STIMULUS AND REINFORCER RELATIVITY IN MULTIPLE SCHEDULES: LOCAL AND DIMENSIONAL EFFECTS ON SENSITIVITY TO REINFORCEMENT

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Pigeons' responses in two successive components of multiple schedules were reinforced according to variable-interval schedules of reinforcement that varied over five different conditions. Within each session of all conditions, line orientations of 0°, 30°, or 45° in Component 1 alternated with orientations of 45°, 60°, or 90° in Component 2. Response rates were recorded in three successive subintervals of each component. Ratios were taken between the response rate in each Component 1 line orientation and the response rate in each Component 2 orientation. These ratios were found to be power functions of the corresponding ratios of obtained reinforcement rates. Sensitivity of response ratios to changes in reinforcer ratios, given by the value of the exponent of the power function, increased systematically with increasing disparity between the dimensional values of orientation stimuli. In addition, sensitivity decreased systematically over successive subintervals of components, that is, with increasing time since component alternation. Dimensional and local (subinterval) effects interacted in that sensitivity increased with stimulus disparity to a far greater extent in the first subinterval than later in components. The data could be described by a combination of rectangular hyperbolae which attributed the interaction between local and dimensional effects to limits set by local effects on the extent that stimulus differences could affect sensitivity.

Key words: generalized matching law, dimensional stimulus control, stimulus disparity, component subintervals, multiple VI VI schedules, key peck, pigeon

The distribution of responses between successive components of multiple variable-interval schedules follows a power function of the ratio of reinforcers obtained in the components, according to the generalized matching law (Baum, 1974; Lander & Irwin, 1968):

$$\frac{P_1}{P_2} = c \left(\frac{R_1}{R_2} \right)^a \quad (1)$$

In Equation 1, P and R denote responses and reinforcers respectively, and the subscripts identify the components in which they occur. The constant c describes bias towards more frequent responding in one or other component independently of variations in reinforcer ratios. The exponent a describes the sensitivity with which response ratios change when rein-

forcer ratios are varied. If a is zero, responding remains nondifferential over a range of reinforcer differentials. If a is 1.0, response ratios match reinforcer ratios. The value for a therefore summarizes discriminative performance over a range of reinforcer differentials.

Despite the potential that a has as a measure of discriminative performance, little is known about the conditions under which a varies. Our reanalysis of data from earlier studies of performance under multiple variable-interval schedules (Lander & Irwin, 1968; Menlove, 1975; Reynolds, 1963; Shettleworth & Nevin, 1965), together with estimates from more recent studies (Davison & Ferguson, 1978; Lobb & Davison, 1977), indicates that values of a typically lie between .2 and .5. Component duration is one variable that has received attention, but its effect is unclear. Reanalysis of some studies with short (5-s) components yielded a values in the region of .85 (Shimp & Wheatley, 1971; 2-key procedure of Merigan, Miller, & Gollub, 1975). But in others, values for a were within the range of those for longer components (Charman & Davison, 1982; Merigan et al., 1975).

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Another variable, namely, time since component alternation, has been shown to exert a strong influence on sensitivity to reinforcement. McLean and White (1981) reported that values of a decreased systematically from around .75 at the beginning of 90-s components to about .3 at the end of components. This is a "local" effect in that changes in a represent changes in the relation between local response rates in the two components as the components progress.

A further variable that has a reliable effect on a is the physical disparity between stimuli signaling the multiple-schedule components (White, Pipe, & McLean, 1983). White *et al.* suggested that the sensitivity parameter could provide a quantitative measure of stimulus control in that the extent of change in response differentials with variation in reinforcer differentials is a function of stimulus difference. Other variables already known to affect a , such as time since component alternation, may limit the effect that stimulus disparity has on a . For example, changes in stimulus disparity might generate a wider range of changes in a at the beginning of components where sensitivity is generally high, than towards the end of components where sensitivity is lower. Such a reduction in the range of variation in a with stimulus disparity would reflect the attenuation of stimulus control at longer times since component alternation. In the present experiment we examined the joint effects of both time since component alternation and stimulus disparity on sensitivity to reinforcement over a range of reinforcer differentials.

METHOD

Subjects

Four adult homing pigeons with prior experimental histories of line-tilt discrimination (G1, G2, G4, and G5) and a fifth homing pigeon without experimental experience (G3), were maintained at 80% of their free-feeding weights. Grit and water were available in their living cages and supplementary feeding ensured maintenance of the prescribed weights. Daily sessions were conducted for a bird if its weight was within $\pm 5\%$ of the prescribed level.

