INTERACTION OF FREQUENCY AND MAGNITUDE OF REINFORCEMENT ON CONCURRENT PERFORMANCES[1]

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Frequency and magnitude of reinforcement were varied in concurrent variable-interval variable-interval schedules of reinforcement. The relative response rate to the two stimuli did not support the notion that choice approximately matches relative total access to food (the product of frequency and magnitude of reinforcement in one schedule divided by the sum of products of frequency and magnitude in both schedules). Relative response rates matched relative reinforcement value when that measure was adjusted to give more emphasis to reinforcement frequency than to reinforcement duration.

In a variable-interval (VI) schedule, reinforcements are arranged for the first response that occurs after varying periods of time have elapsed since the previous reinforcement. When two independent variable-interval schedules are arranged concurrently, each associated with a different operant, the following relative measures are usually made:

(a) Relative rate of responding in the presence of a stimulus associated with one schedule, i.e.,

$$\frac{\frac{R_1}{T}}{\frac{R_1}{T} + \frac{R_2}{T}} = \frac{R_1}{R_1 + R_2}$$

where R and T represent number of responses and time, respectively, subscripts representing the schedules. As T is the same for the computation of response rates of both operants, relative response rates and proportion of responses sometimes are used interchangeably.

(b) Relative time spent in the presence of a stimulus associated with one schedule, i.e.,

$$\frac{T_1}{T_1 + T_2} = \frac{T_1}{T} .$$

(c) Relative frequency of reinforcements obtained in the presence of a stimulus associated with one schedule, i.e.,

$$\frac{\frac{r_1}{T}}{\frac{r_1}{T} + \frac{r_2}{T}} = \frac{r_1}{r_1 + r_2}$$

where r represent the number of reinforcements provided by a given schedule.

(d) Relative reinforcement magnitude (usually measured in number or size of food pellets per reinforcement or period of access to a reinforcer) arranged by one schedule, i.e.,

$$\frac{d_1}{d_1 + d_2} .$$

(e) Relative total access to reinforcement (the product of frequency and magnitude of reinforcement in one schedule divided by the sum of products of frequency and magnitude in both schedules), i.e.,

$$\frac{r_1 d_1}{(r_1 d_1) + (r_2 d_2)} .$$

These relative measures are found also in investigations of performances maintained by concurrent (conc) chain schedules of reinforcement (Autor, 1969), in which each operant is reinforced by the presentation of a single schedule of primary reinforcement. The initial links of both chains are concurrent, but once a terminal link is in effect, the other operandum is ineffective. Relative performance measures refer to responding on the initial links of the chain; relative reinforcement measures are based on parameters of primary reinforcement on the terminal links.

In *conc* VI VI schedules, the relative rate of responding in one schedule is a function of the relative rate of reinforcement provided by that schedule (Herrnstein, 1961; Catania, 1963*a*), i.e.,

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2}. \tag{1}$$

Catania (1963*b*) found that when the *conc* VI VI schedules arranged reinforcements with the same frequency, the proportion of responses associated with one schedule was a function of the relative magnitude of reinforcement arranged by that schedule, i.e.,

$$\frac{R_1}{R_1 + R_2} = \frac{d_1}{d_1 + d_2}. \tag{2}$$

Neuringer (1967), using a concurrent chain procedure in which reinforcement duration was manipulated and reinforcement frequency was held constant, found that relative choices in the initial links approximately matched relative total access to reinforcement in the terminal links, i.e.,

$$\frac{R_1}{R_1 + R_2} = \frac{r_1 d_1}{(r_1 d_1) + (r_2 d_2)}. \tag{3}$$

Ten Eyck (1970) varied both reinforcement duration and reinforcement frequency on concurrent chain schedules and found that the relative rate of responding and the relative time spent on the initial links approximately matched relative total access on terminal link, i.e.,

$$\frac{R_1}{R_1 + R_2} = \frac{T_1}{T_1 + T_2} = \frac{r_1 d_1}{(r_1 d_1) + (r_2 d_2)}. \tag{4}$$

The data from the experiments of Neuringer (1967) and Ten Eyck (1970) confirmed and extended those obtained by Herrnstein (1961) and Catania (1963*b*). Ten Eyck also interpreted his results as offering indirect evidence for the validity of Premack's (1965) suggestion that frequency and duration of reinforcement might be combined into one variable, i.e., the product of frequency and duration.

