FREQUENCY VERSUS MAGNITUDE OF REINFORCEMENT: NEW DATA WITH A DIFFERENT PROCEDURE

JOÃO CLAUDIO TODOROV, ELENICE SEIXAS HANNA, AND MARIA CRISTINA NEVES BITTENCOURT DE SÁ

UNIVERSIDADE DE BRASILIA

Two pigeons, with previous exposure to concurrent schedules, were submitted to 29 sessions of 8 hours each with concurrent variable-interval variable-interval schedules in which reinforcement parameters changed from session to session. In the first nine sessions reinforcement durations were equal in both schedules while reinforcement frequencies varied; in Sessions 10 through 18, both frequency and duration of reinforcement were varied; in Sessions 19 through 29, only reinforcement duration was varied. Results with this different procedure confirm previous findings that behavior is more sensitive to changes in reinforcement frequency than to reinforcement magnitude.

Key words: concurrent schedules, variable-interval schedules, reinforcement frequency, reinforcement magnitude, reinforcement duration, matching relation, undermatching, key pecking, pigeons

In choice situations, which alternative is preferred: high frequency of low-magnitude reinforcement or low frequency of high-magnitude reinforcement, given that in the long run both alternatives lead to the same total access to reinforcers? Early data on this issue seemed to offer a clear answer. Relative responding was found to equal relative frequency of reinforcement, given equal reinforcement duration on both schedules of the concurrent pair (Herrnstein, 1961); relative responding was found to equal relative duration of reinforcement, given equal reinforcement frequencies (Catania, 1963). Both relations would lead to a common variable—relative total access to reinforcers (Premack, 1965).

A controversy began when studies produced data showing that behavior could be more sensitive to changes in frequency than to variations in reinforcement magnitude, even in choice situations (Fantino, Squires, Delbrück, & Peterson, 1972; Walker, Schnelle, & Hurwitz,

1970). In two experiments involving simultaneous variation of both frequency and magnitude of reinforcement (Schneider, 1973; Todorov, 1973; cf. Oscós & Todorov, 1978), frequency was clearly more potent than magnitude in controlling response distribution in concurrent variable-interval variable-interval schedules (concurrent VI VI). Keller and Gollub (1977) and de Villiers (1977) criticized the experimental procedures and found Catania's (1963) data more convincing; Keller and Gollub (1977) presented data from two experiments showing that the relative power of frequency and magnitude might be different for different subjects (Experiment 1), and that both variables were equally potent when data from a group of pigeons were considered (Experiment 2).

In all such cases, an extension of the generalized matching law (Baum, 1974) applies:

$$\frac{R_1}{R_2} \quad \text{or} \quad \frac{T_1}{T_2} = k \left(\frac{r_1}{r_2}\right)^a \left(\frac{d_1}{d_2}\right)^b, \qquad (1)$$

where R, T, r, and d refer to response rate, time allocation, reinforcement frequency, and duration of reinforcement (or number of reinforcers), respectively; subscripts denote schedules of the concurrent pair, and k, a, and b are empirical constants. The parameter k is interpreted as a measure of bias due to uncontrolled variables, and the exponents a and b are viewed as measures of the sensitivity of behavior to variations in frequency (a) and magni-

tude (*b*) of reinforcement (Baum, 1974; Schneider, 1973; Todorov, 1973).

The current controversy centers on the question of which expression is true: *a = b, a > b*, or *a ≧ b*? The first expression is defended on theoretical grounds (de Villiers, 1977) and on empirical grounds (Keller & Gollub, 1977, Experiment 2). The second, *a > b*, is supported by data reported by Schneider (1973) and Todorov (1973; see also Lea, 1979). The third expression represents data from Experiment 1 presented by Keller and Gollub (1977). Considering the possibility that such different results may be explained by procedural differences (cf. de Villiers, 1977; Todorov, Oliveira-Castro, Hanna, Bittencourt de Sá, & Barreto, 1983), the present study extended the investigation of the effects of frequency and duration of reinforcement to new experimental conditions, utilizing a procedure in which reinforcement parameters were varied from session to session and in which sessions lasted 8 hours.

METHOD

Subjects

Two adult domestic pigeons, with extensive training in concurrent schedules, served. The birds were kept at approximately 80% of their ad-lib weights.