Apparatus

A Coulbourn Instruments experimental chamber was enclosed in a sound attenuating

cubicle. A ventilation fan provided effective masking noise. A single translucent response key, 2.4 cm in diameter, was mounted 8 cm to the right of center and 20 cm above the grid floor. Access to wheat for 3 s was provided via a central hopper opening. The response key could be operated by a force .2 N. Each response produced a feedback relay click. Single 2-mm wide white on black lines, 1.8 cm long and oriented 0°, 30°, 45°, 60°, or 90° from vertical could be presented by means of an in-line display mounted directly behind the key. The brightness of the lines was approximately 2 cd/m² and did not vary with orientation. A houselight located at the top center of the intelligence panel and reflected towards the ceiling dimly illuminated the chamber during each session. Experimental events were controlled and recorded by solid state equipment in an adjacent room.

Procedure

Following preliminary training with Bird G3 in which successive approximations to key pecking were reinforced in one session and responding was maintained by continuous reinforcement in another, all birds were directly introduced to the main procedure. In each session, two components (distinguished by their reinforcer schedules) alternated in direct succession. Component durations were 48 s, and each session comprised 30 presentations of Component 1 and 30 presentations of Component 2. During Component 1, responses were reinforced according to one VI schedule, and during Component 2, responses were reinforced according to another, independent, VI schedule. Variable-interval schedules were derived from Fleshler and Hoffman's (1962) constant probability progression, and their values were chosen to keep total reinforcers per session approximately constant over all conditions. Five multiple-schedule conditions were conducted, the first for 40 daily sessions and each subsequent condition for 20 sessions. The conditions were as follows, in the order in which they were conducted (with VI values in seconds): VI 240 VI 48; VI 80 VI 80; VI 120 VI 60; VI 48 VI 240; VI 60 VI 120.

Within each session, line orientations of 0°, 30°, and 45° were presented during Component 1, and orientations of 45°, 60°, and 90° were presented during Component 2. That is, ten 48-s presentations of each of 0°, 30°, and

45° were associated with the Component-1 VI schedule, and ten 48-s presentations of each of 45°, 60°, and 90° were associated with the Component-2 VI schedule, all within the same session. Stimulus orders were randomized in blocks of six in such a way that each Component-1 stimulus followed and preceded each Component-2 stimulus equally often. The 45° versus 45° comparison was included in order to represent a stimulus difference of 0° (a mixed-schedule condition). Responses were recorded in three successive 16-s subintervals of each 48-s component.

RESULTS

Mean response rates for the last five sessions of each condition were calculated by dividing total response frequencies in each stimulus for each component over the last five sessions by the total time spent in a stimulus minus the total time taken up by obtained reinforcers in the stimulus. Response rates were calculated both for responding during the entire 48-s presentation of each stimulus (Table 1) and for responding in each 16-s subinterval of the 48-s components (Table 2).

Figure 1 presents mean response rates (responses per second) in each of the Component 1 and Component 2 orientations averaged over the five birds for each of the five multiple-schedule conditions. These functions are for responding averaged over entire 48-s components. The group mean functions in Figure 1 were representative of the functions for individual birds shown in Table 1. In general, response rates in the different components varied systematically with reinforcer rates. Changes in response rate as a function of orientation were generally symmetrical across components and were greater when reinforcer rates were relatively low than when reinforcer rates were high. The small response differentials obtained when 45° was presented in Components 1 and 2 might have reflected an otherwise weak discrimination between reinforcement frequencies or a temporal discrimination of components. Response rates in the 45° versus 45° comparison serve as a means of assessing the effects of those incidental variables, as well as providing a zero-degree stimulus difference for stimulus-disparity comparisons.

The functions in Figure 1 for the extreme reinforcer differentials, namely, multiple VI

Fig. 1. Absolute response rates averaged over birds in each line orientation for each of the five multiple-schedule conditions. Response rates in Component 1 orientations are shown as filled circles and response rates in Component 2 orientations are shown as unfilled circles.

Table 1

Response rates in 48-s presentations of each line orientation averaged over the last five sessions per condition, and reinforcer frequencies in each orientation summed over the last five sessions per condition.