The present experiment studied further the interaction of the effects of reinforcement frequency and reinforcement magnitude on *conc* VI VI schedules. A procedure was developed to observe, within a single session and on the same subject, the effects of manipulating both variables, using three pairs of concurrent schedules.

METHOD

Subjects

Three adult pigeons from the biotery of the Faculdade de Medici na de Ribeirão Prêto, experimentally naive, were maintained at 80% of free-feeding weights throughout the experiment.

Apparatus

A standard pigeon chamber (Ferster and Skinner, 1957) was modified by locating two translucent response keys on one wall. The right-hand key could be transilluminated by a green, a yellow, or a red light. The left key was transilluminated by a blue light. Each response produced auditory feedback by operating a relay. A solenoid-operated hopper presented grain to the pigeons; a reinforcement was a brief period of access to food.

Procedure

After six training sessions, each key color was associated with a different VI schedule. When the key was green, the schedule (VI 36-sec) arranged 100 reinforcements per hour; when it was red, the schedule (VI 45-sec) arranged 80 reinforcements per hour; when it was yellow, the schedule (VI 90-sec), arranged 40 reinforcements per hour. Pecks on the left key (changeover key), always blue, changed the color on the main key and its associated schedule of reinforcement. Changeovers were followed by a brief timeout period (0 < TO < 1-sec), during which the keylights went off and all scheduling and recording devices stopped. Previous findings (Todorov, 1971) indicated that a brief timeout reduced alternation and resulted in a closer match of relative response rates to relative reinforcement rates.

At any given time, two of the three schedules could be in effect on the main key. The first pair of schedules remained in effect until the twentieth reinforcement of the session. A timeout period of 5 min followed, and then another pair of schedules was used. After the fortieth reinforcement, there was another 5-min timeout period and then the remaining pair of schedules became available. There was a total of 60 reinforcements per session.

Table 1

Reinforcement rates and magnitudes on each key color on the six experimental conditions.

| | | Key color | | | | | |
| | | Green Reinforcement | | Yellow Reinforcement | | Red Reinforcement | |
Experimental Conditions	Sessions	Rate (S^R/hr)	Magn (Sec)	Rate (S^R/hr)	Magn (Sec)	Rate (S^R/hr)	Magn (Sec)
1	25	100	2	40	4	80	8
2	15	100	4	40	8	80	2
3	17	100	8	40	4	80	2
4	16	100	8	40	2	80	4
5	17	100	2	40	8	80	4
6	15	100	4	40	2	80	8

The sequence of presentation of the pairs was varied so that all pairs were presented equally often in the first, second, and third part of the session. The magnitude of reinforcement (duration of the period of access to food) associated with each VI schedule was manipulated throughout the experimental conditions. Table 1 gives the sequence of reinforcement frequencies and reinforcement durations.

A condition was maintained for each subject until responding stabilized with all three pairs. The relative response rate was considered stable when no upward or downward trend was observed for five successive sessions.

RESULTS

The number of responses (R_1 and R_2), seconds (T_1 and T_2), and reinforcements (r_1 and r_2) in each schedule, and the number of changeovers were recorded for the three parts of each session. The effects of changes in reinforcement frequency and reinforcement duration were observed on the relative response rate with respect to one of the VI schedules in each concurrent pair, i.e., $R_1/(R_1 + R_2)$.

Table 2 summarizes the results. The data from the last five sessions of each experimental condition were added and the sum totals were used in the calculations of relative rates of responding.

Figure 1 shows the relationship between relative rate of responding and relative total access to reinforcement. Total access to reinforcement was calculated by the multiplication of the number of reinforcements arranged through a schedule by the duration of each reinforcement on that schedule, e.g., r_1d_1 and

r_2d_2. Relative total access is given by the ratio $(r_1d_1)/(r_1d_1) + (r_2d_2)$. The data clearly show that choice proportions did not match relative total access to reinforcement. Most of the points were outside the limits commonly used to judge matching functions (Herrnstein, 1961; Reynolds, 1963). Generally, there was overmatching when relative total access to reinforcement was lower than 0.50 and undermatching when that relative measure was higher than 0.50.