Apparatus

A standard chamber for operant conditioning studies with pigeons (Grason Stadler Model E3125A-300) was used. The chamber contained two response keys, 7.5 cm apart, 2.5 cm in diameter, and 21 cm from the grid floor. The right key (changeover key) was transilluminated by a red light; the left key (main key) could be transilluminated by a green or a white light, each correlated with a different VI schedule. Standard electromechanical circuitry scheduled and recorded events.
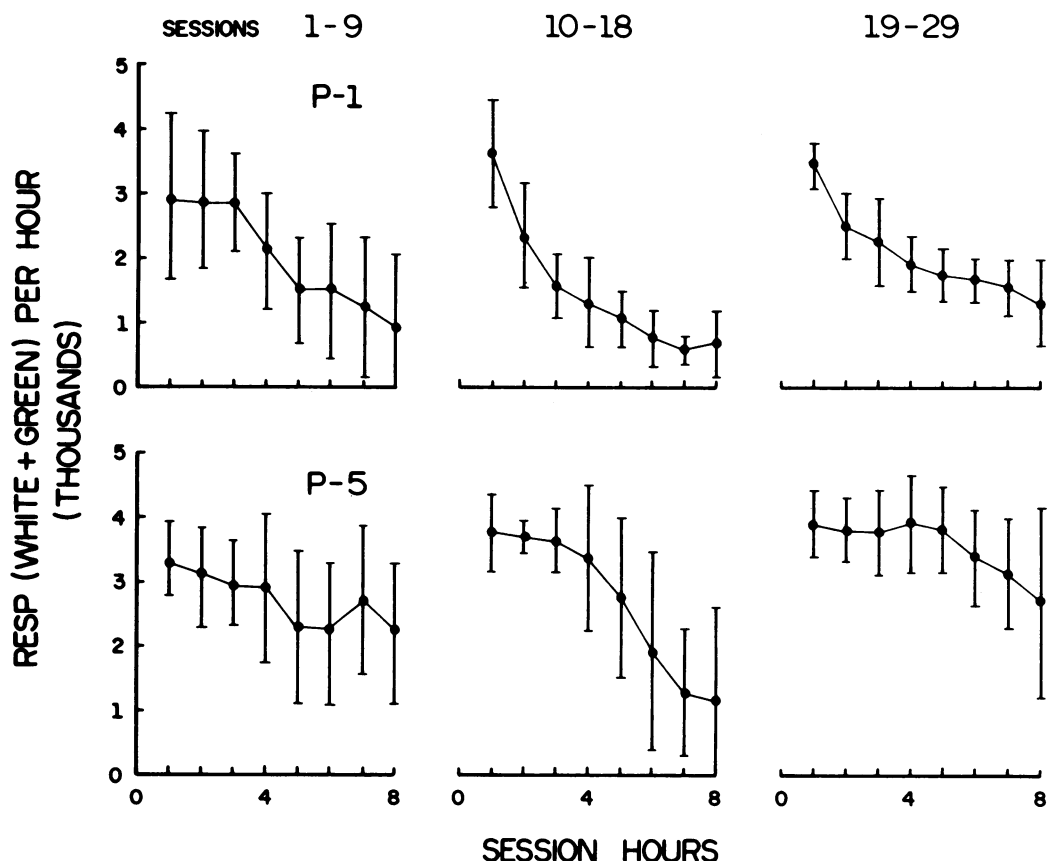

Fig. 1. Rate of responding on the main key as a function of number of hours in the sessions. Points are averages of nine or eleven sessions as indicated in the graphs. Brackets indicate one standard deviation above and below the mean.

Table 1
Number of experimental conditions (sessions), reinforcement parameters per condition, and data obtained in the fourth hour in each session.

