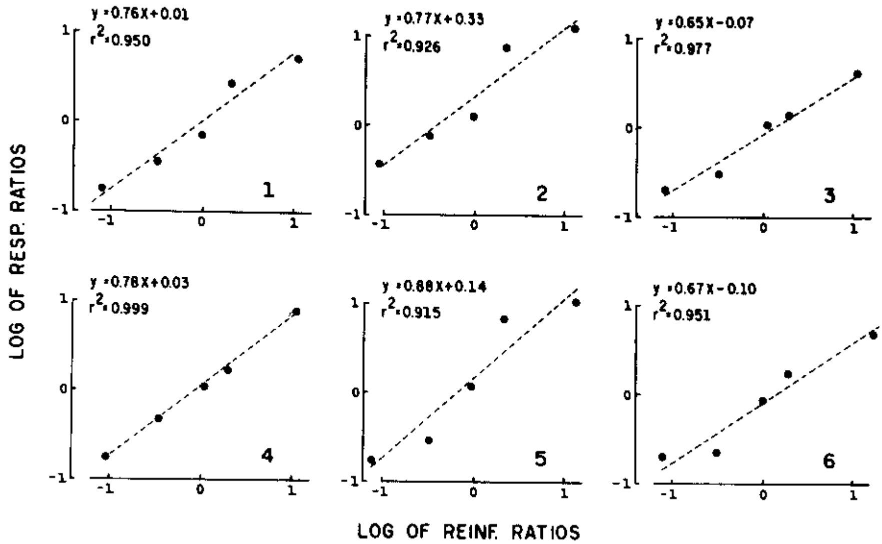

Fig. 3. Logarithm of response ratios as a function of reinforcement ratios, for data from each of six rats.

Equations 1 and 2 were fitted to data on response and time ratios, A good fit was obtained for each subject, the lower coefficient of determination (r^2) being 0.915 for Rat 5. Slopes (the exponent logarithm of k in Equation 1 varied from 0.10 to 0.33).

Figure 4 shows the logarithm of time ratios as a function of the logarithm of reinforcement ratios. The lower coefficient of determination was 0.977 for Rat 5. Slopes varied from 0.39 to 0.64, and intercepts from 0 to 0.12. For all subjects, the slopes for response ratios (Fig. 3) were higher than the slopes for time ratios (Fig. 4).

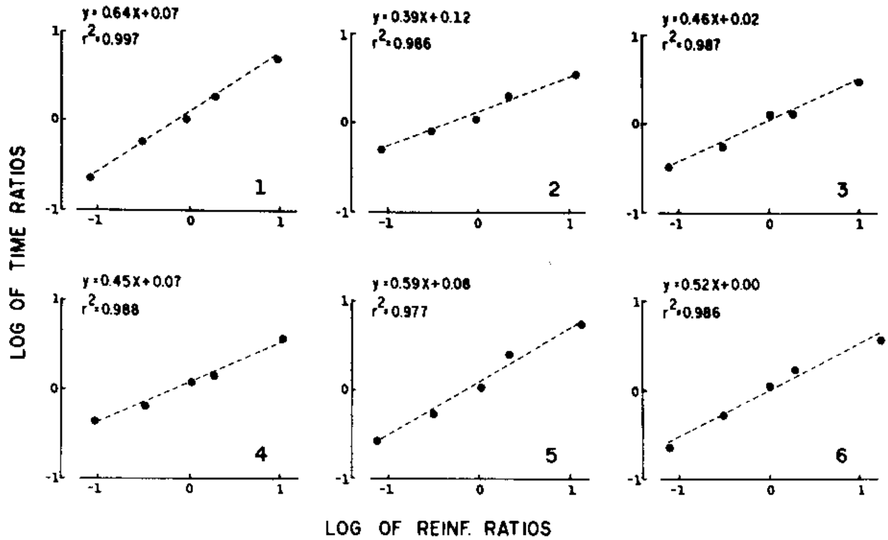

Fig. 4. Logarithm of time ratios as a function of logarithm of reinforcement ratios, for data from each of six rats.

DISCUSSION

The present investigation provides data on performance of rats controlled by concurrent variable-interval, variable-interval schedules, with a switching response topographically different from concurrent operants, and with no changeover delay contingent on switching responses. The data clearly indicate that lawful relationships are observed, under such conditions, both absolute and relative measures of behavior and of reinforcement.

The values of k in Equations 1 and 2, obtained from the present data, are not significantly different from those reported by Baum (1976) and Norman and McSweeney (1978) for rats. The median value of k for Equation 1 (responses), considering 15 rats from the three experiments, is 1.00.

It seems that the presence or absence of a COD contingency, or the duration of the COD, has no systematic effect on the value of k for response ratios. The values of k for time ratios on Baum's experiment (1976) are not available. Of 11 rats, from Norman and McSweeney (1978) and from present data, a median value of 1.17 was obtained for k in Equation 2. The range of values of k from the present investigation is within the range reported by Norman and McSweeney (1978).

According to current interpretation, a in Equations 1 and 2 is a measure of the sensitivity of performance measures to changes in reinforcement distribution between the schedules of the concurrent pair. The data from all subjects in the present investigation show values of a lower than 1.0, and lower than those reported by Baum (1976) and Norman and McSweeney (1978), for rats. Undermatching (Baum, 1974) was clearly the rule for present data. It should be noticed, however, that these values are within the range of values of a in experiments with humans, monkeys, and pigeons (cf. Baum, 1979, pp. 271-273).

GENERAL DISCUSSION

Present results indicate that with a procedure in which each schedule is associated with a different operandum and changeovers are topographically different from concurrent operants, the sensitivity of relative behavior measures to reinforcement distribution may be low. Nevertheless, relationships between behavior and consequences are lawful. In no way the absence of a changeover delay seems to preclude the establishment of quantitative relationships between relative performance and reinforcement measures. Also, as suggested by Todorov (1979), the absence of COD seems to affect the values of a in Equations 1 and 2, but have no effect on bias (k). As in Norman and McSweeney (1978), the present data conform to Baum's (1971) version of the Matching law. Equation 1 accounts for 91.5 to 99.9% of the variance in response ratios, and Equation 2 for 98.0 to 99.7%of the variance in time ratios.

The low exponents for time ratios, as compared to response ratios, is a finding not observed in previous experiments with rats. Stubbs and Pliskoff (1969) and Todorov (1971) report data from pigeons in which, without a changeover delay, response ratios were higher than time ratios. It is not clear, however, why the absence of a COD should produce this difference. The role of a COD in concurrent schedules still needs clarification (cf. Villiers, 1977; Baum, 1979; Pliskoff, Cicerone and Nelson, 1978).

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