However, as also shown in Figure 1, relative response rates approximately matched relative reinforcement values when that measure was adjusted to give more emphasis to reinforcement frequency, i.e.,

$$\frac{R_1}{R_1 + R_2} = \frac{r_1^a d_1^b}{(r_1^a d_1^b) + (r_2^a d_2^b)}. \qquad (5)$$

For each subject, exponent a in equation 5, the power of reinforcement frequency, was greater than exponent b, the power of reinforcement duration. The computation of relative reinforcement value for the function presented in Figure 2 was made considering the scheduled[2] frequency of reinforcements in each schedule[3]. When the number of reinforcements actually delivered per schedule is considered, the values of a are slightly different, as shown in Table 3.

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[2]While it is common to use the obtained frequency of reinforcement in investigations of the matching of relative performance measures to relative reinforcement measures, the scheduled frequency offers the advantage of a priori predictions of behavior.

[3]The data from the first experimental condition for P-32 were excluded because they are clearly inconsistent with those obtained from the remaining conditions.

Table 2

Original Data Totalled Across the Last Five Sessions in each Experimental Condition

Sch 1 Rft r₁	d₁	Sch 2 Rft r₂	d₂	P-31 R₁	R₂	T₁	T₂	% Obtn Rft Sch 1	CO	P-32 R₁	R₂	T₁	T₂	% Obtn Rft Sch 1	CO	P-33 R₁	R₂	T₁	T₂	% Obtn Rft Sch 1	CO
100	2	40	4	698	442	1588	1116	0.73	571	371	1091	1094	1749	0.71	594	788	669	1333	1327	0.71	740
80	8	100	2	397	330	1287	936	0.44	444	1169	196	1731	627	0.48	429	830	506	1194	939	0.44	478
80	8	40	4	770	441	2181	1210	0.68	665	1449	359	2316	935	0.67	566	1339	562	1968	1187	0.67	709
100	4	40	8	518	417	1507	1148	0.69	467	947	477	1661	902	0.70	475	775	406	1422	1183	0.69	536
80	2	100	4	390	479	957	1253	0.45	464	508	681	968	1151	0.44	384	608	579	1083	1101	0.44	440
80	2	40	8	577	520	1691	1817	0.65	580	1203	803	1917	1236	0.67	567	720	474	2193	1370	0.70	700
100	8	40	4	767	420	1484	1120	0.70	653	1195	409	1859	879	0.72	496	964	218	1653	1000	0.72	404
80	2	100	8	410	556	968	1118	0.45	566	315	717	900	1287	0.43	318	223	867	777	1424	0.42	369
80	2	40	4	808	616	1550	1441	0.66	795	917	613	1833	1337	0.63	542	534	373	1703	1482	0.68	571
100	8	40	2	906	364	1656	955	0.85	829	934	304	1744	863	0.72	559	1702	124	2059	746	0.79	366
80	4	100	8	391	598	930	1181	0.50	629	301	681	870	1364	0.42	408	192	917	809	1485	0.38	281
80	4	40	2	826	504	1771	1190	0.67	958	1013	433	1976	1556	0.68	576	1291	242	2253	946	0.68	364
100	2	40	8	687	572	1467	1222	0.69	891	654	344	1643	1020	0.69	683	1012	386	1500	1269	0.68	536
80	4	100	2	606	487	1048	1042	0.45	648	297	389	1013	1115	0.47	489	474	447	1196	954	0.45	398
100	4	40	8	875	557	1651	1338	0.67	953	626	468	1755	1268	0.66	892	701	390	1667	1646	0.65	602
80	4	40	2	711	436	1528	1112	0.71	620	591	315	1565	1003	0.69	696	784	105	2071	845	0.77	443
80	8	100	4	399	443	989	1059	0.45	464	305	373	928	1133	0.44	451	169	334	1264	1040	0.42	374
80	8	40	2	679	433	1608	1275	0.65	634	629	444	1752	1343	0.67	894	513	99	2663	826	0.73	386

