

THE ROLE OF DISCRIMINATIVE STIMULI IN CONCURRENT PERFORMANCES

GORDON BOURLAND AND JAMES T. MILLER

UNIVERSITY OF TEXAS AT ARLINGTON

Key pecking in pigeons was examined under concurrent and parallel arrangements of two independent and simultaneously available variable-interval schedules. Pecks on the changeover key alternated the schedule of reinforcement for responses on the main key. Under concurrent schedules, discriminative stimuli were paired with the reinforcement schedule arranged in each component and changeover responses also alternated these stimuli. Under parallel schedules, changeover responses alternated the effective reinforcement schedule, but did not change the discriminative stimulus. On concurrent procedures, changeover response rate was inversely related to the difference in reinforcement rate between the two components, whereas on parallel schedules no consistent relationship was found. With both schedules, absolute response and reinforcement rates were positively related, although for a given set of reinforcement frequencies, rates were often higher on the concurrent schedules. On concurrent schedules, relative response rates and relative times were equal to relative reinforcement rates. On parallel schedules these ratios were positively related, but response and time ratios were much smaller than were obtained with comparable concurrent schedules. This inequality was most pronounced when absolute reinforcement frequencies were lowest.

Key words: concurrent schedules, parallel schedules, matching law, stimulus control, variable-interval schedules, key pecking, pigeons

Present theoretical interpretations of concurrent behavior can be extended to predict the effects of ambiguous or undifferentiated exteroceptive stimuli, but few tests of these propositions have been made. Herrnstein (1970) has proposed a general formulation of operant performance derived from concurrent schedules with a more recent review and exposition by de Villiers (1977). Specifically, within

This research was supported by funds granted to James T. Miller by the Organized Research Fund of the University of Texas at Arlington. Portions of these data were presented at the Midwestern Association for Behavior Analysis meeting, Chicago, May 1975. The authors would like to thank Samuel S. Saunders for his assistance in collecting the data and for his helpful comments, as well as Elaine Miller, Hilda Gault, and Harriett Fitzgerald for manuscript preparation. Comments by Joel Myerson on a preliminary version were quite helpful. Gordon Bourland acknowledges partial support of manuscript preparation by Training Grant #917, Maternal and Child Health Services, Department of Health, Education, and Welfare to the John F. Kennedy Institute, while he was a postdoctoral fellow there in the Division of Behavioral Psychology. Reprints may be obtained from Gordon Bourland, Program Director, Colin Anderson Center, St. Marys, West Virginia 26170.

the context of concurrent schedules Herrnstein proposes that

$$\frac{P_A}{P_A + P_B} = \frac{R_A}{R_A + R_B} \quad (1)$$

where P_A and P_B are the response frequencies in Components A and B , and R_A and R_B are the reinforcement frequencies for the respective components. Similarly, others (e.g., Baum, 1974) have suggested a generalized relationship:

$$\frac{P_A}{P_B} = K \left(\frac{R_A}{R_B} \right)^a \quad (2)$$

which, when plotted in logarithmic coordinates, becomes:

$$\text{Log} \left(\frac{P_A}{P_B} \right) = a \text{ log} \left(\frac{R_A}{R_B} \right) + \text{log } k \quad (2a)$$

with the slope a and the intercept $\text{log } k$ empirically determined. Equations 1 and 2 are equivalent when k and a assume a value of 1.0.

The term a in Equations 2 and 2a is widely assumed to have a value of 1.0 in concurrent schedules (de Villiers, 1977; however, see Myers & Myers, 1977, for a critique of this as-

sumption). Values less than 1.0 for a have been termed undermatching (Baum, 1974; Davison & Tustin, 1978; Fantino, Squires, Delbruck & Peterson, 1972). According to Baum, one of the factors that should produce undermatching is poor discriminability between the components.

