The role of stimulus disparity in concurrently available reinforcement schedules

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Eight White King pigeons were exposed to various two-component arrangements of concurrently available variable-interval reinforcement schedules. Line orientation stimuli associated with each component differed by 45, 15, or 0 deg for different subjects. Relative responding matched relative reinforcement with 45 deg separation, while undermatching resulted with 15 deg separation and extreme undermatching resulted with 0 deg separation. Since obtained relative reinforcement indicated contact with the contingencies in all conditions of line orientation disparity, it is concluded that stimulus disparity between components of concurrently available reinforcement schedules is an important determinant of response distribution between components.

There is substantial literature (see reviews by deVilliers, 1977, and deVilliers & Herrnstein, 1976) concerning concurrent schedules of reinforcement, a procedure in which two (or more) reinforcement schedules, each associated with a discriminative stimulus, are simultaneously available to the subject. The majority of these studies have dealt with how manipulations of the reinforcement schedules affect response distribution between the available alternatives (components). The most typical finding is that changes in the relative distribution of reinforcers between the components result in an equivalent change in the relative distribution of responses to the components, the matching law. Only a limited number of studies (Beale & Winton, 1970; Catania, Silverman, & Stubbs, 1974; Winton & Beale, 1971) have dealt with stimulus factors, and those studies have been primarily directed at examining the concept of inhibition rather than the effect of changes in the discriminative stimuli per se in concurrent schedules.

Two of the major theoretical models of concurrent behavior (Herrnstein, 1970; Baum, 1974) provide

parameters that potentially can describe the effects of varying the discriminative stimuli. The implications of these parameters for response distribution have yet to be examined directly. Baum has most explicitly stated the conditions for testing the role of discriminative stimuli. Baum's model states that as the discriminative stimuli associated with the various schedules are made more similar, response distribution should tend to go to undermatching, that is, an equal distribution of responses to the components regardless of the degree of reinforcement disparity. Baum asserts that the failure to find matching in multiple schedules of reinforcement—a procedure in which two (or more) reinforcement schedules, each associated with a distinctive discriminative stimulus, are sequentially imposed on the subject—is due, in part, to the failure of the subject to discriminate between the components. If, for example, the duration of each component is decreased, the discriminability of the components would be increased and response distributions approximating matching should be obtained. In the two studies that varied component length in multiple schedules, Shimp and Wheatley (1971) and Todorov (1972), matching was obtained as component length was shortened. The Herrnstein model would predict similar results.

Still, few direct tests of the role of the discriminative stimuli in concurrent schedules have been made. Most studies (deVilliers, 1977; deVilliers & Herrnstein, 1976) used widely disparate stimuli, and only two studies (Bourland & Miller, 1978, Note 1) have directly manipulated the disparity of the discriminative stimuli. The Bourland and Miller studies made use of a concurrent procedure developed by

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Findley (1958). In the Findley procedure, reinforced responses are not directed to two manipulanda, but instead are directed to the same manipulandum, the reinforcement or main key. Distinctive discriminative stimuli are used to delineate the reinforcement schedules that are in effect. Responses to a second manipulandum, the changeover (CO) key, are used to alternate the reinforcement schedules as well as the discriminative stimuli in effect on the main key. In the Bourland and Miller studies, responses to the CO key did alternate the reinforcement schedules but did not alternate the discriminative stimuli. They labeled this procedure the parallel schedule of reinforcement and viewed it as bearing the same relationship to a concurrent schedule as a mixed does to a multiple schedule or as a tandem does to a chain schedule.

Both of the Bourland and Miller papers demonstrated that performance in parallel schedules of reinforcement was very similar to performance in concurrent schedules of reinforcement. Although the changeover response rate in parallel schedules was generally less than the changeover response rate obtained in concurrent schedules, the rate was great enough to permit exposure to both components of the schedule. Appropriate distribution of reinforcers between the components consistently was obtained in parallel schedules. The most striking difference between parallel and concurrent schedules was in the distribution of responses between the available components. In parallel schedules, the matching relationship between relative reinforcers and relative responses was not obtained. Instead, regression slopes of approximately .14 were obtained between relative responding and relative reinforcement when the absolute overall levels of reinforcement were 80 reinforcements/h or less. When the absolute overall levels of reinforcement were 80/h or greater, the slope of the regression equation of response distribution to reinforcement distribution approximated .36. These results were obtained over comparable ranges of relative reinforcement frequencies.