| Sub-ject	Session no.	Scheduled Reinf./hr		Duration (s)		Obtained Reinf./hr		Responses		Time (s)		Change-overs
		White	Green	White	Green	White	Green	White	Green	White	Green	
P-1	1	60	20	5.0	5.0	60	16	2217	647	2496	1097	100
	2	20	60	5.0	5.0	9	30	453	1304	571	3029	14
	3	24	56	5.0	5.0	11	23	382	478	961	2639	36
	4	70	10	5.0	5.0	41	4	951	232	3986	285	15
	5	10	70	5.0	5.0	13	78	407	2286	619	3089	62
	6	56	24	5.0	5.0	32	17	834	456	1480	2119	39
	7	40	40	5.0	5.0	38	35	1501	1272	1862	1722	105
	8	30	50	5.0	5.0	23	49	929	1937	1223	2377	82
	9	50	30	5.0	5.0	29	25	1121	1347	1462	1481	68
	10	20	60	12.0	3.0	11	48	557	1444	746	2711	108
	11	50	30	3.0	12.0	35	24	849	1233	1958	1642	64
	12	70	10	6.0	9.0	46	4	767	262	3340	260	31
	13	40	40	10.0	5.0	21	16	600	272	1272	2328	48
	14	24	56	7.5	7.5	3	8	59	68	1236	2370	9
	15	60	20	3.0	7.0	43	15	1315	748	2205	1422	83
	16	30	50	7.0	3.0	7	9	134	134	3791	283	14
	17	10	70	6.0	4.0	7	45	265	706	1142	2877	34
	18	56	24	3.0	9.0	48	21	1567	697	1830	1770	102
	19	20	20	2.5	15.0	21	27	954	2482	1164	3533	64
	20	20	20	15.0	2.5	21	5	1470	605	2718	942	40
	21	20	20	7.5	7.5	18	18	1497	1108	2032	1508	81
	22	20	20	10.0	5.0	19	18	1148	957	1813	1787	64
	23	20	20	5.0	10.0	17	17	773	765	1618	1982	44
	24	20	20	12.0	4.0	16	13	813	731	2030	1571	40
	25	20	20	4.0	12.0	17	17	1001	1108	1754	1846	51
	26	20	20	15.0	6.0	22	20	919	1008	2615	2122	56
	27	20	20	6.0	15.0	18	18	1026	898	1678	1951	40
	28	20	20	15.0	3.0	16	14	799	531	2157	1543	39
	29	20	20	3.0	15.0	16	16	911	1021	1568	2034	54
P-5	1	20	60	5.0	5.0	18	56	1014	2408	1187	2416	127
	2	60	20	5.0	5.0	51	11	1762	486	2729	771	68
	3	24	56	5.0	5.0	21	46	1054	2042	1158	2042	161
	4	56	24	5.0	5.0	22	13	460	464	1407	2193	18
	5	10	70	5.0	5.0	10	73	438	2492	560	3040	146
	6	40	40	5.0	5.0	39	41	1647	2173	1536	2064	224
	7	70	10	5.0	5.0	64	5	3495	362	2770	360	42
	8	30	50	5.0	5.0	18	32	689	689	1120	2480	78
	9	50	30	5.0	5.0	53	19	2936	570	2883	651	95
	10	20	60	12.0	3.0	21	57	2167	2395	1826	1847	209
	11	50	30	3.0	12.0	45	33	1466	2014	1345	2248	192
	12	70	10	10.0	5.0	83	3	2154	154	4473	144	20
	13	40	40	10.0	5.0	36	37	2429	2030	2230	1370	207
	14	60	20	3.0	7.0	65	19	2624	1085	2462	1138	170
	15	30	50	7.0	3.0	35	52	2052	2146	2032	1969	200
	16	56	24	5.0	5.0	24	10	634	251	2756	844	23
	17	24	56	2.5	7.5	22	61	457	3922	584	3009	112
	18	10	70	9.0	6.0	5	76	73	3163	120	3507	24
	19	20	20	2.5	15.0	16	22	211	2759	513	3092	133
	20	20	20	15.0	2.5	21	20	1246	1397	1939	1661	235
	21	20	20	7.5	7.5	17	16	1114	1385	1340	1744	120
	22	20	20	10.0	5.0	22	20	2014	1915	1923	1678	215
	23	20	20	5.0	10.0	26	24	2294	2680	2119	2310	278
	24	20	20	12.0	4.0	23	23	1668	2359	1858	1970	200
	25	20	20	4.0	12.0	22	21	1281	2600	1355	2245	255
	26	20	20	15.0	6.0	20	21	1464	3138	1524	2076	229
	27	20	20	6.0	15.0	20	22	1189	3652	1231	2386	217
	28	20	20	15.0	3.0	21	18	2344	1686	2349	1251	157
	29	20	20	3.0	15.0	21	22	1895	2884	1366	2243	260
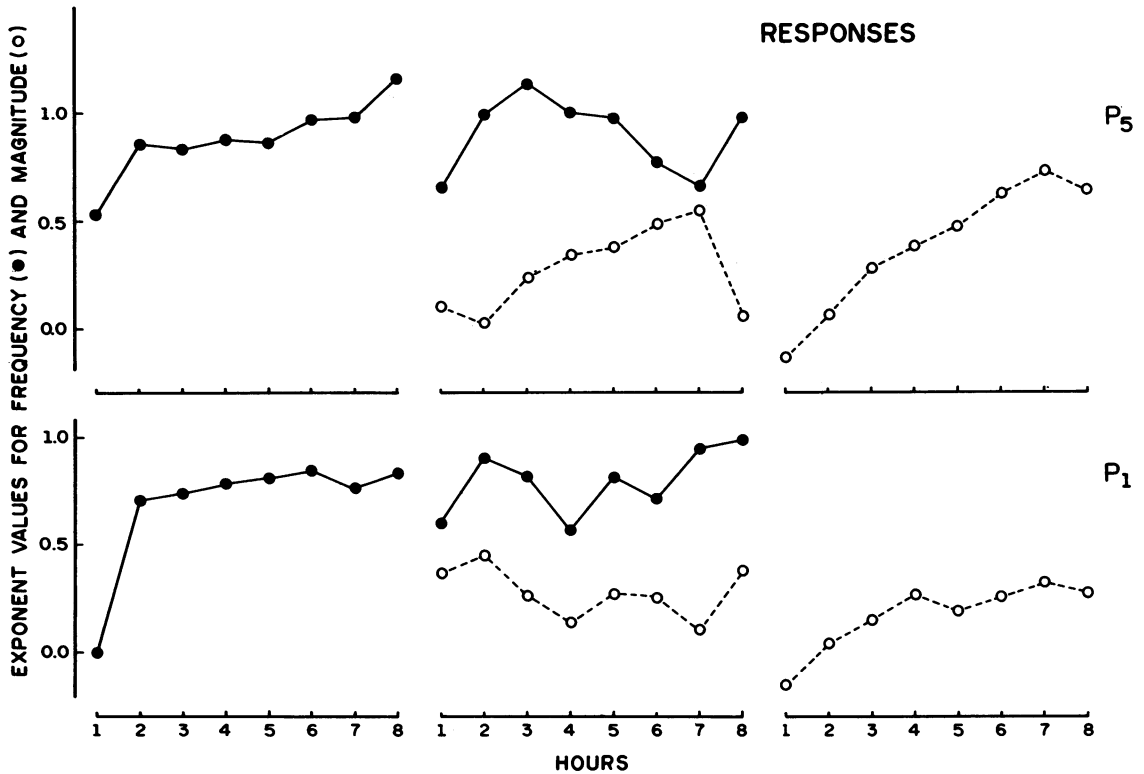
Fig. 2. Values of exponents a (frequency; filled circles) and b (duration; unfilled circles) in Equation 1 based upon response rates for each hour in the sessions. Left graphs show values of a only because reinforcement duration was equal in both schedules. Right graphs show values of b only because reinforcement frequency was equal in both schedules.