Catania (1966) lists stimulus control as one of several determinants of behavior allocation in concurrent schedules. The limited research on stimulus control in concurrent performances (e.g., Beale & Winton, 1970; Catania, Silverman, & Stubbs, 1974; Winton & Beale, 1971) has used generalization tests to assess control by the discriminative stimuli following training on a single set of concurrent schedules. The resulting gradients revealed systematic changes in behavior as some dimension of the training stimuli was varied. Aside from control by the discriminative stimuli, another potential source of stimulus control in concurrent schedules is the interreinforcement interval. Studies have been conducted of sources of stimulus control in schedules in which two or more component reinforcement schedules occur successively (i.e., multiple and mixed schedules). Since differentiated performances have been observed in mixed schedules which do not include discriminative stimuli to distinguish the components, as well as in multiple schedules which do include discriminative stimuli (cf., Ferster & Skinner, 1957), differentiated performances also may result when reinforcement schedules are concurrently available but without discriminative stimuli paired with each schedule.

Bourland and Miller (1978; see also Miller, Saunders, & Bourland, 1980) developed a procedure which they termed *parallel schedules* of reinforcement to study the role of discriminative stimuli in concurrent schedules. This schedule is a modification of the changeover procedure developed by Findley (1958) to study concurrent performances. Under Findley's procedure, responses on one key, the main key, are reinforced according to one of two reinforcement schedules. Responses on a second key, the changeover key, alternate the effective reinforcement schedule as well as the discriminative stimuli (e.g., the color of the key) on the main key. In parallel schedules, the procedure is identical except that responses on the changeover key alter the rein-

forcement schedule without altering the discriminative stimulus.

A comparison of parallel and concurrent schedule performances provides information about the role of the discriminative stimuli as a determinant of a . If the reinforcement ratios for the parallel and concurrent schedules are matched, the differences in the slope of the functions associated with the different schedules should reveal the contributions of the exteroceptive stimuli to discriminability of the different reinforcement rates in the two components.

METHOD

Subjects

Three experimentally naive, mixed breed pigeons obtained from a local supplier were individually housed with free access to pigeon grit and water except when in the experimental chamber. The birds were reduced to approximately 80% normal body weights at the start of the experiment and maintained at that weight by varying the number of reinforcers delivered and by postsession supplemental feeding as necessary.

Apparatus

Two sound-attenuated experimental chambers, 38.4 by 34.2 by 30.5 cm, were used. Each had two response keys (BRS/LVE Model 121-15) requiring approximately 20 g (.2N) force for operation located on a Plexiglas wall. The keys were 2.5 cm in diameter and located 17.5 cm apart (center to center), 22 cm above the hardware cloth floor. The aperture for the grain magazine (BRS/LVE Model 114-10) was centered beneath the keys 6.0 cm above the floor.

The stimuli (either a white line or one of two hues) were projected onto the response keys using rear projection units obtained from Industrial Electronics Engineers, Inc., Model 10-3034. The white vertical line was 2.0 by 2.5 cm on a black background and bisected the right response key. Red and green key colors were obtained by illuminating the left key through Wratten filters 74 and 72B to produce hues with dominant wavelengths of 538 nm or 606 nm, respectively. White noise was continuously presented by a small speaker centered above the magazine behind the intel-

Table 1

Summary of stimuli, reinforcement schedules, and number of sessions in each condition with totals of performance measures over the final four days of each condition.