Although the data obtained from the parallel schedules of reinforcement, when compared with the existing concurrent schedules data, provide the endpoints of the stimulus disparity continuum, the parametric data for a theoretical analysis that the Baum model would seem to require have not been obtained. The present study proposed to examine three different values of stimulus disparity on a continuum that had been used previously by Bloomfield (1966) to establish different degrees of stimulus discriminability using multiple schedules of reinforcement. An examination of the data obtained by Bloomfield would suggest that a difference of 45 deg in line orientation would yield maximal discriminability between the stimuli, while a 15-deg difference in line orientation

would be moderately difficult and a 0-deg disparity in line orientation would represent a parallel schedule procedure.

METHOD

Subjects

Eight White King pigeons obtained from a local supplier were used as subjects. The pigeons had had prior experience on a mixed variable-interval schedule of reinforcement which used a green hue (538 nm peak wavelength) as the stimulus. All pigeons were maintained at 75% normal body weight during the course of the experiment. Each pigeon was individually housed with free access to pigeon grit and water except when in the experimental chamber.

Apparatus

Two standard operant conditioning chambers ($38.4 \times 43.2 \times 30.5$ cm) were used. Two keys (2.53 cm in diameter), which required .2 N force for operation, were located 17.5 cm apart (center to center) 20 cm above the hardware cloth floor. Reinforcers consisted of 3-sec access to a grain magazine located 6.0 cm above the floor and centered between the response keys. White noise was continuously presented by means of a small speaker located to one side of the magazine. All programming and data recording were done using electromechanical equipment located in an adjacent room.

Various line orientations or hue stimuli could be presented on the response keys using rear-mounted miniature projectors (IEE Model 10-3043). The white lines were 2.54 cm long $\times$ 2 mm wide and presented on a black surround. Seven line orientations could be obtained by rotating a horizontal (0 deg) line that bisected the center of the key to the vertical (90 deg) in 15-deg increments. The hue stimulus (606 nm peak wavelength) appeared as red to the human eye.

Procedure

Since all pigeons had had equivalent previous training, each pigeon was randomly assigned to the initial stimulus disparity condition and no pretraining was given. Training was then begun. All pigeons had a red stimulus projected onto the CO key during the training sessions, and the line stimuli and associated reinforcement schedules were in effect for the main key, as indicated in Tables 1, 2, and 3. All schedules were equal-probability variable interval, determined by the formula presented in Catania and Reynolds (1968, Appendix 2). Responses to the CO key for pigeons in the 0-deg disparity group alternated the effective reinforcement schedules, but no change occurred in the line orientation projected onto the main key. Responses to the CO key for pigeons in the 15- and 45-deg stimulus disparity groups alternated the effective reinforcement component and the line stimulus that was projected onto the main key. Each CO response began a changeover delay (the COD) period that was 2 sec long. Responses to the main key were not reinforced during the COD period.

All pigeons were given six daily training sessions per week. Each session was terminated when the pigeon had obtained a nominal 30 reinforcers for that session. Training on a given set of conditions continued until relative responding to the denser reinforcement component for each of four successive sessions differed by less than 10% from mean relative responding for those four sessions, and there were no increasing or decreasing trends in relative responding over successive sessions. Regardless of these criteria, a minimum of 14 sessions were conducted on each condition, with a few exceptions due to experimenter error.

RESULTS

The data were initially examined to assure that the pigeons had experience with the reinforcement contingencies in both components regardless of the stim-

ulus disparity condition. An examination of the range of relative reinforcement ratios for the pigeons (see Figure 1) indicates that the ranges of obtained reinforcement ratios were substantial across all stimulus disparity conditions. This examination indicates that any differential experience that occurred did not form a pattern and seems to be limited to individual conditions (see columns k and l of Tables 1, 2, and 3).

