*CONJOINT CONTROL OF PERFORMANCE IN CONDITIONAL
DISCRIMINATIONS BY SUCCESSIVE AND
SIMULTANEOUS STIMULI*

K. GEOFFREY WHITE

UNIVERSITY OF OTAGO, DUNEDIN, NEW ZEALAND

In a conditional discrimination, reinforcement of pigeons' responses to pairs of simultaneously presented wavelength stimuli depended on the orientation of white lines superimposed on the wavelengths. Over different conditions in Experiment 1, three wavelength differences were combined with two differences between successively presented line orientations. Measures of stimulus discriminability increased with increases in the difference between both orientation and wavelength stimuli. Conditional-discrimination performance was thus conjointly determined by stimulus disparity in the successive and simultaneous discriminations. In Experiment 2, ratios of rates of reinforcement contingent upon the two categories of correct responses were varied over several conditions for difficult and easy discriminations. Ratios of responses to wavelength pairs were sensitive to variations in the reinforcement ratio to a greater extent for the more difficult orientation discrimination than for the easier orientation discrimination. Performance in the conditional discrimination was therefore determined by the interacting effects of stimulus disparity and the relative rates of reinforcement contingent upon the two correct choices. It was concluded that the effect of temporally distant reinforcement on behavior in a prevailing schedule component is attenuated to an extent that depends on similarity of stimuli that delineate the successive components.

Key words: conditional discrimination, stimulus discriminability, free-operant detection, successive discrimination, simultaneous discrimination, multiple-concurrent schedules, variable-interval schedules, key peck, pigeons

In the context of elucidating the basis for concept or rule learning in conditional discriminations, Goldiamond (1966) showed how conditional discriminations involved conjoint control by instructional and dimensional stimuli. For instance, a simple conditional discrimination might require a choice between colors conditional upon the orientation of lines superimposed on the colors. In this instance, the nature of the dimensional control by simultaneously presented colors would depend on instructional control by successively presented line orientations.

Conjoint control in a conditional discrimination has been demonstrated for procedures in which a pigeon is presented with a single compound stimulus and, for example, pecking at vertical-on-red or horizontal-on-green compounds produces food, but pecking at compounds with horizontal-on-red or vertical-on-green does not produce food. Stimulus control

by wavelength or orientation, assessed by generalization tests, depends on the values of stimuli on both dimensions (Blough, 1972; Boneau & Honig, 1964; Richards, 1979), on the reinforcement schedules correlated with the compounds (Chase & Heinemann, 1972; Heinemann & Chase, 1970), and on the relative salience of the elements comprising the compound stimuli (Looney, Cohen, Brady, & Cohen, 1977; Sidman, 1980; Williams, 1984). In particular, studies in which generalization tests were conducted following acquisition of conditional discriminations have provided convincing evidence that the values of stimuli on both dimensions contribute to the conditional discrimination, probably according to a multiplicative rule (Blough, 1972; Zuckerman, 1973).

Conditional discriminations are involved in a wide range of procedures, including matching to sample and delayed matching to sample (Carter & Werner, 1978; Cumming & Berryman, 1965), same-different discrimination (Honig, 1965; White, 1974), concept learning (Goldiamond, 1966; Schrier & Thompson, 1980), category discrimination and stimulus-equivalence learning (Medin & Dewey, 1984; Sidman & Tailby, 1982; Wright & Cum-

This research was supported by Grants 77/162 and 79/124 from the University Grants Committee, and W. Attrill contributed helpful assistance. Reprints may be obtained from Dr. K. G. White, Department of Psychology, University of Otago, P.O. Box 56, Dunedin, New Zealand.

ming, 1971), and the conditional control of attention (Heinemann, Chase, & Mandell, 1968; Reynolds & Limpo, 1969). Signal-detection procedures involve discrete-trial conditional discriminations (Nevin, 1969) where a choice between simultaneously available alternatives such as red-green, left-right, or yes-no depends on the value of the successively presented stimulus. Although detection procedures have traditionally incorporated a discrimination between the presence or absence of a stimulus, the focus of many studies of animal psychophysics is the discrimination of proximal stimulus values on particular sensory continua (Blough & Blough, 1977; Wright, 1974). That is, the signal-detection (or recognition) problem is to establish how well the successively presented stimuli can be discriminated.

Typically, psychophysical studies have assumed that the simultaneous discrimination involved in the choice phase of detection procedures is asymptotically easy (Wright, 1974). Similarly, an important assumption is that the effects of factors biasing the choice are independent of discriminability of the successive stimuli. Insofar as detection requires a conditional discrimination between simultaneous choice alternatives (Nevin, 1970), the measure of discriminability of successive stimuli may be influenced by discriminability of the simultaneous stimuli. An obvious example is the limiting case in which simultaneous stimuli are indiscriminable—in this case, a measure of successive discriminability will be maximally attenuated. The likelihood of conjoint control in the conditional discrimination also suggests that the way the choice responses are maintained by the reinforcement of correct choices may depend upon discriminability of the successive stimuli. The possibility that the stimulus difference in the simultaneous discrimination determines the level of performance in the successive discrimination was examined in Experiment 1 of the present study, using a free-operant conditional discrimination.