Subject	Schedule	Sessions	VI (sec)		Reinforcers		Responses		Time (min)		
			A	B	A	B	A	B	A	B	
224	Concurrent	50	90	90	100	103	6263	5434	61.96	55.25	
	A = Red	92	90	270	213	67	2523	9638	214.46	68.58	
	B = Green	14	90	540	202	33	23464	8307	202.15	54.33	
		16	90	90	108	108	11026	9151	86.15	65.64	
		15	540	90	176	176	5446	22468	48.45	187.00	
		14	900	90	16	135	2603	2879	22.37	218.25	
	Lean										
	Parallel	32	900	90	16	181	17169	20917	28.00	161.92	
	A = Red	16	270	90	59	192	17281	21196	129.69	159.32	
	B = Red	14	90	540	173	39	17484	13949	131.85	129.84	
	225	Lean									
		Parallel	16	90	90	105	104	8206	8060	85.56	80.88
		A = Red	37	90	270	168	47	11384	9910	138.73	123.37
		B = Red	56	90	540	208	30	6548	5248	173.57	141.04
		14	90	90	110	106	2992	2844	87.03	82.72	
		23	540	90	38	199	5144	6258	146.12	168.99	
		14	900	90	20	177	3573	4685	123.13	144.14	
Concurrent		16	900	90	10	192	399	12364	11.33	262.66	
A = Red		14	270	90	37	182	541	11066	23.40	225.07	
B = Green											
Concurrent		15	90	540	180	28	6088	1326	191.55	49.29	
		21	90	120	117	100	2908	3336	100.89	104.53	
Dense											
Parallel		30	90	15	32	180	626	967	18.14	32.25	
A = Red	31	15	90	214	44	1476	824	40.31	24.99		
B = Red	26	30	90	145	58	1313	1115	44.84	40.34		
333	Dense										
	Parallel	28	90	90	120	112	6077	5697	103.31	91.01	
	A = Green	17	90	30	56	252	2036	5511	124.40	115.10	
	B = Green	56	90	15	30	229	1195	3212	18.65	49.79	
		32	90	30	58	210	2069	4026	49.40	87.57	
		15	90	90	113	105	2554	2522	73.58	76.41	
		38	15	90	168	51	1952	1168	47.94	27.19	
	Concurrent	14	15	90	132	17	1874	283	35.85	8.27	
	A = Red	15	30	90	174	57	2312	1106	61.94	28.61	
	B = Green	14	90	15	23	212	128	1748	10.05	48.83	
	Lean										
	Parallel	14	90	270	157	44	6379	4670	27.27	96.25	
	A = Green	24	540	90	26	155	2748	3962	92.50	138.09	
	B = Green	16	90	540	148	22	6315	4340	127.12	99.73	

ligence panel. Programming and recording equipment was located in an adjacent room.

Procedure

Following magazine training, the birds were trained by the method of successive approximation to peck the left key and then placed in the concurrent or parallel schedule conditions shown in Table 1. During the next five sessions, the reinforcement schedules were gradually changed from fixed ratio 1 to variable interval (VI) 90-sec. The color of the left key (main key), either red or green, and the as-

sociated reinforcement schedules are indicated in Table 1. A 2-sec changeover delay was in effect. At all times each response on the right key (changeover key) initiated a 2-sec period during which main key responses were not reinforced. In Table 1 the designations *A* and *B* refer to the two independent schedule components and associated data collection systems; a changeover response alternated which component was in effect. Under concurrent schedules, the *A* and *B* systems were paired with red and green stimuli, respectively, on the main key. Under parallel schedules, the only

change from this procedure was that stimuli of only a single color were used; the two components and their data collection systems, also designated *A* and *B*, alternated with each changeover response.

A white vertical line on a black background was projected onto the changeover key at all times. In the parallel conditions, a response on the changeover key did not change the color of the main key (with the possible exception of a change in stimulus intensity on component transitions for the second set of parallel schedules for Bird 333).¹ No further contingencies were programmed for changeover responses nor was a main key response required to occur before the changeover key was again operative.

All reinforcement schedules were based on 45-interval constant probability tapes constructed from the formula given by Catania and Reynolds (1968, Appendix II). One component of each condition always contained a VI 90-sec schedule. As shown in Table 1, two sets of parallel conditions with different overall reinforcement densities were used. In one set, the lean parallel conditions, the reinforcement schedule that was varied had a mean interreinforcement interval greater than 90 sec. In dense parallel conditions, the variable component had mean interreinforcement intervals equal to, or less than, 90 sec. The reinforcement schedules for the concurrent conditions were those used in the lean parallel conditions in which the varied schedule had a mean interreinforcement interval greater than 90 sec. Sessions were conducted daily and lasted until approximately 50 reinforcers had been obtained; occasional sizable deviations from this number evident in Table 1 resulted from adjusting the number of reinforcers to maintain deprivation weights and from occasional experimenter errors. The component in effect at the start of each session alternated daily.