Procedure

Table 1 shows the sequence of schedules used and reinforcement frequency and duration for each schedule of the concurrent pair in sucessive sessions. Each VI schedule was arranged as a randomized sequence of nine intervals taken from an arithmetic progression. VI tape programmers operated simultaneously and independently. Reinforcements were periods of access to mixed grain. During reinforcements, the hopper light was on, all other lights were off, and programming and recording devices stopped. Responses and time spent in each schedule, reinforcements, and changeovers were recorded for each hour of the sessions. A session ended after 8 hours, and at least 2 days elapsed between sessions (average

Table 2

Exponent values for frequency (a) and magnitude (b) of reinforcement, values of bias (k), and values of the coefficient of determination (r^2), from response and time data based on the session hour with higher r^2 value.

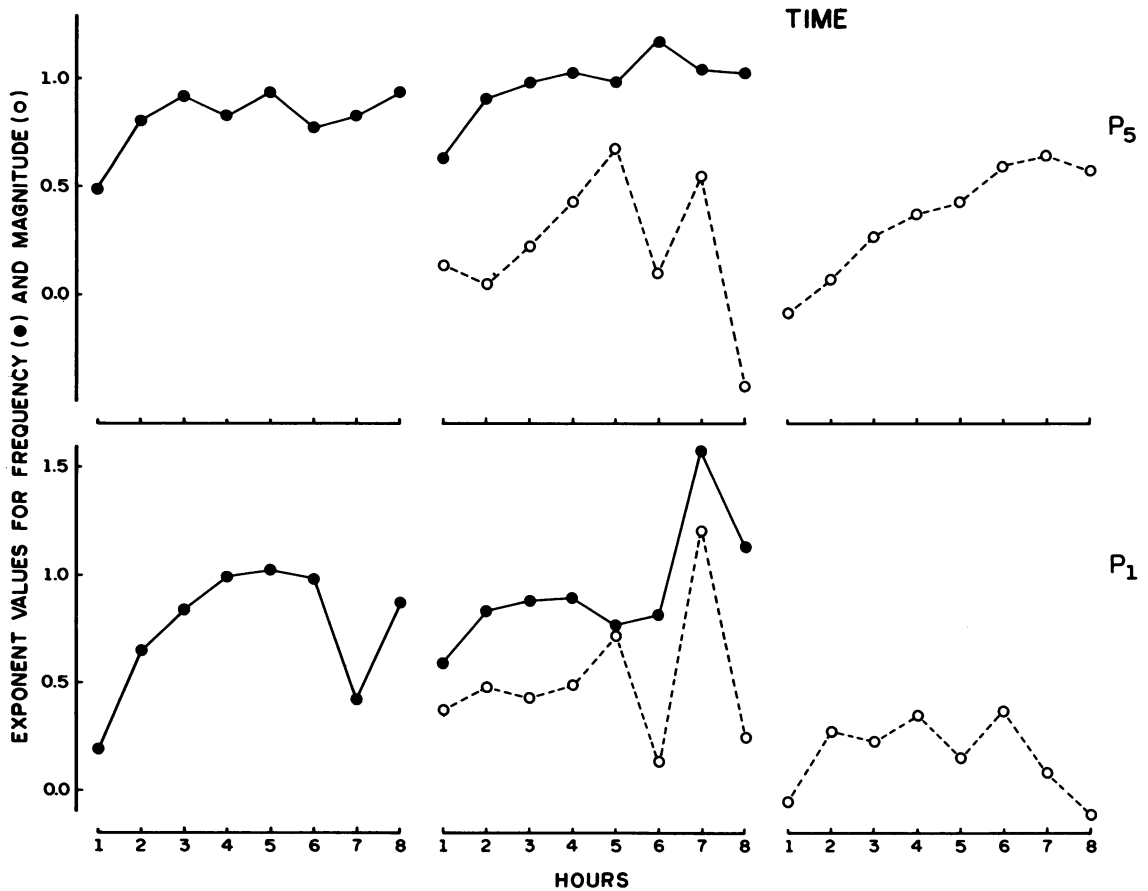| Subject	Frequency				Frequency × Duration					Duration			
	Hour	a	k	r^2	Hour	a	b	k	r^2	Hour	b	k	r^2
	RESPONSES												
P-1	6	0.84	1.19	.98	5	0.81	0.26	1.07	.93	7	0.32	1.07	.80
P-5	6	0.97	1.08	.98	3	1.13	0.23	0.83	.97	6	0.62	0.65	.79
	TIME												
P-1	5	1.01	0.96	.92	8	1.13	0.24	0.89	.87	4	0.34	1.05	.69
P-5	5	0.93	1.19	.98	3	0.98	0.21	0.83	.95	6	0.60	0.87	.85

Fig. 3. Values of exponents *a* (frequency; filled circles) and *b* (duration; unfilled circles) in Equation 1 based upon time allocations for each hour in the sessions. Left graphs show values of *a* only because reinforcement duration was equal in both schedules. Right graphs show values of *b* only because reinforcement frequency was equal in both schedules.

of 3 days, maximum of 6 days) to ensure that the subjects' body weights were approximately 80% of their ad lib weights at the beginning of each session. A 6-s changeover delay (COD; Herrnstein, 1961) was contingent on changeovers.

RESULTS

Table 1 shows the data obtained in the fourth hour in each session (a complete set of data may be obtained from the authors). Figure 1 shows how main-key responding (responses on white plus responses on green) changed during the sessions. Data are presented separately for those sessions in which only reinforcement frequency was varied (Sessions 1 through 9), reinforcement *and* duration were varied (Sessions 10 through 18), and only reinforcement duration was varied (Sessions 19

through 29). Generally, response rates decreased during the sessions, but subjects were responding even in the eighth hour of each session.