Condition	Responses per second						Total obtained reinforcers					
	Component 1			Component 2			Component 1			Component 2		
	0°	30°	45°	45°	60°	90°	0°	30°	45°	45°	60°	90°
Bird G1												
VI 240 VI 48	.954	.864	1.453	1.480	1.570	1.492	16	12	9	46	49	48
VI 120 VI 60	1.170	1.261	1.471	1.576	1.530	1.700	17	21	23	52	34	42
VI 80 VI 80	1.542	1.320	1.662	1.625	1.435	1.657	32	25	33	21	25	41
VI 60 VI 120	1.733	1.755	1.648	1.636	1.184	1.384	47	33	47	26	11	25
VI 48 VI 240	1.952	2.086	1.832	1.768	1.226	1.184	54	37	50	7	8	12
Bird G2												
VI 240 VI 48	.630	.841	1.651	1.742	2.054	1.771	4	10	12	43	44	54
VI 120 VI 60	.983	1.108	1.367	1.428	1.611	1.631	20	23	17	39	46	37
VI 80 VI 80	.650	.795	.896	.779	.959	.801	25	28	33	28	28	33
VI 60 VI 120	1.260	1.602	1.200	1.175	.848	.641	36	55	30	23	18	20
VI 48 VI 240	1.647	1.521	1.373	1.250	.919	.513	54	39	44	12	16	10
Bird G3												
VI 240 VI 48	.561	.673	1.098	1.307	1.539	1.653	13	11	10	49	46	50
VI 120 VI 60	.579	.660	.972	1.059	1.127	1.274	20	23	16	41	41	48
VI 80 VI 80	.768	.872	1.072	1.051	1.063	.959	30	29	31	31	26	29
VI 60 VI 120	.929	.785	.731	.630	.574	.630	59	30	38	19	19	22
VI 48 VI 240	1.286	.998	.872	.707	.434	.488	54	43	50	7	6	9
Bird G4												
VI 240 VI 48	.668	.644	1.317	1.422	1.705	1.879	10	9	15	46	48	44
VI 120 VI 60	1.409	1.207	1.986	2.159	1.967	2.002	31	12	17	43	45	35
VI 80 VI 80	1.306	1.441	1.429	1.405	1.648	1.439	34	30	25	23	34	30
VI 60 VI 120	1.574	1.786	1.771	1.738	1.270	.864	49	38	37	19	23	18
VI 48 VI 240	2.162	2.410	2.324	2.184	1.359	.969	53	42	48	6	8	6
Bird G5												
VI 240 VI 48	.545	.708	1.000	1.148	1.083	1.067	8	10	8	45	54	48
VI 120 VI 60	.671	1.044	1.235	1.280	1.423	1.435	23	20	17	44	36	44
VI 80 VI 80	.902	.994	1.138	1.206	1.192	1.095	32	33	23	31	33	27
VI 60 VI 120	1.266	1.617	1.403	1.323	1.027	1.000	38	43	45	22	21	19
VI 48 VI 240	1.198	1.643	1.596	1.475	1.125	.683	54	44	48	18	16	7

240 VI 48 and multiple VI 48 VI 240, were analogous to those obtained in the few previous studies where responding in one set of stimuli from a given dimension was reinforced according to a VI schedule and responding in another set was not (D. S. Blough, 1975, in press; P. M. Blough, 1980; Farthing, 1974; Malone & Rowe, 1981; Malone & Staddon, 1973). In those studies and in Figure 1, the systematic changes in responding as a function of dimensional stimulus value, under conditions of a reinforcement differential, define a gradient of dimensional stimulus control (Honig & Urcioli, 1981). The gradients in Figure 1 varied with the reinforcer differentials maintaining responding.

Mean response rates in successive 16-s sub-intervals of the 48-s presentations of Compo-

nent 1 and Component 2 orientations are given in Table 2 for individual birds, for each multiple schedule. Table 2 describes in detail both the dimensional effect illustrated in Figure 1 and the effect of time since component alternation, that is, "local" effects. Both dimensional and local effects were consistent across individual birds and are illustrated in Figure 2 by the mean response rates averaged over the five birds for the extreme reinforcer differentials, namely, multiple VI 240 VI 48 and multiple VI 48 and VI 240. Several features of this illustration are of interest. First, the effect of orientation on local response rates paralleled the changes shown in Figure 1 for overall rates in that the functions were reasonably symmetrical for reversal of the reinforcer differential, and greater changes in responding

as a function of orientation occurred in VI 240 components than in VI 48 components. Second, time since component alternation had the effect of decreasing response differentials, as shown by the decrease in slope of the dimensional functions across subintervals. Third, as subintervals progressed, the increase in response rates in VI 240 components was greater than the decrease in response rates in VI 48 components, with larger changes for intermediate stimuli. Fourth, response rates in VI 48 components were higher in 30° than in 0°, and higher in 60° than in 90° for responding in the first subinterval. This pattern of absolute response rates over stimuli in richer schedules is consistent with what D. S. Blough (1975, in press) has referred to as "dimensional contrast," and confirms P. M. Blough's (1983) con-

clusion that the contrast effect may be stronger soon after transition from low- to high-valued components. The absence of the inverse of this pattern for response rates in the VI 240 components is also consistent with D. S. Blough's (in press) conclusions.