In Experiment 2, frequencies of reinforcement produced by correct choices were differentially varied in order to alter the bias towards choosing one or the other stimulus in the simultaneous discrimination. The question asked was whether disparity of the successive stimuli would determine the extent to which choices were biased by such variation

in contingencies of reinforcement. According to recent models of signal detection that make the role of reinforcement explicit (Davison & Tustin, 1978; McCarthy & Davison, 1981; Nevin, 1981; Nevin, Jenkins, Whittaker, & Yarensky, 1982), the biasing effects of reinforcement variation on choice responses should be independent of discriminability of the successive stimuli. But if performance in conditional discriminations is determined by the conjoint influence of successive and simultaneous discriminations, an interaction between successive-stimulus disparity and the effects of reinforcement variation might be expected.

EXPERIMENT 1

The aim of Experiment 1 was to examine the combined effects of the disparity between successive orientation stimuli and the disparity between simultaneous wavelength stimuli on conditional-discrimination performance. In the conditional-discrimination procedure, pairs of wavelengths were simultaneously presented on two response keys. Over different conditions, wavelength pairs were 538 nm/555 nm, 538 nm/576 nm, and 538 nm/606 nm. During each 60-s presentation of a wavelength pair, variable-interval reinforcement of responses on a key displaying one of the wavelengths as background depended on the orientation of single white lines superimposed on the background. In one set of conditions, line orientations on both keys were 0° or 90°, and in another set of conditions, the successively presented line orientations were 45° and 60°.

Performance in the conditional discrimination was assessed in terms of a measure of stimulus discriminability proposed by Davison and Tustin (1978). As shown in Table 1, the procedure involved a choice between P_{11} and P_{12} responses in the presence of stimulus S_1 , and a choice between P_{21} and P_{22} responses in the presence of stimulus S_2 . The discriminability measure, $\log d$, is given by half of the difference between the log response ratio in the presence of S_1 and the log response ratio in the presence of S_2 , as follows:

$$\log d = 0.5 [\log(P_{11}/P_{12}) - \log(P_{21}/P_{22})]. \quad (1)$$

The index given by Equation 1 is identical to the d' measure derived by Luce (1963) from a choice approximation to signal-detection theory, and is similar to d' of signal-detection theory (Green & Swets, 1966). Nevin (1981)

also has proposed a discriminability index identical to that given by Equation 1, but from a different theoretical point of view (Nevin et al., 1982). Subsequent research by McCarthy and Davison (1981, 1984) has established the utility of the $\log d$ measure in the context of discrete-trial signal-detection procedures, and McCarthy, Davison, and Jenkins (1982) used it to describe performance in a free-operant conditional discrimination similar to that described in the present experiment.

Although Equation 1 was intended to provide a measure of discriminability between successive stimuli, the potential influence of simultaneous stimuli disparity would question that interpretation. Indeed, if a measure of discriminability between the *simultaneous* stimuli were to be derived in the same way as that for successive stimuli in Equation 1, the measure would be identical to $\log d$. That is, Equation 1 can be rewritten in terms of response ratios occasioned by the successive stimuli as follows:

$$\log d = 0.5 [\log(P_{11}/P_{21}) - \log(P_{12}/P_{22})]. \quad (2)$$

Equation 2 shows that there is some ambiguity as to whether $\log d$ should be construed as a measure of discriminability between successive stimuli or between simultaneous stimuli. The ambiguity would be confirmed by showing that $\log d$ was affected by disparity between both successive and simultaneous stimuli.

METHOD

Subjects

The subjects were 5 experimentally naive adult homing pigeons, maintained at 80% of their free-feeding body weights. Maintenance of the prescribed weights was achieved by supplementary feeding of mixed grain in the living cages, where water and grit were always available. Experimental sessions were conducted daily for each bird if its weight was within $\pm 5\%$ of the 80% weight.

Apparatus

A sound-attenuating experimental chamber with internal dimensions of 33 cm by 33 cm by 34 cm high contained an interface panel. The interior of the chamber was painted matte black and an exhaust fan served to mask extraneous sounds. There was no houselight. Mounted on the interface panel were two Gerbrands response keys, normally closed, lo-

Table 1

Response and reinforcement designations for the matrix of events in the conditional discrimination.