The parameters of Equation 1 were computed utilizing data from each of the eight hours in the sessions, and separately for those sessions in which only reinforcement frequency was varied, both reinforcement frequency and duration were varied, and only reinforcement duration was varied. Figures 2 and 3 show how the sensitivity of behavior (measured as responding and time spent in each schedule) to changes in reinforcement frequency and duration varied as a function of number of hours in the sessions. For both pigeons, exponent values for responses (Figure 2) show values of *a* higher than values of *b* irrespective of whether both reinforcement frequency and
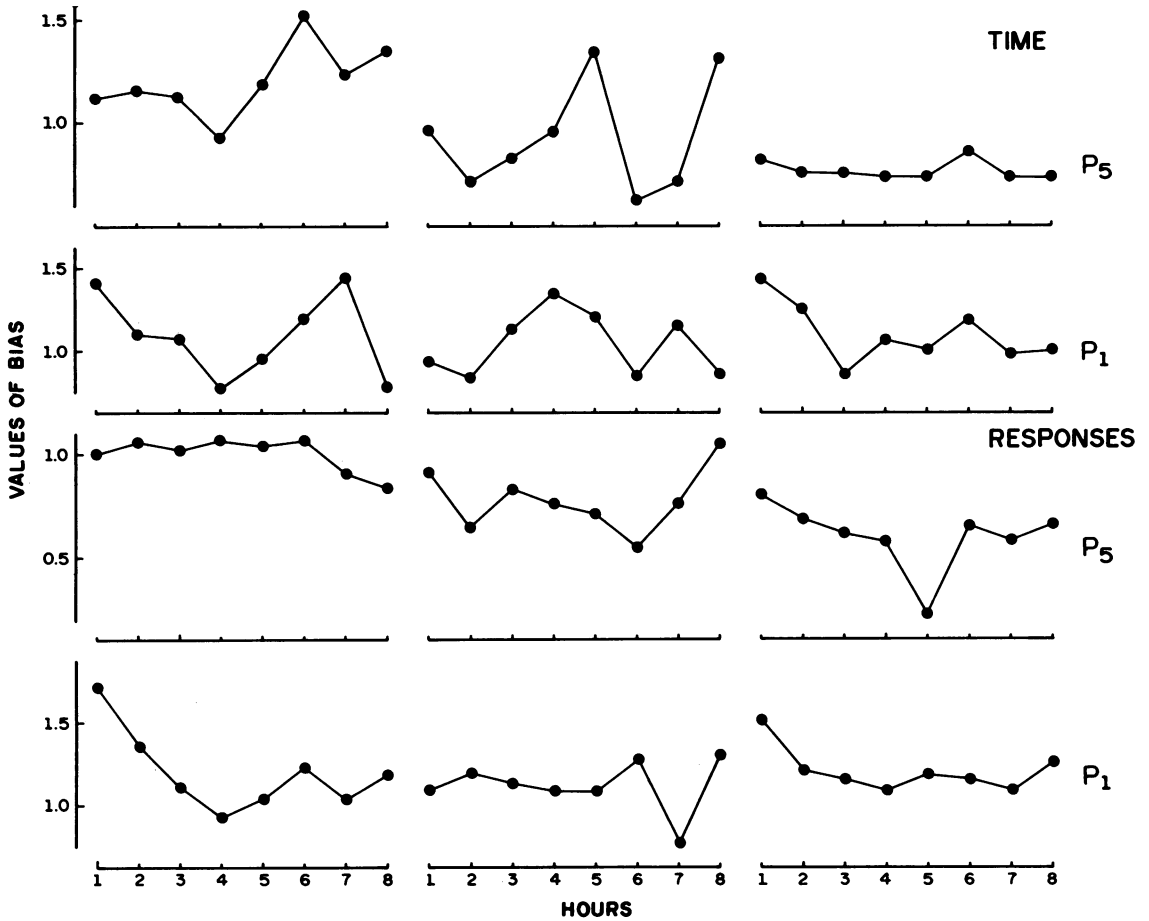
Fig. 4. Values of parameter *k* (bias) in Equation 1 (responses and time) for each hour in the sessions. Data for the left graphs were pooled over sessions for which reinforcement frequencies were varied. Data for the right graphs were pooled over sessions for which reinforcement durations were varied. The center graphs are based on data pooled over sessions for which both frequencies and durations of reinforcement were varied.

duration were varied (central graphs) or whether each variable was manipulated separately (lateral graphs). Figure 3 shows similar results when time spent in each schedule was taken as the behavioral measure.

Figure 4 shows values of *k* (bias) for responses and time. Values of bias did not change systematically as a function of number of hours in the sessions.

Table 2 shows values of exponents and bias obtained from data which produced best fits to Equation 1 (higher values of the coefficient of determination, r^2). Response data show values of *a* (frequency) varying from 0.81 to 1.13 across subjects and conditions, and values of *b* (duration) varied from 0.23 to 0.62. Time data show similar ranges: from 0.93 to 1.13 (values

of *a*) and from 0.21 to 0.60 (values of *b*). Lower values of the coefficient of determination were found in the data from sessions in which only reinforcement duration was varied (except for time data from Bird P-5).