The focus of the present study was on changes in relative responding. The logarithmic form of Equation 1 predicts a linear relation between response and reinforcer ratios:

$$\log (P_1/P_2) = a \log (R_1/R_2) + \log c. \quad (2)$$

For each bird, ratios were taken between the mean response rate in each Component 1 orientation and the response rates in each Component 2 orientation, for each of the five multiple-schedule conditions. Note that we are thus obtaining nine response-rate ratios from only six independent response rates, so that the ratios analyzed below are not all indepen-

Table 2

Responses per second in the first, second, and third 16-s subintervals of each line orientation, averaged over the last five sessions per condition.

Condition		First subinterval					
		Component 1			Component 2		
		0°	30°	45°	45°	60°	90°
Bird G1							
VI 240	VI 48	.787	.595	1.547	1.508	1.630	1.447
VI 120	VI 60	.992	1.053	1.489	1.607	1.595	1.761
VI 80	VI 80	1.509	1.125	1.728	1.673	1.517	1.646
VI 60	VI 120	1.740	1.774	1.729	1.744	1.038	1.330
VI 48	VI 240	1.985	2.195	1.887	1.830	.966	.921
Bird G2							
VI 240	VI 48	.540	.761	1.624	1.785	2.132	1.737
VI 120	VI 60	1.051	1.080	1.414	1.497	1.736	1.687
VI 80	VI 80	.680	.815	.881	.766	1.060	.837
VI 60	VI 120	1.274	1.693	1.271	1.254	.850	.610
VI 48	VI 240	1.664	1.661	1.456	1.312	.892	.487
Bird G3							
VI 240	VI 48	.327	.345	1.118	1.474	1.771	1.827
VI 120	VI 60	.394	.457	.949	1.071	1.169	1.394
VI 80	VI 80	.787	.825	1.105	1.059	1.121	.873
VI 60	VI 120	1.036	.877	.743	.610	.497	.578
VI 48	VI 240	1.374	1.044	.907	.769	.372	.331
Bird G4							
VI 240	VI 48	.422	.440	1.259	1.389	1.770	1.745
VI 120	VI 60	1.042	.930	1.900	2.143	2.081	2.050
VI 80	VI 80	1.247	1.387	1.348	1.351	1.692	1.442
VI 60	VI 120	1.447	1.685	1.811	1.699	1.166	.665
VI 48	VI 240	2.163	2.462	2.376	2.149	1.023	.435
Bird G5							
VI 240	VI 48	.465	.518	.999	1.115	1.083	1.033
VI 120	VI 60	.544	.919	1.064	1.228	1.423	1.381
VI 80	VI 80	.662	.947	1.086	1.232	1.123	1.022
VI 60	VI 120	1.210	1.672	1.487	1.332	.888	.822
VI 48	VI 240	.965	1.648	1.493	1.444	.945	.404

Table 2 continued

Condition		Second subinterval					
		Component 1			Component 2		
		0°	30°	45°	45°	60°	90°
Bird G1							
VI 240	VI 48	.989	.962	1.504	1.496	1.566	1.513
VI 120	VI 60	1.189	1.293	1.432	1.556	1.522	1.645
VI 80	VI 80	1.562	1.281	1.679	1.584	1.401	1.669
VI 60	VI 120	1.726	1.755	1.615	1.588	1.198	1.394
VI 48	VI 240	1.922	2.097	1.847	1.739	1.282	1.244
Bird G2							
VI 240	VI 48	.588	.830	1.661	1.712	2.099	1.800
VI 120	VI 60	.912	1.131	1.379	1.434	1.586	1.592
VI 80	VI 80	.594	.754	.915	.803	.937	.803
VI 60	VI 120	1.272	1.493	1.170	1.093	.848	.645
VI 48	VI 240	1.656	1.460	1.298	1.326	.917	.511
Bird G3							
VI 240	VI 48	.613	.693	1.051	1.170	1.497	1.541
VI 120	VI 60	.637	.794	.975	1.101	1.144	1.277
VI 80	VI 80	.739	.864	1.026	.987	1.081	.984
VI 60	VI 120	.880	.730	.700	.657	.602	.634
VI 48	VI 240	1.279	.986	.883	.661	.451	.536
Bird G4							
VI 240	VI 48	.738	.542	1.367	1.475	1.644	1.820
VI 120	VI 60	1.564	1.283	2.040	2.194	1.905	1.973
VI 80	VI 80	1.338	1.468	1.485	1.420	1.645	1.439
VI 60	VI 120	1.603	1.865	1.785	1.768	1.286	9.30
VI 48	VI 240	2.165	2.409	2.291	2.219	1.429	1.039
Bird G5							
VI 240	VI 48	.528	.763	.992	1.199	1.072	1.068
VI 120	VI 60	.743	1.127	1.305	1.325	1.394	1.491
VI 80	VI 80	.990	1.055	1.174	1.211	1.250	1.150
VI 60	VI 120	1.255	1.700	1.378	1.279	1.023	1.101
VI 48	VI 240	1.319	1.669	1.706	1.535	1.214	.760