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$$\frac{R_1}{R_1 + R_2} = \frac{r_1 d_1}{(r_1 d_1) + (r_2 d_2)}$$

$$\frac{R_1}{R_1 + R_2} = \frac{r_1{}^a d_1{}^b}{(r_1{}^a d_1{}^b) + (r_2{}^a d_2{}^b)}$$
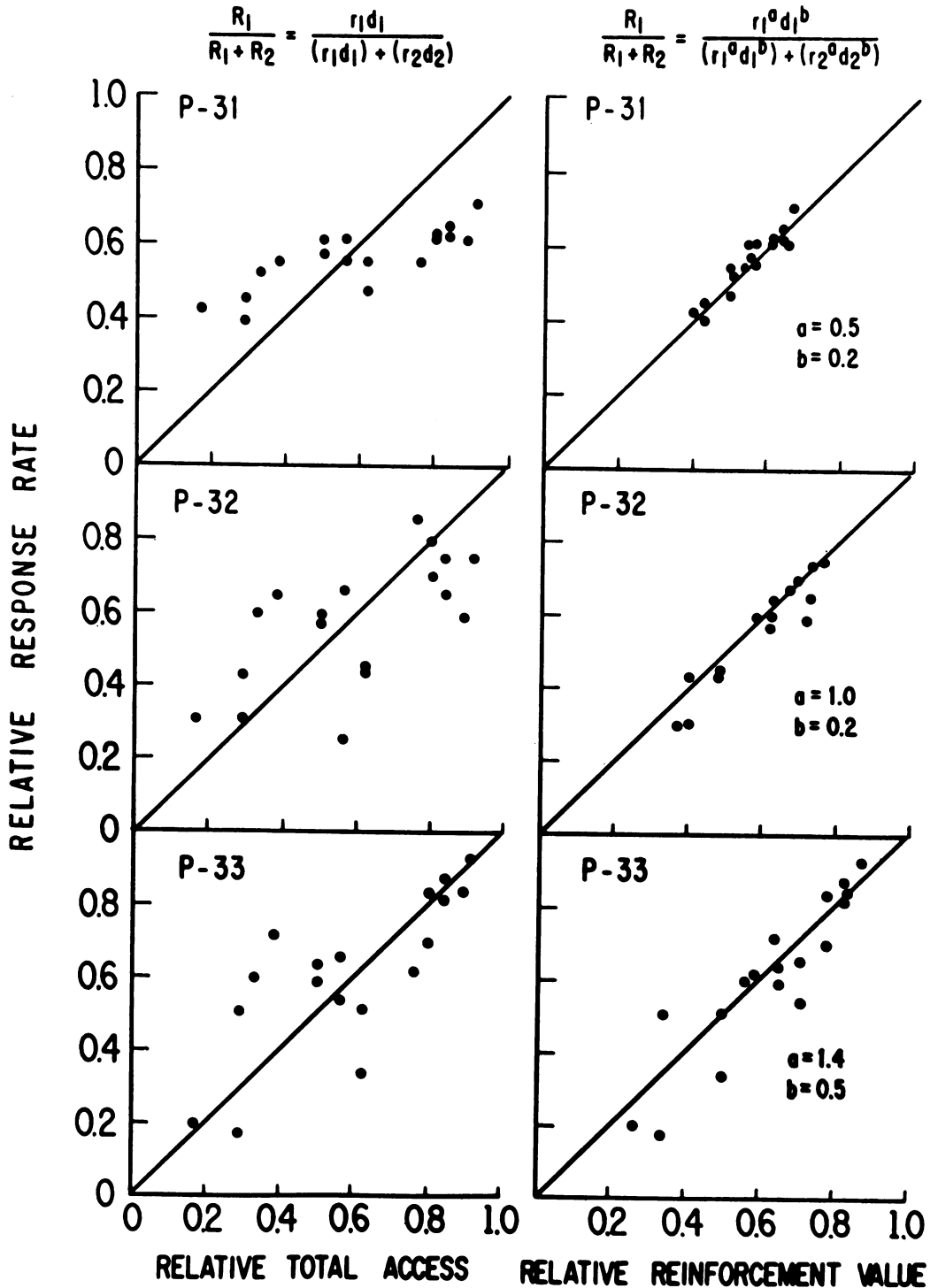