Thus, any differences in the response distribution between the components for the various stimulus conditions were not due to differential experience with the obtained reinforcers. Two pigeons, birds 520 and 522, drastically decreased rates of changeover responding following the first shift in reinforcement contingencies. These pigeons continually responded to the initial reinforcement contingency in a

Table 1
The Mean Overall, Local, Changeover Delay, Postchangeover Delay, and Changeover Rates Presented with ± 1.0 Standard Deviation in Parentheses for Pigeons in the 0-deg Disparity Group

Subject	Stimulus	Reinforcement		Response Rate												Sessions	Reinforcement	
				Overall		Local		COD		Post-COD		CO						
		A	B	A	B	A	B	A	B	A	B	CO						
		(Sec)	(Sec)	a	b	c	d	e	f	g	h	i	j	k	l			
		VI	VI															
523	90° 90°	30	90	21.7 (8.6)	12.6 (5.9)	32.7 (14.8)	38.7 (12.5)	44.9 (16.7)	40.9 (12.0)	31.6 (14.2)	40.9 (12.0)	3.2 (1.4)	78	101	22			
		270	90	27.0 (6.3)	29.4 (10.9)	31.0 (1.2)	28.9 (2.6)	33.6 (5.3)	35.2 (9.3)	30.5 (1.0)	27.8 (2.3)	4.0 (.5)	25	30	101			
		60	60	27.9 (1.8)	24.9 (2.8)	53.1 (3.6)	51.9 (3.5)	70.6 (5.5)	75.7 (11.0)	49.8 (2.6)	47.5 (4.0)	5.6 (1.6)	27	55	65			
		90	270	33.7 (4.8)	27.4 (2.5)	60.5 (7.5)	65.3 (4.4)	74.0 (8.7)	72.7 (5.3)	58.2 (7.6)	63.7 (4.9)	5.5 (.9)	13	89	32			
		270	30	36.2 (5.8)	27.0 (.3)	64.9 (22.2)	56.6 (11.5)	76.3 (4.5)	69.8 (1.1)	60.3 (28.8)	54.7 (12.8)	4.3 (.6)	11	81	10			
		60	60	22.2 (3.1)	25.1 (4.9)	46.9 (6.0)	53.8 (23.3)	59.6 (8.2)	59.0 (8.1)	44.9 (6.1)	53.0 (25.6)	4.4 (.5)	26	58	69			
		90	30	16.3 (5.7)	17.7 (5.1)	47.0 (8.7)	27.7 (10.5)	63.6 (9.5)	66.6 (9.1)	44.4 (9.3)	23.4 (7.9)	3.8 (1.8)	16	32	88			
518	45° 45°	90	270	26.9 (2.0)	22.2 (1.4)	50.7 (3.5)	47.5 (1.9)	49.5 (5.6)	49.6 (7.6)	50.7 (3.4)	47.2 (1.7)	2.9 (1.5)	88	107	37			
		60	60	50.7 (15.1)	50.6 (13.2)	99.7 (27.1)	103.3 (29.2)	141.3 (35.6)	143.7 (27.7)	97.2 (26.8)	100.6 (29.6)	1.8 (.5)	20	66	57			
		30	90	77.4 (10.0)	51.0 (11.5)	132.5 (12.8)	126.3 (35.9)	276.1 (9.6)	231.9 (89.7)	119.4 (4.6)	107.4 (34.5)	3.0 (2.2)	23	87	34			
		30	270	94.0 (10.8)	59.0 (14.2)	152.8 (22.3)	153.4 (30.4)	296.8 (16.5)	266.7 (37.6)	142.9 (22.1)	140.0 (35.5)	2.5 (.8)	30	108	13			
		90	270	55.5 (6.7)	58.4 (6.3)	111.9 (11.0)	117.5 (10.4)	222.9 (38.7)	251.8 (27.1)	106.7 (12.8)	111.4 (12.0)	1.4 (.7)	14	91	29			
		60	60	32.3 (2.4)	32.5 (2.5)	65.6 (3.8)	64.2 (5.0)	50.6 (18.0)	53.0 (15.2)	67.7 (3.7)	65.7 (4.6)	4.3 (1.2)	55	51	72			
		270	90	27.3 (2.6)	32.3 (2.3)	57.3 (2.8)	61.8 (4.6)	44.2 (9.0)	41.0 (8.3)	58.5 (2.7)	63.6 (5.1)	3.2 (.5)	16	34	94			
		90	270	28.6 (1.8)	23.2 (3.8)	54.2 (2.6)	48.8 (4.5)	37.8 (10.6)	30.0 (10.2)	56.8 (4.5)	51.9 (5.2)	5.1 (.9)	14	84	36			
522	45° 45°	90	30	21.1 (4.7)	35.8 (8.0)	53.2 (18.1)	60.8 (10.4)	136.4 (151.4)	58.9 (7.0)	51.5 (19.8)	61.6 (11.4)	2.1 (2.6)	67	36	101			
		60	60	Subject not changing over										87				
		270	90	24.7 (6.2)	41.1 (6.5)	59.4 (14.1)	70.8 (12.6)	36.3 (26.7)	48.9 (25.2)	59.9 (14.6)	71.1 (12.5)	.7 (.3)	126	38	101			
520	0° 0°	90	270	12.8 (5.2)	8.6 (3.7)	22.6 (10.6)	20.0 (8.8)	39.6 (21.1)	33.1 (9.8)	21.2 (9.6)	18.1 (7.8)	3.4 (2.1)	57	88	32			
		90	30	Subject not changing over										312				