Successive stimuli	Simultaneous stimuli	
	538 nm	606 nm
Responses		
S_1 (0°)	P_{11} (correct)	P_{12} (error)
S_2 (90°)	P_{21} (error)	P_{22} (correct)
Reinforcements		
S_1 (0°)	R_1	Ext
S_2 (90°)	Ext	R_2

cated 10 cm either side of center and 24 cm above the wire mesh floor. A central hopper 5 cm from the floor could allow 3-s access to wheat. Key stimuli were darkened when the hopper was raised and illuminated by white light. Each response key required a force of 0.18 N to operate and each response was followed by a feedback relay click and also by a 40-ms offset of the key stimulus.

In-line digital displays (IEE) mounted behind each key contained Kodak Wratten filters and line-tilt transparencies. In order to minimize desaturation of the wavelengths when keys were illuminated by the combination of a white line and a background color, a Kodak neutral density filter No. 96 was mounted between the 24-V GE1820 lamps and miniature lenses in the in-line displays. Stimuli were projected onto the back of the translucent keys. Single white lines, 0.9 cm long and 0.2 cm wide, were centered on a 0.9-cm diameter disc of color. The lines could be oriented at 0°, 45°, 60°, or 90° from horizontal. The background colors were produced by Wratten filters Nos. 74, 99, 73, and 72B with peak transmissions at wavelengths of 538 nm, 555 nm, 576 nm, and 606 nm, respectively. Brightness of all stimulus combinations was equated at 0.56 cd/m² by adding neutral density filters to some of the Wratten filters. Experimental events were controlled and recorded by solid-state equipment located in an adjacent room.

Procedure

Preliminary training began with reinforcement of successive approximations to pecking the left key and continuous reinforcement of 30 left-key pecks in the first session, followed by shaping right-key pecking and continuous

Table 2

Order of conditions combining orientation differences between successive stimuli with wavelength differences between simultaneous stimuli in Experiment 1.

Orientations	Wavelengths		
	538/555	538/576	538/606
0°/90°	1, 7	4, 8	5, 12
45°/60°	2, 9	3, 10	6, 11

reinforcement of 30 right-key pecks in the second session. A further four sessions with responses on both keys reinforced at intervals averaging 10 s were followed by 72 sessions in which responses on both keys were reinforced at intervals averaging 48 s (VI 48 s), depending on the stimulus combination projected on the key. In the first 16 of these sessions, lines were not presented and the wavelengths on left and right keys were 538 nm and 606 nm, randomly alternating every 60 s with 606 nm and 538 nm on left and right keys, respectively. That is, responses at both colors were reinforced equally often. In subsequent sessions, white lines were superimposed on the colors, with vertical lines on both keys for 60-s periods alternating randomly with 60-s presentations of horizontal lines on both keys, for a total of 48 min per session. In the presence of 0° orientations, responses on the key with 606 nm were reinforced but those on 538 nm were not, whereas with 90° orientations, responses on 538 nm were reinforced but those on 606 nm were not. Wavelengths of colors remained 538 nm and 606 nm for 20 sessions, after which they were changed to 538 nm and 576 nm for 20 sessions, followed by 538 nm and 555 nm for 16 sessions. The constant-probability VI schedules that arranged reinforcement of pecks at the "correct" line-color combinations were independent. Throughout the 56 preliminary sessions with the line-color combinations, the diameters of the key stimuli were 1.8 cm. Key-stimulus diameter was reduced to 0.9 cm for all subsequent sessions.

In each session of the main conditions, responses on the key (left or right) with a 538 nm background were reinforced according to a VI 48-s schedule if the lines on both keys were, in different conditions, 0° or 45°. Responses on the other key, which was illuminated with a different wavelength, were not

reinforced. The simultaneously presented wavelength was 555 nm, 576 nm, or 606 nm in different conditions. Responses on the (left or right) key illuminated by these wavelengths were reinforced according to a VI 48-s schedule if the line superimposed on both keys was oriented at 90° or 60° (in different conditions). Each session lasted for forty-eight 60-s periods. The four possible combinations of left and right keys, orientation, and a pair of wavelengths were randomized over a block of 12 components so that each combination followed each other equally often. The 12-component order was recycled four times within each session. In some conditions, the successively presented line orientations were 0° and 90°, and in other conditions orientations were 45° and 60°. These conditions were combined with conditions in which the wavelengths of a simultaneously presented pair were 538 nm/555 nm, 538 nm/576 nm, or 538 nm/606 nm. Each condition lasted for 20 daily sessions and was conducted twice, in the order given in Table 2, to give a total of 40 sessions per combination of orientation- and wavelength-difference.

RESULTS AND DISCUSSION

The ratio of reinforcers produced by correct responses on the two keys consistently remained at 1.0 for each bird in each condition. Any observed bias towards or against pecking at one color of a pair therefore cannot be attributed to fluctuations in obtained reinforcers. Response frequencies recorded in the presence of each combination of orientation and wavelength were summed over the last 5 of 20 sessions of each of the two repetitions per condition, and over the two repetitions, to give response totals for 10 sessions. The resulting data represent a total presentation time of 240 min for each stimulus combination. Table 3 gives the response totals for the different combinations of wavelength and orientation for individual birds.