Table 2 continued

Condition	Third subinterval					
	Component 1			Component 2		
	0°	30°	45°	45°	60°	90°
Bird G1						
VI 240 VI 48	1.087	1.034	1.309	1.436	1.515	1.151
VI 120 VI 60	1.328	1.438	1.490	1.564	1.471	1.694
VI 80 VI 80	1.553	1.554	1.579	1.619	1.386	1.655
VI 60 VI 120	1.733	1.735	1.600	1.576	1.316	1.427
VI 48 VI 240	1.949	1.965	1.761	1.734	1.432	1.386
Bird G2						
VI 240 VI 48	.761	.930	1.669	1.731	1.931	1.775
VI 120 VI 60	.985	1.112	1.307	1.355	1.511	1.615
VI 80 VI 80	.675	.816	.892	.769	.881	.761
VI 60 VI 120	1.234	1.622	1.157	1.178	.847	.667
VI 48 VI 240	1.622	1.442	1.365	1.112	.948	.541
Bird G3						
VI 240 VI 48	.743	.980	1.127	1.277	1.348	1.591
VI 120 VI 60	.705	.728	.992	1.004	1.069	1.150
VI 80 VI 80	.778	.926	1.086	1.107	.988	1.021
VI 60 VI 120	.869	.748	.749	.625	.624	.679
VI 48 VI 240	1.206	.966	.827	.692	.480	.595
Bird G4						
VI 240 VI 48	.846	.948	1.325	1.403	1.701	2.071
VI 120 VI 60	1.622	1.409	2.020	2.139	1.915	1.983
VI 80 VI 80	1.334	1.469	1.453	1.444	1.607	1.438
VI 60 VI 120	1.670	1.807	1.716	1.747	1.358	.997
VI 48 VI 240	2.159	2.360	2.303	2.184	1.626	1.435
Bird G5						
VI 240 VI 48	.643	.842	1.010	1.129	1.094	1.098
VI 120 VI 60	.726	1.085	1.335	1.286	1.453	1.433
VI 80 VI 80	1.056	.982	1.153	1.176	1.205	1.113
VI 60 VI 120	1.335	1.480	1.343	1.359	1.171	1.076
VI 48 VI 240	1.311	1.611	1.588	1.446	1.216	.885

dent of one another. Logarithms of response ratios for each of the nine possible stimulus comparisons were plotted as a function of logarithms of the corresponding ratios of reinforcers given in Table 1. It should be noted that although average obtained reinforcer totals in Table 1 closely approximated programmed totals, obtained reinforcers in individual orientations for each bird sometimes varied widely, probably owing to a combination of the relatively small amount of time spent in a stimulus over five sessions (40 min) and the random arrangement of the 12 inter-reinforcer intervals over the VI tapes. Discrepancies between obtained and programmed reinforcer frequencies do not, however, pose a problem for analysis according to Equation 2, which uses obtained frequencies.

Figure 3 shows log response-rate ratios plotted as a function of log reinforcer ratios

Fig. 2. Absolute response rates averaged over birds in successive 16-s subintervals of Component 1 orientations (filled circles) and Component 2 orientations (un-filled circles) for multiple VI 240 VI 48 and multiple VI 48 VI 240 conditions.

for entire 48-s components, for each of the nine possible stimulus comparisons. Values for the slope (a), intercept ($\log c$), and standard error of the estimate (se) for the least squares fits of Equation 2 to each set of data points are given in Figure 3 for each function. Standard errors were always very small, indicative of excellent fits of Equation 2 to the data. Values for bias, $\log c$, fluctuated around zero. Changes in sensitivity to reinforcement, a , as a function of stimulus difference were very consistent across individual birds. For each triad of comparisons (0° , 30° , or 45° in Component 1 versus Component 2 orientations), a increased systematically with stimulus disparity for all birds. The weakest sensitivity was for the 45° versus 45° comparison. Here, the small non-zero values for a (range .022 to .112) reflected discriminations based on dimensions other than orientation, such as reinforcer frequency or temporal alternations of components.