Each condition lasted a minimum of 14 days. However, conditions were not changed until the relative response allocation between the

two components remained constant for four days, differing by not more than 5% from the mean for the previous four days with no increasing or decreasing trends.

RESULTS

The data reported in Table 1 are from the final four days of each condition. The rate of changeover responding was determined by taking the total number of changeovers per session divided by the total session time less reinforcement time. Figure 1 shows this rate as a function of the *absolute* value of the logarithm of the ratio of reinforcers received in each component. Under the concurrent conditions (shown by unfilled circles) the rates were inversely related to the reinforcer ratios, i.e., as the relative difference in reinforcer frequency increased, changeover responses decreased. By comparison, no consistent relationship is evident between changeover rate and reinforcer ratios under the parallel schedule conditions (shown by the triangles). These outcomes are perhaps most readily evident in the data for Bird 225 (center panel). Occasional monitoring of performances during sessions revealed no obvious differences in patterns or bouts of changeover responding across conditions.

One measure of concurrent schedule performance is the overall response rate in each component based on total session duration, minus reinforcement time (see Table 1). Figure 2 presents these data as a function of the ratio of the reinforcers received in each component. On the concurrent schedules (top row), absolute response rates in a given component were positively related to the relative reinforcer frequency in that component and inversely related to the relative reinforcer frequency in the alternative component; the data for Bird 224 clearly illustrate this result. The same relationships also were present for the dense parallel training schedules (middle row). However, even though the range of relative reinforcement rates in the dense parallel condition were comparable to the concurrent condition, the degree of differentiation of response rate was not as marked as was the case in the concurrent condition.

A much greater variance between and within subjects occurred during the lean parallel condition (Figure 2, bottom row). For one bird (224), the relationships closely approxi-

¹Due to experimenter error during the second condition for Bird 333, there was a slight change in brightness of the green main key stimulus when the component changed. The stimulus was slightly brighter in the A component. Data from this condition do not appear to differ systematically from those of other parallel conditions with comparable reinforcement schedules.