The patterns of responses in Table 3 reflect the influence of the conditional relations between stimuli and reinforcement. For example, response totals were high in the 0°/538 nm and 90°/555 nm combinations, reflecting the reinforcement of "correct" responses. In addition, response totals were low in the 0°/555 nm and 90°/538 nm combinations, indicating extinction of "error" responses. Table

Table 3

Response frequencies in each combination of orientation and wavelength summed over 10 sessions (240 min total per stimulus).

Orientation pair	Wavelength pairs					
	538 nm	555 nm	538 nm	576 nm	538 nm	606 nm
Bird M1						
0°	6,428	30	7,879	28	11,797	44
90°	33	5,716	39	6,206	45	7,986
45°	7,831	465	7,767	269	9,704	266
60°	673	6,998	396	5,928	515	7,235
Bird M2						
0°	27,063	187	30,188	162	27,348	193
90°	171	25,258	200	23,160	148	24,421
45°	22,715	1,927	29,553	1,191	28,552	869
60°	2,319	19,969	1,629	23,029	1,597	23,294
Bird M3						
0°	19,727	193	20,487	121	22,838	215
90°	131	18,831	95	19,377	98	18,079
45°	15,716	2,043	18,291	1,276	20,296	1,375
60°	1,498	15,702	700	18,164	1,098	14,596
Bird M4						
0°	26,636	361	28,925	272	24,344	127
90°	186	28,194	354	24,475	215	21,261
45°	19,476	2,301	22,840	1,463	24,709	449
60°	1,797	18,879	1,882	20,628	292	19,279
Bird M5						
0°	14,888	79	12,386	49	14,113	75
90°	105	13,326	58	8,745	45	12,943
45°	12,487	186	10,886	164	12,043	174
60°	504	9,938	278	8,960	191	10,339

3 also shows that as disparity between the orientations and between the wavelengths decreased, frequencies of error responses increased relative to the frequencies of correct responses.

Measures of discriminability, $\log d$, were calculated from the response frequencies in Table 3 for individual birds according to Equation 1. The $\log d$ measures are shown in Figure 1 for the combinations of three wavelength differences and two orientation differences. For each bird, $\log d$ measures were much higher for the 0°/90° discrimination than for the 45°/60° discrimination, and generally increased as the difference between wavelengths increased. Analysis of variance confirmed that $\log d$ increased with increasing stimulus disparity for both orientation [$F(1, 4) = 101.48, p < .01$] and wavelength [$F(2, 8) = 5.40, p < .05$]. The extent of change in $\log d$ with increasing wavelength difference was greater for the 45°/60° discrimination than

for the 0°/90° discrimination. The reliability of this differential effect was confirmed by the significant interaction between orientation and wavelength in the analysis of variance [$F(2, 8) = 5.04, p < .05$]. It should be noted that $\log d$ values would decrease to nearly zero if the wavelength difference were zero. That is, points in Figure 1 lie on hyperbolic-like functions of wavelength difference (cf. White, Pipe, & McLean, 1984). Increasing the wavelength difference over a wider range would therefore yield a greater change in $\log d$ than that shown in Figure 1.

The results shown in Figure 1 demonstrate that the wavelength difference between the stimuli that occasion the choice response contributes to the measure of the discriminability between the successive-orientation stimuli. In other words, to the extent that conditional discrimination is involved, $\log d$ or equivalent detection measures obtained from a successive-discrimination procedure cannot be taken

as necessarily reflecting the absolute effects of disparity on the stimulus dimension of the successive stimuli. Instead, $\log d$ may be a measure of conjoint control by both successive and simultaneous stimuli in the conditional discrimination.

The interaction between the effects of orientation and wavelength differences in Figure 1 may not appear to be very strong; however, extension of the functions to near-zero levels of $\log d$ at zero wavelength difference would confirm the reliability of the interaction. The interaction suggests that the effects of the dimensions are not simply additive, but may follow a multiplicative rule as proposed by Blough (1972) and Zuckerman (1973). For the smaller orientation difference ($45^\circ/60^\circ$), changes in wavelength disparity were more effective than for the larger orientation difference. The same result for a symbolic matching-to-sample procedure in which simultaneous and successive stimuli were physically separated (cf. Carter & Eckerman, 1975) would also indicate an interaction between the dimensions. Such an interaction demonstrates that conditional discriminations can be understood only in terms of conjoint control by the two stimulus dimensions, not in terms of the separate effects of individual dimensions.