Fig. 1. Relative response rates as a function of relative total access to reinforcement and of relative reinforcement value. Total access to reinforcement is defined as the scheduled frequency of reinforcements on a key color multiplied by the duration of each reinforcement. Reinforcement value is defined as the ath power of scheduled reinforcement frequency multiplied by the bth power of the duration of each reinforcement. The diagonal lines show theoretical points of perfect matching between the relative measures.

$$\frac{T_1}{T_1 + T_2} = \frac{r_1 d_1}{(r_1 d_1) + (r_2 d_2)}$$ $$\frac{T_1}{T_1 + T_2} = \frac{r_1^a d_1^b}{(r_1^a d_1^b) + (r_2^a d_2^b)}$$
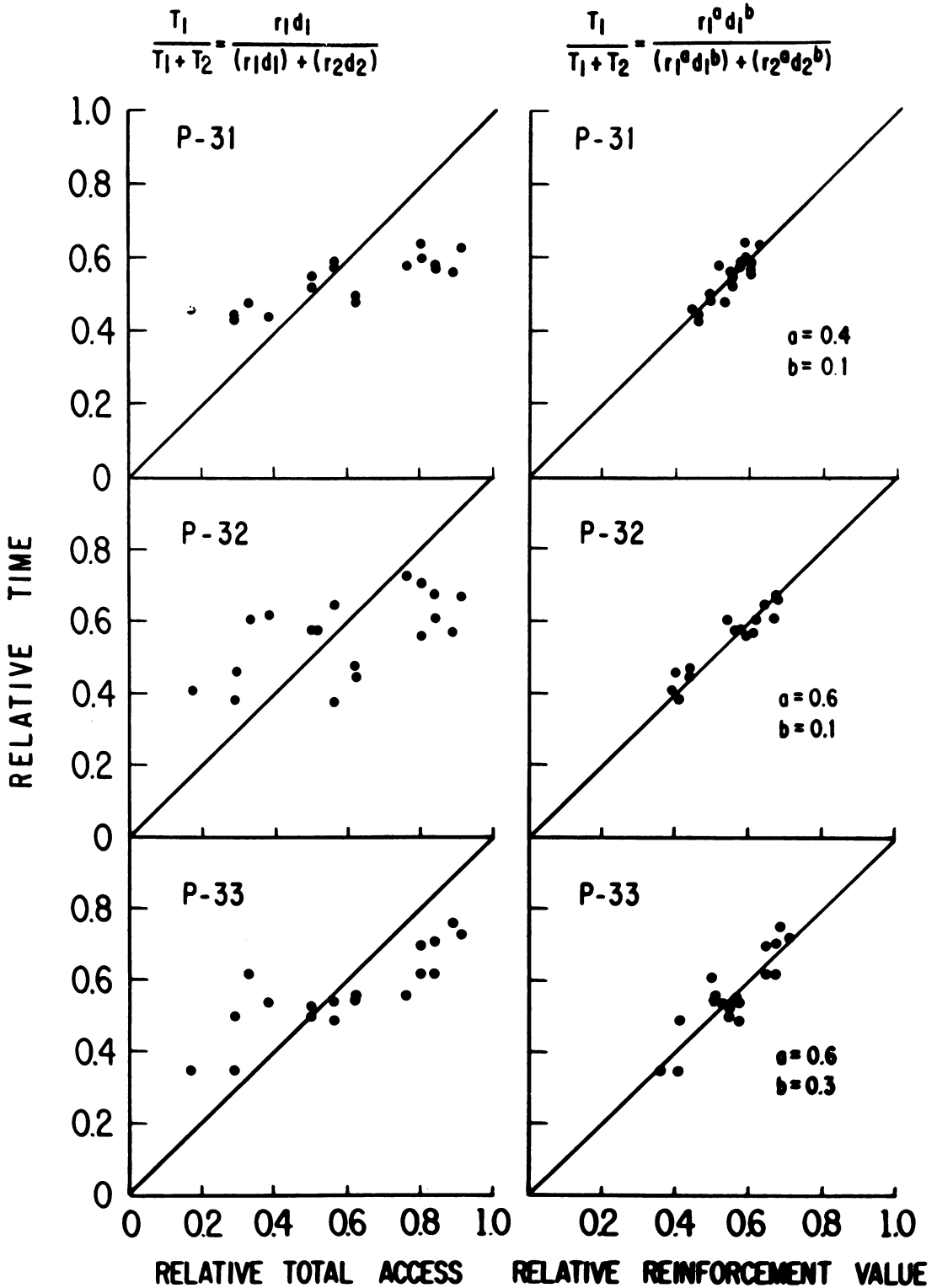

Fig. 2. Relative time as a function of relative total access to reinforcement and of relative reinforcement value. The diagonal lines show theoretical points of perfect matching between the relative measures.