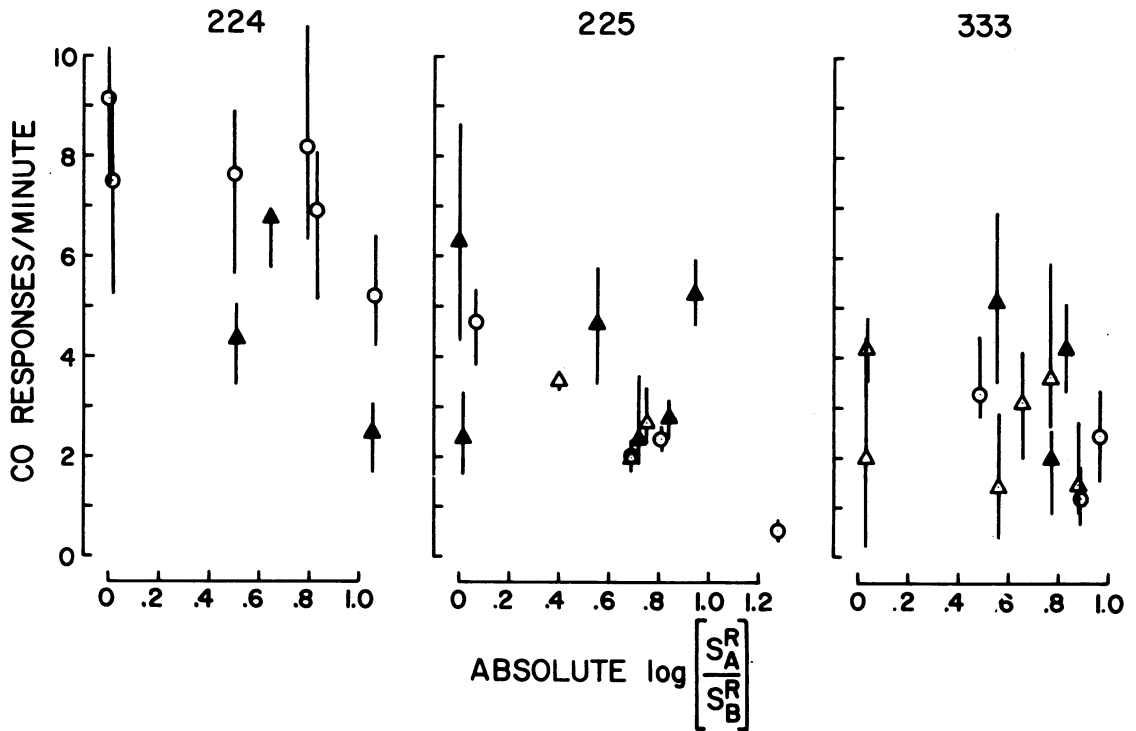


Fig. 1. Mean rate of changeover responding as a function of the *absolute* value of the logarithm of the reinforcers obtained in Component A divided by the reinforcers obtained in Component B for the four criterion days of each condition. Data for lean and dense parallel conditions are shown as filled and unfilled triangles, respectively. Data for concurrent conditions are shown as unfilled circles. The range about the mean is indicated by the lines extending from each data point.

mated those described for the dense parallel condition. For the other two birds (225 and 333), rates in the component with the greater reinforcement frequency did not vary systematically as a function of relative reinforcement rates, although for a given condition response rates were slightly higher in the component with the higher reinforcement frequency.

The top part of Figure 3 shows the log ratios of responding in each component, as a function of log ratios of reinforcement rate for each pair of schedules. (Derived measures are based on data presented in Table 1.) A least squares fit of response data on the concurrent schedules (results shown by squares) indicated slopes approximating 1.0. On the parallel schedules, however, the slope was appreciably lower. The dense parallel schedules (results shown by unfilled triangles) resulted in slopes of .28 and .44, whereas the values obtained for the lean parallel conditions (results shown

by filled triangles) were .11, .12, and .21. The bottom part of Figure 3 shows similar relationships in the time data. These outcomes for all three schedule conditions are clearly shown in the data of Bird 333.

DISCUSSION

The present results indicate that discriminative stimuli play a significant role in performances on simultaneously available reinforcement schedules. Most previous studies of concurrent performances have focused on reinforcement schedule phenomena, and discussions of Equations 1 and 2 have neglected the role of the stimuli used in concurrent schedules. Specifically, the value of *a* in Equation 2 has been treated as if determined solely by reinforcement schedule factors. Given that reinforcement ratios for the parallel and concurrent schedules covered similar ranges, the greater slope, i.e., value of *a*, for concurrent