The same analysis as described in Figure 3 for responding in entire 48-s components was conducted for ratios of response rates within each 16-s subinterval of the components, resulting in a total of 27 log ratio functions for each of the five birds. Equation 2 was fitted to

Fig. 3. Logarithms of ratios of response rates in Component 1 orientations and Component 2 orientations as a function of logarithms of obtained reinforcer rates in Component 1 and Component 2 orientations, for different pairs of orientations. The origin for each function is shown as a large cross. Values for the slope (a), intercept (log c), and standard error of the estimate (se) for the best fitting straight lines are given for each set of data points.

the data points for each function by the method of least squares, and values for a , $\log c$, and standard error of the estimate, se , are given in Table 3 for these fits. In much the same way that Equation 2 gave a good account of the data for whole components in Figure 3, generally small standard errors of the estimate indicated satisfactory fits to the log response

ratios for subintervals. Changes in a with orientation difference across subintervals were similar for individual birds (Table 3). Figure 4 plots values for sensitivity to reinforcement (a) from Table 3 averaged over the five birds, for the different stimulus comparisons and successive subintervals. A plot of sensitivity changes for individual birds showed that the

Table 3

Values for sensitivity to reinforcement (a), bias ($\log c$), and the standard error of the estimate (se) for straight line fits of the logarithmic form of Equation 1 to response ratios in Component 1 and Component 2 line orientations for first, second, and third 16-s subintervals of 48-s components.

Component 2:	Component 1: 0°			Component 1: 30°			Component 1: 45°		
	45°	60°	90°	45°	60°	90°	45°	60°	90°
<i>First subinterval</i>									
G1									
a	.224	.472	.533	.332	.622	.723	.012	.217	.222
Log c	-.118	-.071	-.015	-.130	-.072	.019	0	.075	.089
se	.046	.012	.020	.075	.029	.023	.017	.050	.080
G2									
a	.376	.553	.585	.431	.672	.720	.083	.321	.440
Log c	-.083	-.043	.072	-.053	-.030	.079	.012	.037	.157
se	.045	.062	.090	.051	.044	.075	.022	.072	.094
G3									
a	.652	.885	.997	.568	.822	.967	.131	.368	.448
Log c	-.209	-.209	-.145	-.170	-.149	-.079	-.001	.037	.068
se	.091	.055	.043	.131	.119	.084	.032	.036	.039
G4									
a	.339	.646	.865	.371	.656	.886	.071	.394	.671
Log c	-.235	-.167	-.116	-.159	-.045	.037	-.010	.060	.146
se	.080	.035	.073	.082	.060	.049	.011	.060	.068
G5									
a	.235	.363	.495	.373	.536	.627	.081	.241	.392
Log c	-.230	-.156	-.099	-.062	.012	.055	-.011	.074	.149
se	.073	.133	.125	.049	.072	.077	.025	.078	.099
<i>Second subinterval</i>									
G1									
a	.156	.283	.330	.190	.339	.412	.027	.126	.140
Log c	-.057	-.029	-.011	-.045	-.010	.024	.004	.048	.040
se	.039	.029	.014	.048	.015	.028	.017	.028	.045
G2									
a	.354	.524	.562	.345	.560	.628	.022	.252	.379
Log c	-.089	-.046	.049	-.055	-.031	.059	.010	.037	.137
se	.045	.067	.105	.052	.038	.052	.028	.036	.065
G3									
a	.408	.557	.569	.291	.460	.469	.115	.267	.260
Log c	-.085	-.110	-.091	-.045	-.054	-.042	.013	.010	.007
se	.027	.046	.025	.019	.036	.021	.017	.034	.014
G4									
a	.182	.355	.470	.292	.448	.567	.035	.206	.341
Log c	-.132	-.071	-.063	-.119	-.026	-.009	-.008	.054	.082
se	.047	.039	.050	.084	.092	.101	.014	.049	.058
G5									
a	.283	.306	.361	.250	.299	.348	.096	.157	.236
Log c	-.137	-.096	-.090	-.019	.023	.030	.006	.053	.076
se	.047	.074	.060	.045	.070	.058	.014	.037	.064

Table 3 continued

Component 2:	Component 1: 0°			Component 1: 30°			Component 1: 45°		
	45°	60°	90°	45°	60°	90°	45°	60°	90°
<i>Third subinterval</i>									
<i>G1</i>									
a	.116	.198	.260	.134	.229	.297	.031	.102	.134
Log c	-.033	-.008	-.006	-.018	.012	.025	-.013	.022	.008
se	.028	.028	.013	.035	.029	.016	.007	.013	.020
<i>G2</i>									
a	.310	.416	.476	.351	.508	.583	.094	.233	.377
Log c	-.041	-.010	.072	-.018	.004	.078	.026	.047	.131
se	.004	.050	.098	.034	.025	.066	.025	.033	.069
<i>G3</i>									
a	.343	.438	.451	.212	.330	.341	.088	.194	.191
Log c	-.064	-.056	-.072	-.024	-.005	-.029	.017	.041	.006
se	.044	.042	.031	.049	.053	.036	.022	.014	.016
<i>G4</i>									
a	.139	.290	.383	.157	.284	.377	.034	.174	.271
Log c	-.100	-.067	-.078	-.059	-.004	-.002	-.009	.027	.033
se	.030	.044	.083	.034	.043	.085	.006	.047	.081
<i>G5</i>									
a	.214	.244	.291	.162	.223	.274	.047	.115	.180
Log c	-.105	-.088	-.069	-.030	-.011	.010	.004	.029	.062
se	.053	.088	.079	.027	.057	.054	.021	.028	.035