EXPERIMENT 2

Davison and Tustin (1978) derived their discriminability measure, $\log d$, from an extension of the generalized matching law (Baum, 1974; Staddon, 1968). According to generalized matching, the ratio of responses in concurrent schedules or simultaneous discriminations is a power function of ratios of rates of reinforcement contingent upon those responses. For a two-component concurrent schedule,

$$P_1/P_2 = c(R_1/R_2)^a \quad (3)$$

where P and R are rates of responding and of reinforcement, respectively, and the subscripts identify the components in which they occurred. In Equation 3, the exponent a describes the sensitivity of response ratios to changes in reinforcement ratios, and the constant c describes an overall bias or constant preference towards one or the other response alternative. For concurrent schedules, the value of a usually lies between 0.8 and 1.0 (Baum, 1979; Taylor & Davison, 1983).

Application of the generalized matching law to signal-detection procedures or conditional discriminations recognizes that the procedures involve two choices: one in the presence of stimulus S_1 and the other in the presence of S_2 (Davison & Tustin, 1978; Nevin, 1969, 1970, 1981). As illustrated in Table 1, there is a choice of emitting response P_{11} or response P_{12} in the presence of S_1 , and of emitting response P_{21} or P_{22} in the presence of S_2 . Reinforcements of the correct responses P_{11} and P_{22} are R_1 and R_2 , respectively, and the error responses P_{12} and P_{21} are without consequence. Davison and Tustin suggested that two equations following Equation 3 predict the choices occasioned by the successive stimuli, but with an additional source of bias d , owing to the discriminability of S_1 versus S_2 . Davison and Tustin also assumed that the reinforcement ratio determining the concurrent choice was the ratio that would be effective in the absence of discriminable differences between S_1 and S_2 —namely, the ratio of reinforcements in the successive components, R_1/R_2 . The constant d in Equations 4 and 5 describes a bias towards P_{11} responses occasioned by S_1 and towards P_{22} responses occasioned by S_2 . The extent of this bias is greater (i.e., larger values of d) with more discriminable differences between S_1 and S_2 . Equations 4 and 5 are extensions of the logarithmic form of Equation 3:

$$\begin{aligned} \text{In } S_1: \log(P_{11}/P_{12}) &= a \log(R_1/R_2) + \log d \\ &\quad + \log c; \quad (4) \\ \text{in } S_2: \log(P_{21}/P_{22}) &= a \log(R_1/R_2) - \log d \\ &\quad + \log c. \quad (5) \end{aligned}$$

Subtraction of Equation 5 from Equation 4 gives Equation 1—namely, the “stimulus function” that defines the discriminability measure $\log d$ (McCarthy & Davison, 1981).

Nevin (1981) has proposed an identical measure of discriminability from a different theoretical point of view (see also Nevin et al., 1982). Rather than assuming that the effect of stimulus discriminability is to bias the choices towards correct responses, Nevin (1981) assumed that the effects of reinforcement during S_2 generalized to behavior occasioned by S_1 (and vice versa), so that in effect the choice occasioned by each successive stimulus was controlled by reinforcement in the presence of that stimulus and by generalized effects of other reinforcement that maintained error responses during that stimulus. A gen-

Fig. 1. Discriminability measures, $\log d$, as a function of the wavelength difference between simultaneous stimuli combined with line-orientation difference between successive stimuli of the conditional discrimination in Experiment 1.

eralized version of Nevin's model ends up being identical to that of Davison and Tustin (1978), but perhaps has the advantage of being theoretically more acceptable in view of its consistency with the notion that choices within a single component of a multiple-concurrent schedule are solely between concurrently available reinforcers (McLean & White, 1983).

The model for performance in signal-detection procedures proposed by Davison and Tustin (1978) and described by Equations 4 and 5 assumes that sensitivity (a) of the concurrent response ratios to changes in the ratios of reinforcements produced by correct responses is independent of stimulus discriminability, $\log d$. The assumption is a crucial one because it allows separation of discriminability from bias factors (McCarthy & Davison, 1984), consistent with the aim of classical and modern detection theories (Wright, 1974). Theoretically, the assumption results from treating the effect of discriminability between the successive stimuli as a factor biasing the choice (towards correct responses) between the simultaneous stimuli. That is, stimulus disparity is assumed to affect $\log d$ in Equations 4 and 5, and not the sensitivity term, a .

McCarthy and Davison (1980) tested the independence assumption using a discrete-trials detection procedure that required difficult or easy discriminations of duration. They

varied the R_1/R_2 reinforcer ratio by varying the relative probability of the S_1 and S_2 components (i.e., signal-presentation probability) for constant and equal rates of reinforcement produced by choice responses (reinforcers per S_1 or S_2 trial). McCarthy and Davison did not find an effect of discriminability on sensitivity to reinforcement. Of 12 pairs of reinforcement functions for difficult and easy discriminations performed by 6 birds, 7 showed greater sensitivity to reinforcement in the more difficult discrimination.