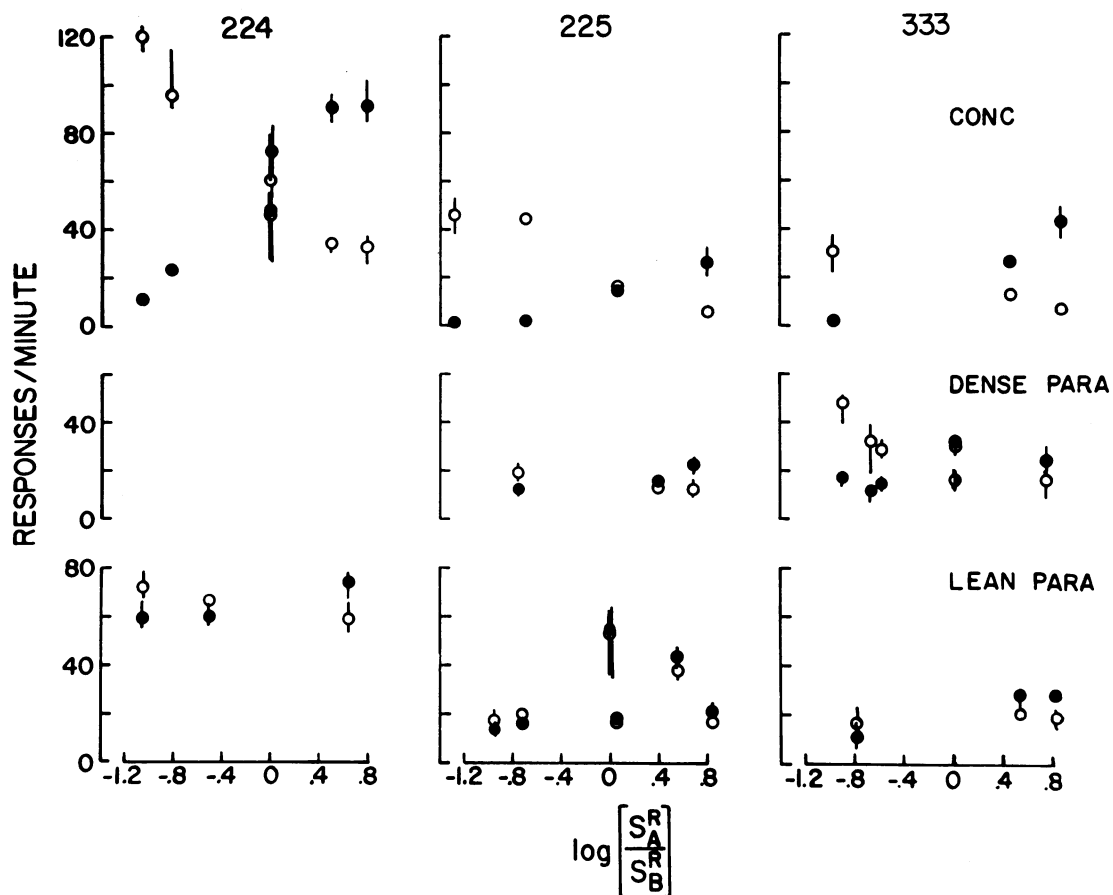


Fig. 2. Response rate in each component (range about the mean is indicated by the line through each point) as a function of the logarithm of the number of reinforcers obtained in Component A divided by the number of reinforcers obtained in Component B. Rate for Component A is shown as the filled symbol, whereas rate for Component B is shown as the unfilled symbol. In concurrent schedules, Component B was the one paired with green stimulus on the main key and one set of reinforcement contingencies; in parallel schedules, Component B referred to one set of reinforcement contingencies with nondifferential stimuli on the main key.

schedules indicates that the discriminative stimuli contributed substantially to schedule discriminability. These results replicate and extend those obtained in preliminary work by Miller et al. (1980).

The role of the discriminative stimuli in simultaneously available reinforcement schedules can be further determined by comparing the performances in dense and lean parallel schedules. When overall time and response allocation ratios were compared, performance on the dense parallel schedules was more differentiated than performance on the lean parallel schedules. The findings suggest that the differentiated performances on parallel schedules were not due to differences in the local

response rates, i.e., the rate computed by dividing the number of responses in a given component by the time spent in that component. (Differences in local rates can be inferred from the relationship between slopes of the response and time ratio functions, i.e., equality of the two implies equal rates in the components, whereas a steeper response function implies a higher local rate in the component with the higher reinforcement rates.) Instead, differentiated performances occurred because of virtually constant rates for more protracted periods in the component with the greater reinforcement density than in the other component, thus resulting in a larger number of responses in the component with the greater