Figure 5 shows the relationship between the logarithm of obtained response ratios and the logarithm of response ratios predicted by Equation 1, for the fourth, fifth, and sixth hours of the sessions, when only reinforcement frequency was varied. Figure 6 shows the same relationship when both reinforcement frequency and duration were varied, and Figure 7 shows data from those sessions when only reinforcement duration was varied. Generally, the standard errors of estimation (S.E.) were larger when reinforcement duration was var-
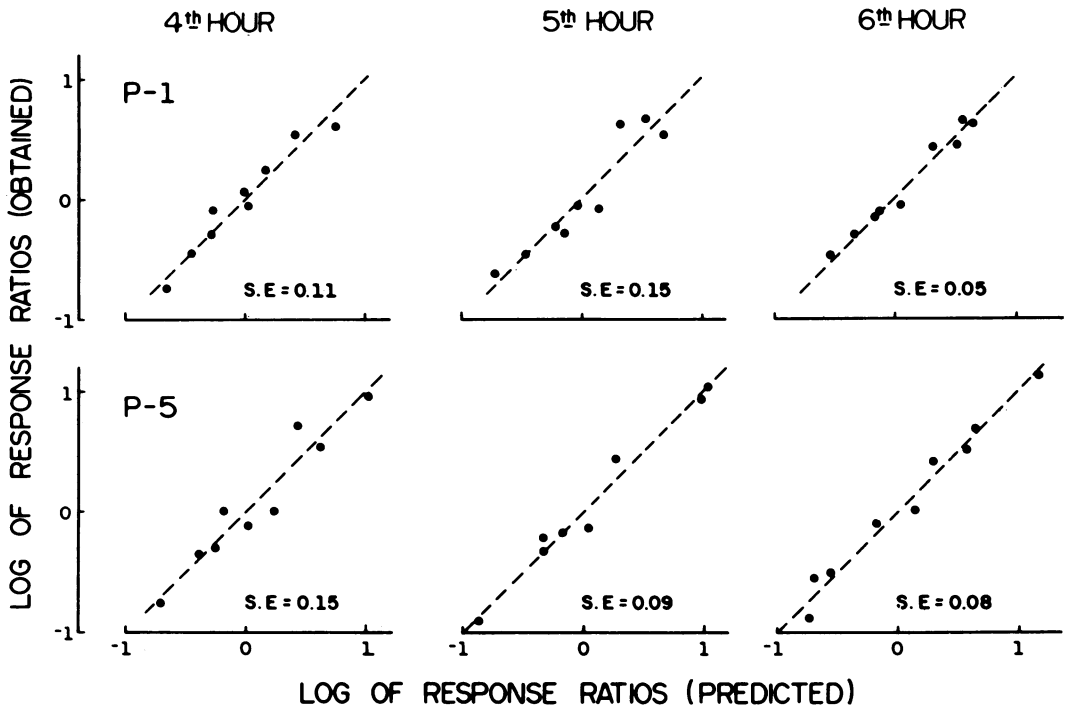
Fig. 5. Logarithm of obtained response ratios as a function of logarithm of response ratios predicted by Equation 1, for the fourth, fifth, and sixth hours of Sessions 1 through 9 (only reinforcement frequency was varied). The standard error of estimation (S.E.) is indicated in each graph.

ied, either alone or with changes in reinforcement frequency. The data shown in Figure 8 indicate a possible reason for such increase in the standard error of estimation.

Figure 8 shows how exponent values in Equation 1 changed as a function of the number of experimental conditions used for the computation. When only reinforcement frequency was varied, the increase in number of experimental conditions had no systematic effect on exponent values based upon the fourth, fifth, and sixth hours in the sessions (filled circles, left-side graphs). When only reinforcement duration was varied, exponent values tended to decrease with increases in number of conditions, except for Bird P-1, sixth hour (unfilled circles, left-side graphs). The effects of number of experimental conditions when frequency *and* duration of reinforcement were varied (right-side graphs) were not so clear, but some differences from the left-side graphs are visible: Generally, exponent values for frequency were lower than those values ob-

tained when only reinforcement frequency was varied; exponent values for duration were lower (Bird P-5) or as low as (Bird P-1) those values obtained when only reinforcement duration was varied; and variability across subjects and hours is larger in the right-side graphs than in the left-side graphs.