In the present Experiment 1, reducing the disparity between stimuli in the simultaneous discrimination attenuated $\log d$. In simple concurrent discriminations in which the reinforcement rates correlated with the simultaneous stimuli are varied, reducing stimulus disparity decreases the size of the exponent describing sensitivity to reinforcement (Bourland & Miller, 1981; Miller, Saunders, & Bourland, 1980). Taken together, these two results suggest the possibility that sensitivity to reinforcement in conditional discriminations is indeed related to stimulus discriminability, notwithstanding McCarthy and Davison's (1980) failure to demonstrate such a relation. In Experiment 2, therefore, the rates of reinforcement correlated with a pair of simultaneously presented wavelength stimuli (538 nm/606 nm) were varied in combination with difficult (45°/60°) and easy (0°/90°) suc-

Table 4

Nominal values (seconds) of VI schedules and order of conditions in Experiment 2, and numbers of reinforcers obtained by each bird summed over the last five sessions of each condition.

Condi- tion	Orien- tation	Schedules		Reinforcers									
				Bird M1		Bird M2		Bird M3		Bird M4		Bird M5	
		538 nm	606 nm	538 nm	606 nm	538 nm	606 nm	538 nm	606 nm	538 nm	606 nm	538 nm	606 nm
1	45°	VI 48	Ext	140	0	131	0	137	0	137	0	131	0
	60°	Ext	VI 48	0	140	0	143	0	145	0	143	0	137
3	45°	VI 360	Ext	22	0	27	0	23	0	23	0	20	0
	60°	Ext	VI 30	0	245	0	253	0	252	0	251	0	250
4	45°	VI 30	Ext	241	0	237	0	242	0	232	0	244	0
	60°	Ext	VI 360	0	29	0	26	0	26	0	28	0	27
5	45°	VI 120	Ext	61	0	59	0	57	0	59	0	60	0
	60°	Ext	VI 48	0	154	0	145	0	150	0	146	0	144
6	45°	VI 48	Ext	141	0	196	0	142	0	142	0	—	—
	60°	Ext	VI 120	0	69	0	68	0	63	0	69	—	—
2	0°	VI 48	Ext	135	0	133	0	144	0	131	0	141	0
	90°	Ext	VI 48	0	138	0	148	0	144	0	137	0	148
7	0°	VI 360	Ext	46	0	48	0	48	0	46	0	50	0
	90°	Ext	VI 30	0	248	0	257	0	254	0	248	0	252
8	0°	VI 30	Ext	238	0	240	0	239	0	241	0	238	0
	90°	Ext	VI 360	0	50	0	45	0	51	0	48	0	48
9	0°	VI 120	Ext	60	0	60	0	60	0	59	0	59	0
	90°	Ext	VI 48	0	146	0	144	0	145	0	148	0	147
10	0°	VI 48	Ext	146	0	135	0	143	0	141	0	129	0
	90°	Ext	VI 120	0	61	0	60	0	61	0	61	0	62

cessive orientation discriminations, using the same procedure as in Experiment 1.

METHOD

Subjects, apparatus, and the main procedure were identical to those used in Experiment 1, except for the values of the VI schedules. In all conditions, the simultaneously presented background wavelengths, located on left and right keys for randomly alternating 60-s periods, were always 538 nm and 606 nm. In five conditions, lines of 0° orientation randomly alternated in succession with 90° lines, and in five conditions the orientations of successively presented lines were 45° and 60°. "Correct" responses were pecks on the key with 538 nm if the line orientation on both keys was 0° (or 45°) and pecks on the key with 606 nm if line orientation was 90° (or 60°). As in Experiment 1, correct responses were followed by 3-s access to wheat and incorrect responses were not reinforced. Different constant-probability VI schedules were arranged in different conditions, each of which lasted

for 20 sessions. Table 4 shows the nominal values (in seconds) of the VI schedules, the order in which the conditions were conducted, and the numbers of reinforcers obtained by each bird in the last five sessions of each condition. Bird M5 did not complete Condition 6 because of a chipped beak.

RESULTS AND DISCUSSION

Frequencies of responses on each combination of orientation and wavelength were summed over the last five sessions of each condition and are shown in Table 5 for individual birds. In general, the pattern of responses followed the pattern of reinforcer delivery (Table 4), with smaller differentials between correct and incorrect responses in the 45°/90° discrimination than in the 0°/90° discrimination. The response and reinforcement frequencies in Tables 4 and 5 were used in all subsequent analyses.

In order to determine whether sensitivity to reinforcement changed with discriminability, two separate analyses were conducted, one for

Table 5

Response frequencies summed over the last five sessions per condition in Experiment 2.