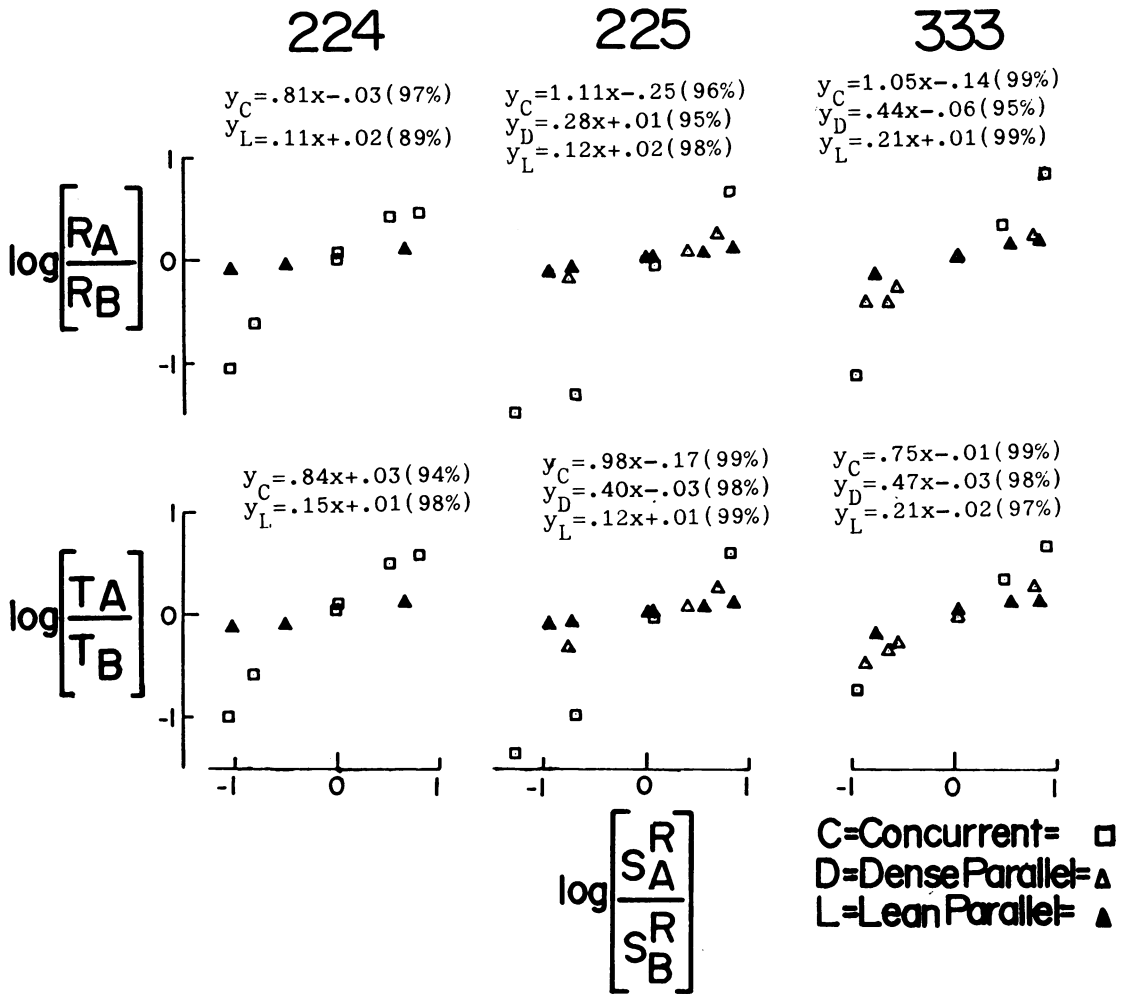


Fig. 3. The logarithm of the number of responses in Component A divided by the number of responses in Component B and the logarithm of the time spent in Component A divided by the time spent in Component B as a function of the logarithm of the number of reinforcers obtained in Component A divided by the number of reinforcers obtained in Component B. Concurrent conditions are represented by the unfilled squares, dense parallel by the unfilled triangles, and lean parallel conditions by the filled triangles. Equations for least squares fit lines are given for each set of conditions; the percentages in parentheses following each equation are the percentage of variance accounted for by the equation.

reinforcement density. In the concurrent conditions, consistent differences in local rates also were absent.

On the parallel schedule, changes in absolute response rates, i.e., numbers of responses in the component divided by total session duration, as a function of reinforcer frequency ratios were similar to those observed on concurrent schedules. Specifically, response rate was directly related to reinforcement frequency in the same component and inversely related to reinforcement frequency in the other com-

ponent. Similar results have been reported for concurrent schedules (e.g., Catania, 1963; Rachlin & Baum, 1972). For the lean parallel conditions, however, absolute rates were not consistently related to the ratio of reinforcers received in a given component other than that rate was greater in the component with the greater rate of reinforcement.