Table 3 (Continued)

Subject	Stimulus	Response Rate														Reinforcement
		Reinforcement		Overall		Local		COO		Post-COO		CO	Sessions	Reinforcement		
		A	B	A	B	A	B	A	B	A	B	A		B		
		(Sec)														
VI		VI	a	b	c	d	e	f	g	h	i	j	k	l		
525	0° 45°	30	90	46.1 (11.4)	4.7 (2.1)	56.7 (11.1)	32.5 (12.8)	112.5 (21.9)	70.1 (86.7)	54.5 (10.6)	29.0 (26.1)	2.1 (1.1)	58	120	15	
		270	90	8.6 (1.0)	134.3 (14.2)	108.8 (27.8)	143.2 (10.4)	84.0 (32.5)	170.1 (59.4)	117.6 (33.5)	171.2 (60.6)	2.0 (.5)	99	21	99	
		60	60	84.0 (7.9)	59.8 (9.2)	144.5 (9.4)	143.1 (21.6)	69.6 (16.5)	62.6 (29.0)	147.3 (9.6)	146.8 (23.3)	1.3 (.5)	28	67	53	
		270	30	14.2 (1.6)	120.1 (8.9)	128.6 (5.4)	131.3 (9.6)	116.7 (41.5)	108.0 (24.2)	132.0 (2.6)	131.3 (9.9)	.9 (.7)	93	4	119	
		30	90	66.1 (3.3)	38.7 (5.8)	102.9 (7.9)	109.4 (10.2)	83.3 (14.6)	98.2 (18.5)	103.5 (8.1)	110.2 (11.5)	1.3 (.4)	14	103	25	
		90	30	22.6 (4.5)	84.4 (19.7)	98.1 (10.1)	110.0 (25.8)	123.4 (31.6)	119.6 (19.4)	95.3 (10.2)	109.9 (26.1)	1.8 (.8)	32	26	128	

session and did not change over for extended periods. Data from these subjects are omitted from the subsequent discussion.

The distribution of responses as a function of the distribution of reinforcers can be found in Figure 1. These data are the logarithms of the quotients pro-

duced by dividing the number of responses emitted in component A by the number of responses emitted in component B. The data for the relative reinforcement and relative time measures were derived in comparable manner. An examination of Figure 1 indicates that there is an orderly relationship between the slope of the regression function obtained for relative rate, or time, and relative reinforcement. Pigeons in the 45-deg stimulus disparity condition show the matching relationship, pigeons in the 15-deg stimulus disparity condition show moderate undermatching, and pigeons in the 0-deg disparity group show no stimulus preference, as would be expected. However, at least one pigeon in each of the other two conditions showed a preference for one of the stimuli. Comparable findings were obtained for the relative time regression analyses.

A more detailed analysis examined the absolute rates of responding for each pigeon (see columns a and b in Tables 1, 2, and 3). The overall rate of responding to each component was determined by dividing the number of responses emitted in that component by the total session time less reinforcement time. An examination of the data indicates that there is a great deal of intercondition similarity in response rates for pigeons in the 0-deg disparity condition. Although greater overall response rates were correlated with the more frequently reinforced component, little absolute disparity between the overall response rates to the two components exists. The differences between the overall response rates to the two components for the 15- and 45-deg disparate stimuli were much more pronounced. The rate of responding in the component with the higher reinforcement rate was generally much greater than the rate of responding in the other component.