Condi- tion	Orien- tation	Bird M1		Bird M2		Bird M3		Bird M4		Bird M5	
		538 nm	606 nm	538 nm	606 nm	538 nm	606 nm	538 nm	606 nm	538 nm	606 nm
1	45°	3,677	94	15,028	1,404	12,035	297	15,665	335	4,905	110
	60°	118	3,301	1,734	14,212	338	10,119	342	14,005	69	4,161
3	45°	2,968	1,759	4,146	7,593	4,833	2,896	8,543	2,010	5,251	638
	60°	89	7,743	133	18,497	209	14,516	189	17,079	112	12,523
4	45°	12,061	66	20,671	88	19,131	114	20,638	229	13,368	172
	60°	2,786	2,526	6,203	2,721	3,283	3,869	2,144	8,204	1,636	4,138
5	45°	6,659	644	10,241	2,202	11,107	723	11,629	1,137	5,442	228
	60°	100	6,219	134	18,686	163	13,011	163	16,534	115	10,023
6	45°	9,846	106	17,943	277	18,586	173	17,774	106	—	—
	60°	225	4,132	524	12,142	461	6,608	143	10,017	—	—
2	0°	3,690	27	14,335	66	12,055	87	9,640	61	5,740	56
	90°	42	3,452	81	13,295	100	9,738	239	8,309	92	6,895
7	0°	4,563	27	9,014	104	9,234	135	7,787	113	5,208	47
	90°	30	5,591	52	16,524	130	15,169	94	14,631	39	9,703
8	0°	7,762	29	16,538	79	17,590	160	12,426	121	11,365	67
	90°	33	3,272	52	11,113	47	7,350	64	7,442	41	6,102
9	0°	5,248	35	12,096	76	10,672	112	10,598	75	7,389	104
	90°	32	4,651	52	17,007	81	14,627	97	15,481	68	9,461
10	0°	6,766	30	16,301	85	15,429	178	15,891	101	10,020	56
	90°	28	3,169	62	13,000	74	10,402	78	10,309	48	5,858

the 0°/90° conditions and the other for the 45°/60° conditions. In both analyses, logarithms (to the base 10) of ratios of choice responses in the presence of each of the successive stimuli were related to logarithms (base 10) of ratios of obtained reinforcers, following Equations 4 and 5. The ratios for concurrent choices were always responses on the 606-nm key divided by responses on the 538-nm key. The log ratios are shown in Figure 2 for each line orientation. Straight lines were fitted to these data by the method of least squares, and the slopes and intercepts of the best fitting straight lines are given in Figure 2. Figure 2 also shows values for the standard error of the estimate (*SE*), which indicate that in all cases the data were well described by linear functions. The functions fitted to the data in Figure 2 correspond to Equations 4 and 5. Sensitivity to reinforcement, *a*, is given by the slope of the lines, and the values for the intercepts correspond to $\log c \pm \log d$. Lines fitted to ratios of P_{11} and P_{12} responses are above the origin (large cross) when stimulus discriminability biases the choice to P_{11} ($+\log d$), and lines fitted to P_{21}/P_{22} ratios are below the origin when discriminability biases the choice to P_{22} ($-\log d$). The difference between the in-

tercepts ($2 \log d$) gives a measure of stimulus discriminability according to Equation 6.

For each bird, the slopes of the functions in Figure 2 for the 45°/60° discrimination are always much greater than for the 0°/90° discrimination. Figure 2 thus provides convincing evidence that sensitivity to reinforcement (*a*) is greater for the more difficult discrimination. It should be noted that the fairly flat functions for the 0°/90° discrimination are not the trivial result of a ceiling effect, inasmuch as it is technically possible for log ratios to extend to infinity. Further, a ceiling effect would involve frequencies of correct responses remaining invariant with reinforcement-rate variation, but as will be shown below, ratios of correct response rates actually varied systematically with ratios of reinforcement rates.

The present data are consistent with a result reported earlier by White, Pipe, and McLean (1985), who varied VI schedules in a conditional discrimination in the same way as in the present Experiment 2. Right responses were reinforced in the presence of a 0° line on both keys and left responses were reinforced when any of 15°, 30°, 45°, 60°, or 75° lines were presented. The 0° lines directly alternated with the other orientations within

Fig. 2. Logarithms of ratios of choice responses ($\log P_{11}/P_{12}$ or $\log P_{21}/P_{22}$) as a function of logarithms of ratios of reinforcers produced by correct responses for 45°/60° and 0°/90° discriminations in Experiment 2. Best fitting straight lines are shown along with values for their slopes (a) and intercepts ($\log c + \log d$, or $\log c - \log d$) predicted by Equations 4 and 5 and standard errors of the estimate (se) for the best fitting lines. The large crosses are the origins for each pair of functions.

sessions. Measures of discriminability, $\log d$, increased monotonically from about 1.9 to about 2.3 for the 2 birds in the study. For each bird there was a corresponding decrease in sensitivity to reinforcement (a) from about 1.4 to about 0.9 for the log ratio functions in the different line orientations from 15° through 75°. The earlier data therefore confirm the present result by demonstrating nonindependence of reinforcement sensitivity and discriminability for a range of orientation differences.