The finding that parallel performances were less differentiated than concurrent performances appears consistent with the theoretical proposition that undermatching, i.e., slopes

less than 1.0 for functions relating relative response and reinforcement distributions, occurs whenever the discriminability between the components is poor (Baum, 1974). Clearly on parallel schedules the discriminability between the components would be expected to be far less than on comparable concurrent schedules. Earlier work involving concurrently available reinforcement schedules using the Findley procedures used here (Miller et al., 1980) demonstrated that performances became more differentiated as the difference between stimuli used as discriminative stimuli was increased. Such performance changes would seem correlated with increased discriminability.

The results indicated that changeover rate was inversely related to reinforcement ratios on the concurrent schedules but not on the parallel schedules. Given that the degree of preference as indicated by response ratios was limited in parallel conditions, the minimal variation in changeover rate across reinforcement ratios appears consistent with the theoretical position of Myerson and Miezin (1980). They proposed a kinetic account of concurrent performances in which changeover behavior plays a primary role. Within that formulation probability of changing over to a given component is proportional to preference for that component. One implication of the model is that as preference becomes extreme, changeover rate will decrease; conversely, if preference is virtually nondifferential across a range of reinforcement ratios, changeover rates should vary little. On parallel schedules, reinforcement distribution did not affect preference as markedly as on concurrent schedules and thus, according to this position, would be expected to have less impact on changeover responding in parallel than in concurrent conditions.

Unlike the present study, Bourland and Miller (1978) found that changeover response rate was consistently greater in the concurrent as compared to the parallel schedules. These different results may be due to the particular sequences of parallel and concurrent schedules. In the earlier study, concurrent and parallel conditions were conducted in double-alternation fashion. This contrasts with the present study in which concurrent or parallel conditions were alternated only after experience with three or more pairs of schedules in a

given condition. Possibly extended exposure to parallel schedules without interpolated exposure to concurrent schedules or an extensive history with concurrent schedules interferes with control by exteroceptive stimuli.

REFERENCES

- Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 231-242.
- Beale, I. L., & Winton, A. S. W. Inhibitory stimulus control in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1970, **14**, 133-137.
- Bourland, G., & Miller, J. T. Role of discriminative stimuli in concurrent performances: Duration of changeover delays. *Psychological Record*, 1978, **28**, 263-271.
- Catania, A. C. Concurrent performances: Reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 253-263.
- Catania, A. C. Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: Areas of application and research*. New York: Appleton-Century-Crofts, 1966.
- Catania, A. C., & Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 327-383.
- Catania, A. C., Silverman, P. J., & Stubbs, D. A. Concurrent performances: Stimulus-control gradients during schedules of signalled and unsignalled concurrent reinforcement. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 99-107.
- Davison, M. C., & Tustin, R. D. The relation between the generalized matching law and signal-detection theory. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 331-336.
- de Villiers, P. A. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Fantino, E., Squires, N., Delbruck, N., & Peterson, C. Choice behavior and the accessibility of the reinforcer. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 35-43.
- Ferster, C. B., & Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 123-144.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Miller, J. T., Saunders, S., & Bourland, G. The role of stimulus disparity in concurrently available reinforcement schedules. *Animal Learning and Behavior*, 1980, **8**, 635-641.
- Myers, D. L., & Myers, L. E. Undermatching: A reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1977, **27**, 203-214.

Myerson, J., & Miezin, F. M. The kinetics of choice: An operant systems analysis. *Psychological Review*, 1980, 87, 160-174.

Rachlin, H., & Baum, W. M. Effects of alternative reinforcement: Does the source matter? *Journal of the Experimental Analysis of Behavior*, 1972, 18, 231-241.

Winton, A. S. W., & Beale, I. L. Peak shift in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 73-81.

Received November 6, 1977

Final acceptance February 16, 1981