A similar pattern was obtained when the local rates of responding were examined (see columns c and d

Figure 1. The relative rate of responding and relative time spent in each component as a function of the relative rate of reinforcement for the various conditions. Response data are presented as closed circles and time data as open squares. The subscripts R and T refer to responses and time, respectively.

in Tables 1, 2, and 3). Local response rates were obtained by dividing the number of responses in a given component by the amount of time in that component, less reinforcement time for that component. As expected, the overall disparity between response rates to the two components, regardless of the reinforcement schedules, is greatly attenuated. The same relationship between rates and frequency of reinforcement is still observed, however, in that the rate of responding in the component with the greater reinforcement rate generally exceeds the rate of responding in the other component. Reversals in this pattern occurred for the pigeons in the 15-deg disparity group.

The local response rates were also partitioned into the COD rates and the post-COD rates for each component (see columns e and f and columns g and h in Tables 1, 2, and 3). The COD rates were determined by dividing the number of responses during COD to the main key for a component by the amount of COD time for that component. The COD response rates were then compared with the post-COD response rates. Post-COD response rates were determined by taking the number of responses to the main key for a component less the number of COD responses, divided by the time spent in that component less the COD time and reinforcement time for that component. The COD rates generally exceeded the post-COD rates for both pigeons in the 0-deg disparity group (see Table 1), although the absolute differences between comparable component rates for one pigeon were larger than for the other. The decrease in COD responding relative to post-COD responding for pigeon 518 during the later conditions replicates the previous findings of Bourland and Miller (Note 1). A very similar pattern was obtained for the 15-deg disparity pigeons, although there was an occasional inversion of the relationship. The few inversions that did occur were generally in the first few conditions. One pigeon of the 45-deg disparity group had a similar pattern of relationship between the COD and post-COD response rates. However, a comparison of the COD and post-COD response rates for the other pigeon of this group does not show the same pattern. In several conditions, the post-COD rates for this pigeon, pigeon 525, exceeded the COD response rates. All of these data are characteristically idiosyncratic, however.

DISCUSSION

The present study demonstrates that the distribution of responses between components of simultaneously available schedules depends, in large measure, on the distinctiveness of the discriminative stimuli used to indicate the components. Previous work (Bourland & Miller, 1978, Note 1) had used nondifferential discriminative stimuli to establish that

the mean interreinforcement intervals provide some measure of distinctiveness to the simultaneously available components. However, the prior work had not established that orderly behavioral changes occur as the result of varying stimulus disparity. Since using widely disparate stimuli—the typical concurrent situation—results in the matching function, and using nondifferential stimuli results in a significant degree of undermatching, the determination of moderate undermatching when very similar discriminative stimuli are used suggests that a continuum exists. Both the Herrnstein (1970) and Baum (1974) theoretical models of concurrently available reinforcement schedules would predict the outcome of the present study.

A comparison of the degree of matching found in the present study with that found in prior work by Bourland and Miller suggests that at least two salient stimuli are available to the organism for discrimination between the available components of a concurrent schedule. Bourland and Miller (Note 1) established that mean absolute frequency of reinforcement can serve as a significant stimulus in parallel training by demonstrating that the slope of the least square fit between relative response allocation and relative rate of reinforcement increases from approximately .14 to approximately .36 when the absolute overall rates of reinforcement increase from less than 80 to more than 80 reinforcers per hour while holding the relative disparity between reinforcement rates constant. The degree of matching obtained for the dense absolute rates of reinforcement used by Bourland and Miller (Note 1) is approximately the same as the degree of matching obtained for the 15-deg disparate stimuli in the present study. This suggests that similar degrees of stimulus control can be obtained using either stimulus disparity, as in the present study, or mean interreinforcement interval, as in the Bourland and Miller study. The nature of the interaction, if any, between these two stimulus dimensions cannot be determined from a comparison of the present data with data from previous work. The degree and nature of the interaction, however, are of interest.

Undoubtedly, when multiple sources of reinforcement are simultaneously available, response and/or time distribution occurs as the result of several mechanisms, although at present the exact nature of these mechanisms is not fully known. It is apparent from a consideration of the literature on parallel schedules that response distribution is a function of the distinctiveness of the components. Two factors, at a minimum, seem to play instrumental roles in determining component distinctiveness in simultaneously available schedules: the discriminability of the stimuli used to denote the components, and the absolute rates of reinforcement that can be obtained for responding to the components.

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1. Bourland, G., & Miller, J. T. *The role of discriminative stimuli in concurrent performances*. Manuscript accepted for publication pending revision.

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