DISCUSSION

The present results confirm and extend previous findings on the greater sensitivity of behavior to changes in reinforcement frequency when both frequency and duration of reinforcement are varied simultaneously (Schneider, 1973; Todorov, 1973). Exponent values from Equation 1 were within the range reported for the earlier experiments. The data also indicate the adequacy of a new procedure (Todorov, Ferrara, Gurgel Azzi, & Oliveira-Castro, 1982) for the study of concurrent performances—a procedure in which the experimental conditions were in effect for only one
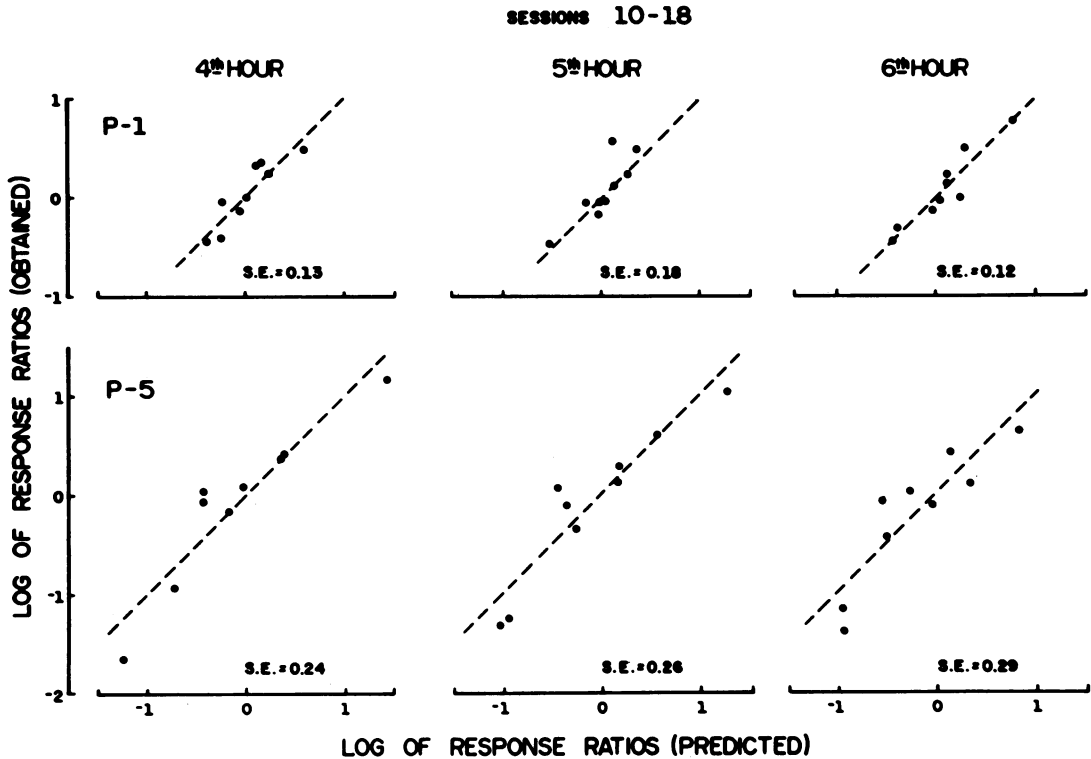
Fig. 6. Logarithm of obtained response ratios as a function of logarithm of response ratios predicted by Equation 1, for the fourth, fifth, and sixth hours of Sessions 10 through 18 (reinforcement frequency *and* duration were varied). The standard error of estimation (S.E.) is indicated in each graph.

session of long duration. Data from this procedure were comparable to those obtained from procedures involving several times the number of experimental hours (cf. Baum, 1979; de Villiers, 1977; Todorov et al., 1983; Wearden & Burgess, 1982). However, data from Todorov and Bigonha (1982) indicate that this "one-session procedure" may be adequate only for subjects with previous exposure to concurrent schedules.

The generality of Equation 1 with $a > b$ is questioned by only one set of data from Experiment 2 in Keller and Gollub (1977). In Experiment 1 of that study, two of three birds produced results in accord with the generalization that in choice situations reinforcement frequency has a more potent effect than magnitude of reinforcement. In Experiment 2 seven pigeons were exposed to concurrent VI VI schedules in only two experimental conditions. In the first condition, reinforcement frequency and duration were equal in both schedules of the concurrent pair; in the second condition, frequency and/or duration were different in

each schedule, with a different pair of schedules for each subject. When the data of the group of seven birds were analyzed, results indicated equal sensitivity of behavior to changes in frequency and magnitude of reinforcement. No such effect has been reported for data from individual subjects. One possible explanation of this discrepancy is that a loss of sensitivity to reinforcement magnitude occurred as a function of the number of different pairs of schedules used in an experiment, an effect similar to that reported by Todorov et al. (1983) for reinforcement frequency in concurrent schedules and to that observed for reinforcement duration in the present experiment (Figure 8).

A recent article by Dunn (1982) reports matching of response ratios to ratios of reinforcement duration using (1) a changeover ratio (COR) as a requirement for the switching response and (2) two feeders in the experimental chamber. A COR has been shown to produce overmatching of response ratios to reinforcement-frequency ratios (Pliskoff, Cice-
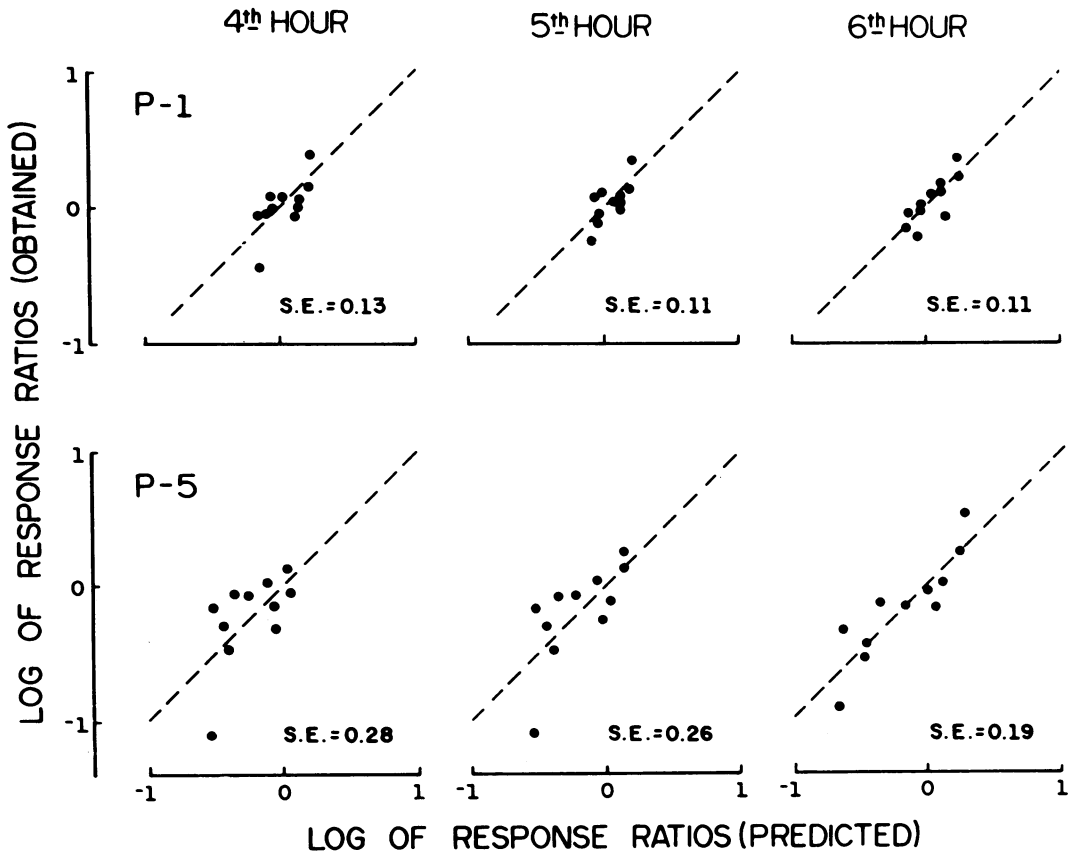
SESSIONS 19-29