Table 3

Values of *a* and *b* in equations 5 (Rel Resp) and 6 (Rel Time) for scheduled and obtained frequency of reinforcement.

| | *Rel Resp* vs *Rel Reinf Value* Reinforcement frequency | | | | *Rel Time* vs *Rel Reinf Value* Reinforcement frequency | | | |
| | Scheduled | | Obtained | | Scheduled | | Obtained | |
Subjects	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
P-31	0.5	0.2	0.5	0.2	0.4	0.1	0.3	0.1
P-32	1.0	0.2	1.0	0.2	0.6	0.1	0.6	0.1
P-33	1.4	0.5	1.2	0.4	0.6	0.3	0.6	0.3

Figure 2 shows the relationship between relative time spent in one schedule and relative total access to reinforcement in that schedule. There is no matching between the two relative measures. However, relative time also matched an adjusted measure of scheduled reinforcement value (right side of Figure 2) in which more emphasis is given to reinforcement frequency, *i.e.*,

$$\frac{T_1}{T_1 + T_2} = \frac{r_1{}^a d_1{}^b}{(r_1{}^a d_1{}^b) + (r_2{}^a d_2{}^b)} . \qquad (6)$$

As was observed for relative rate of responding, *a* in equation 6 was greater than *b* for all subjects. Table 3 shows that there is a small difference in values of *a* when relative reinforcement value is computed considering the frequency of reinforcements obtained in each schedule.

Table 3 also shows that with all subjects, different values of *a* and of *b* were needed for the matching of relative responding and relative time to relative reinforcement value. Reinforcement frequency had a stronger effect on relative response rate than on relative time. The differences in values of *a* for equations 5 and 6 are especially clear for Subjects P-32 and P-33.

DISCUSSION

Choice behavior did not match the product of frequency by magnitude of reinforcement in the manner suggested by Premack (1965), Neuringer (1967), and Ten Eyck (1970). Instead, reinforcement frequency had a more potent effect upon choice than did magnitude of reinforcement. Frequency and magnitude of reinforcement were combined in a way that their product approximately matched relative response rate or relative time by giving more weight to reinforcement frequency. The data

from two experiments by Fantino, Squires, Delbruck, and Peterson (1972) support the conclusion that rate and duration of reinforcement are not interchangeable. When reinforcement duration was equal on both *conc* VI VI schedules, the matching of relative response rates to relative total access to reinforcement was obtained when the absolute frequencies of reinforcement varied from 600 and 300 to six and three reinforcement per hour. When the schedules arranged equal reinforcement frequencies, but different reinforcement durations, matching of relative rates of responding to relative total access to reinforcement failed to occur.

Apparently, the present results do not confirm previous data on the matching of relative responding and relative time to relative total access to reinforcement. However, some aspects of the procedure employed in the present experiment should be emphasized. Frequency and duration of reinforcement were manipulated in *conc* VI VI schedules, while Neuringer (1967) and Ten Eyck (1970) used concurrent chain schedules. Catania (1963*b*) reported the use of a changeover delay contingent on switching responses in *conc* VI VI, while a brief timeout period was employed here. Previous findings (Todorov, 1971) indicate that relative time does not match relative rate of responding when a brief timeout follows changeovers. It should be noticed also that in the present experiment, subjects were exposed to three different combinations of reinforcement frequency and duration within a single session, while in Catania (1963*b*) reinforcement frequency was kept constant throughout the experiment and the same pair of reinforcement durations was maintained until the criterion of stability was reached.

In view of the differences between relative time and relative response rate, it is difficult to

evaluate the present data in the light of previous statements that the same type of law governs the distribution of responses and the distribution of time (Brownstein and Pliskoff, 1968; Baum and Rachlin, 1969; Brownstein, 1971). In this experiment, relative reinforcement frequency had a more potent effect on relative response rate than on relative time.

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