mean sensitivity changes in Figure 4 were remarkably representative of those for individual birds. Three main aspects of the data are clear in Figure 4. First, for each comparison of 0°, 30°, or 45° in Component 1 with the Component 2 orientations (45°, 60°, and 90°), sensitivity increased systematically, and apparently hyperbolically, with stimulus difference. Second, sensitivity decreased systematically with increasing time since component alternation (i.e., over successive subintervals). Third, the functions relating sensitivity to stimulus value flattened over successive subintervals. Highest values for a were recorded in the first 16-s subinterval. For individual birds, a values for the 30° versus 90° orientations were .72, .72, .97, .89, and .63 (Table 3). These values are well above those typically found for responding averaged over whole components for the same birds (Figure 3). Over individual birds and all stimulus comparisons, values for a in the first subinterval ranged from .012 for 45° versus 45° (G1) to .997 for 0° versus 90° (G3). In the third subinterval, a values for 30° versus 90° for individual birds were .30, .58, .34, .38, and .27 (Table 3). Orientation difference and time since component alternation clearly interacted in their effect on sensitivity to reinforcement.

DISCUSSION

In the present study, response ratios were plotted as a function of reinforcer ratios for a total (over birds) of 135 combinations of stimulus pairs and subintervals. In all cases, the data were consistent with the conclusion that response ratios in multiple schedules vary as a power function of reinforcer ratios. A large number of studies of concurrent-schedule performance have established that the generalized matching law (Equation 1 or its logarithmic form in Equation 2) provides a satisfactory account of choice between concurrently available alternatives (Baum, 1979; de Villiers, 1977; Lobb & Davison, 1975; Myers & Myers, 1977; Staddon, 1968). In multiple schedules, successive alternation of components precludes choice between component schedules. Yet the generalized matching law also offers an accurate description of performance in multiple schedules, as shown by the present data and by results of previous studies (Charman & Davison, 1982; Davison & Ferguson, 1978; Lander & Irwin, 1968; McLean & White, 1981). In this respect, "matching" or "undermatching" must refer to an empirical relation between response and reinforcer ratios rather than to a behavioral process of choice between programmed

Fig. 4. Sensitivity to reinforcement, a , averaged over birds for stimulus comparisons of 0°, 30°, or 45° in Component 1 with 45°, 60°, or 90° in Component 2, for responding within successive 16-s subintervals of 48-s components.

reinforcer schedules. The aim of an experimental analysis is therefore to determine the conditions of which undermatching and bias in multiple schedules are a function. The parameters for sensitivity (a) and bias ($\log c$) may serve as useful higher-order dependent measures in that they allow a means of describing the determinants of multiple-schedule performance.

The aim of the present study was to examine the joint effects of time since component alternation and stimulus disparity on sensitivity to reinforcement (a). Sensitivity was affected in three main ways. First, a decreased systematically with time since component alternation, that is, with successive subintervals

of components, in agreement with McLean and White's (1981) result. Both a reduction in response rates in higher-valued reinforcer-rate components and an increase in response rates in lower-valued components, with a greater change in lower-valued components (cf. Nevin, 1974), contributed to the decrease in a . The within-component changes in absolute response rates were similar to those observed in previous studies with fewer schedule variations (Arnett, 1973; Ettinger & Staddon, 1982; Malone & Staddon, 1973; Menlove, 1975; Nevin & Shettleworth, 1966). To the extent that recording behavior in short components is equivalent to recording behavior in a short period at the beginning of longer components (McSweeney, 1982), the present data are also consistent with higher a values sometimes found for short components.

Second, a increased with stimulus disparity within each triad of stimulus comparisons, for all birds. In a previous study with two birds (G1 and G2 of the present study) and in a similar procedure, White *et al.* (1983) reported systematic increases in a from .23 to .45 and from .20 to .58 for each bird respectively in one experiment, and from .22 to .36 and from .45 to .57 in a second experiment, for stimulus differences of 15° through 75° in 15° steps. In the present experiment, a difference of zero degrees (45° vs. 45°) produced values for a in the region of .1 or smaller, whereas differences of 75° and 90° resulted in a values around .5 for whole components or .7 for first subintervals. For each of the comparisons between one of the Component 1 orientations (0°, 30°, or 45°) and Component 2 orientations (45°, 60°, or 90°), the increase in a with stimulus disparity appeared hyperbolic. Presumably some limit may be set on values of a by factors determining multiple-schedule performance other than stimulus disparity, in that increases in stimulus differences that are already large would be minimally effective in increasing a .