Fig. 7. Logarithm of obtained response ratios as a function of logarithm of response ratios predicted by Equation 1, for the fourth, fifth, and sixth hours of Sessions 19 through 29 (only reinforcement duration was varied). The standard error of estimation (S.E.) is indicated in each graph.

rone, & Nelson, 1978; Pliskoff & Fetterman, 1981; Stubbs & Pliskoff, 1969). Perhaps such procedural changes will reveal conditions under which Equation 1, with $a > b$, does not hold.

The present results, like most of those collected previously, support the likehood that reinforcement frequency has a more potent effect on behavior than does reinforcement magnitude. However, a word of caution is advisable regarding the use of the term "magnitude" to refer to reinforcement duration. The studies cited on the effects of reinforcement magnitude on concurrent performances, with the exception of Schneider (1973), refer to reinforcement duration. Magnitude of reinforcement has been used to refer also to other parameters such as number, weight, or density of

the reinforcing substance (cf. Harzem & Harzem, 1981; Schneider, 1973). The effects of relative weight or relative density on relative behavioral measures are not known. Present findings may relate only to reinforcement duration (Todorov, 1973) and number (Schneider, 1973).

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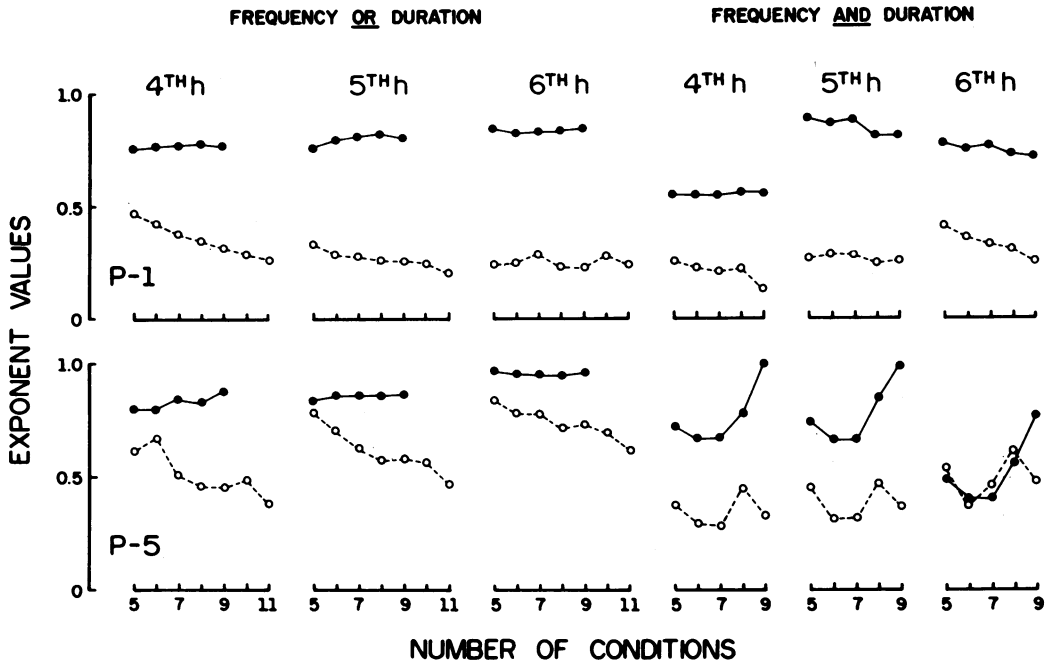FREQUENCY **OR** DURATION   FREQUENCY **AND** DURATION

Fig. 8. Values of exponents *a* (frequency; filled circles) and *b* (duration; unfilled circles) in Equation 1 as a function of number of conditions used in the computation, for the fourth, fifth, and sixth hours in the sessions. Graphs on the left refer to Sessions 1 through 9 (frequency) or to Sessions 19 through 29 (duration). Graphs on the right refer to Sessions 10 through 18 (frequency *and* duration were varied).

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