Third, dimensional and local effects interacted in determining a . Values of a increased with stimulus disparity to a far greater extent in the first 16-s subintervals of components than in second or third subintervals. The simplest way of understanding this interaction is that particular values of one determinant of sensitivity may limit the extent to which a can vary when another determinant is manipulated. Under conditions of small differences

between dimensional values of stimuli in different components, time since component alternation (and perhaps other variables) is relatively ineffective in producing changes in a . Similarly, towards the end of components, changes in stimulus difference have little effect on a .

Assuming that a particular set of conditions establishes an asymptote for a , the function relating a to stimulus difference will increase monotonically to that asymptotic level. At a first approximation, the data reported by White et al. (1983) and individual functions from the present study (Table 3) were fitted well by rectangular hyperbolae, although normal ogives which also have upper asymptotes (cf. Heinemann & Chase, 1975) may afford a better fit to the data. The decrease in a with time since component alternation for individual subjects in McLean and White's (1981) study, and for data averaged over stimulus pairs in the present study, also appeared hyperbolic but were also fitted well by negative exponential functions (cf. McCarthy & White, in press). Nevertheless, the interaction between stimulus disparity and time since component alternation in the present study can be accounted for reasonably well by assuming that a increases with stimulus difference according to a hyperbolic function that has an asymptote determined by time since component alternation as illustrated by Equation 3:

$$a = \left(\frac{bg}{g + T} \right) \left(\frac{kS}{h + S} \right). \quad (3)$$

In Equation 3, b and k are scaling constants, g is a constant describing rate of decrement in a with increasing time T since component alternation, and h is a constant describing rate of increment in a with increasing stimulus difference S . The variable S may measure relative stimulus difference as in various psychophysical relations (Wright, 1974). Perhaps not surprisingly, given the number of free parameters involved, predictions from Equation 3 can account for a high proportion of variance in multiple-schedule sensitivities (Figure 4). More importantly, Equation 3 provides a good example of how variables may be combined to predict their interacting effects on sensitivity to reinforcement.

The nature of the dimensional and local effects on a suggests that sensitivity to reinforcement in multiple-schedule components

reflects limits on discrimination. For given stimulus and reinforcer differentials, discrimination is measured by the response differential. The parameter a describes the extent to which response differentials change when reinforcer ratios are varied, and therefore affords a measure of the extent of discrimination between successive components over a range of reinforcer differentials. That is, a is independent of the effects of reinforcer differentials. Interpretation of a as a measure of discrimination is consistent with the increase in a with increasing stimulus difference (White et al., 1983; and present data) and with the reduction in a reported by White and Redman (1983) when responding in a mixed schedule was under delayed control by prior discriminative stimuli.

The magnitude of a is, however, a function of other factors that may influence discrimination. To reiterate the argument above, certain conditions such as time since component alternation place limits on the extent to which a may vary as a function of stimulus difference. There may be different reasons for the effects that limiting variables have. In the case of time since component alternation, one possibility is that the stimulus signaling the prior component, or the stimulus transition, exerts delayed stimulus control over responding later in a component (White & Redman, 1983). Another possibility is that there is a change in the opportunity to obtain reinforcement for other behavior as the component progresses (Ettinger & Staddon, 1982; Staddon, 1982). Either possibility could result in diminished response differentials.

The notion that a affords a measure of discriminative performance or stimulus control, unconfounded by the specific influence of the reinforcer differentials that maintain response differentials, is analogous to the idea that discriminability in detection procedures can be measured independently of the biasing effects of reinforcement. McCarthy and Davison (1980) applied the generalized matching law to predict behavior in each of the concurrent choices offered by the standard discrete-trials detection procedure. Their analysis yields a "stimulus function" that defines a measure of discriminability, d . The algebraic relation between d and a for multiple schedules is unclear because "errors" in a standard multiple-schedule procedure cannot be operationally identi-

fied without building in the additional source of stimulus control required by the conditional discrimination of the detection procedure. However, discriminability measures in detection procedures may be best suited to near-threshold stimulus differences, their traditional concern, but not above-threshold differences, in which case discriminability becomes indeterminate with highly accurate performance. Ceiling effects on a in multiple schedules using above-threshold stimulus differences are minimized by the factors that limit discriminative performance. White, Pipe, and McLean (1980) arranged a free-operant version of the detection procedure (a multiple-concurrent schedule) and varied orientation difference in exactly the same way as for the multiple schedules of White *et al.* (1983). For orientation differences ranging from 15° to 75° , discriminability (d) was overall very high, whereas a for the multiple schedules nearly doubled over that range. The use of a as a measure of discriminative performance may therefore be particularly appropriate for above-threshold stimulus differences of the kind used in more traditional stimulus-control studies.

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