Although the data in Figure 2 were fitted well by the model proposed by Davison and Tustin (1978) and represented by Equations 4 and 5, the result that sensitivity to reinforcement is inversely related to stimulus discriminability violates the main assumption of the model—namely, independence of reinforce-

ment bias and stimulus discriminability. Davison and Tustin's notion that ratios of responses in the *concurrent* choice in S_1 or S_2 would be sensitive to ratios of reinforcement across *successive* components seemed plausible in the context of the limiting condition of zero discriminability. But for conditions of moderate or high discriminability, the notion is implausible because it requires that reinforcers occurring in the presence of a temporally distant stimulus should have the same influence on the concurrent response ratio as reinforcers accompanied by the prevailing stimulus. The notion is also implausible on the theoretical grounds that the only determinants of response ratios in a concurrent choice are reinforcers that occur within the immediate situation (McLean & White, 1983).

A plausible alternative account for the pres-

ent data assumes that the effects of reinforcement in one component on behavior in another are attenuated as the stimuli correlated with the two components become more discriminable. That is, temporally distant reinforcers do not directly affect behavior except indirectly through stimulus generalization. One possible way of expressing this idea is to assume that within each component of the conditional discrimination, choice is controlled by direct reinforcement of correct responses and by "generalized reinforcement" (cf. Nevin, 1981). If the effect of stimulus generalization is assumed to modify or attenuate the effects of the temporally distant reinforcements, the separate effects of R_1 and R_2 reinforcements on response ratios in the presence of each stimulus will differ. If the effect of temporally distant reinforcements is qualified by an exponent $(1 - n)$, where n describes the extent of attenuation owing to temporal distance, equations describing concurrent choice in S_1 between R_1 and generalized R_2 , and in S_2 between generalized R_1 and R_2 , are:

$$\begin{aligned} \text{In } S_1: \log(P_{11}/P_{12}) &= a \log R_1 - a(1 - n) \cdot \log R_2 + \log k; \quad (6) \\ \text{in } S_2: \log(P_{21}/P_{22}) &= a(1 - n) \log R_1 - a \cdot \log R_2 + \log k. \quad (7) \end{aligned}$$

Equations 6 and 7 were fitted to the data in Figure 2 using multiple linear regression, and the parameters for the best fitting functions are given in Table 6. Values of the mean-squared error and variance accounted for indicate that Equations 6 and 7 fitted the data very satisfactorily. Values for $\log k$ (a fitting constant) approximated zero. Values for the coefficient of attenuation, n , for the 45°/60° and 0°/90° discriminations were consistent with what would be expected according to the assumption that temporally distant reinforcement would have less effect when the stimulus difference is large—namely, larger n for the larger stimulus difference. Values for sensitivity to concurrent reinforcement, a , should have remained the same for the 45°/60° and 0°/90° discriminations, however. The fact that a differed between the two discriminations (Table 6) suggests that the above analysis may be inappropriate. An alternative possibility is that the sensitivity of choice to concurrent contingencies of reinforcement is attenuated when the concurrent reinforcement ratio remains

Table 6

Parameter values a , n , and $\log k$, obtained from multiple linear regression analyses conducted to predict $\log_{10}$ ratios of responses from Equations 9 and 10, estimates of mean squared error (MS_e), and variance accounted for (VAC) in the data by the predictions for 45°/60° and 0°/90° discriminations.

Bird	a	n	$\log k$	MS_e	VAC
45°/60°					
M1	1.362	.500	-.111	.037	.984
M2	1.582	.375	.064	.106	.952
M3	1.299	.537	-.113	.040	.983
M4	1.114	.704	.020	.073	.973
M5	1.031	.743	-.045	.042	.984
0°/90°					
M1	.706	1.513	.095	.017	.996
M2	.751	1.507	.075	.018	.996
M3	.538	1.875	.071	.015	.996
M4	.605	1.671	-.029	.054	.987
M5	.698	1.483	.025	.030	.993

high, as it would for high S_1/S_2 discriminability.

Predictions for Ratios of Correct Responses

In that the conditional discrimination arranges successive conditions of reinforcement, the schedules that were arranged for reinforcement of correct responses can be likened to a multiple schedule, in which "correct" responses are reinforced without making "error" responses explicit. Ratios of correct responses in Experiment 2 were plotted as a function of reinforcement ratios in order to examine the possible correspondence between the conditional discrimination and a simple multiple schedule. In multiple schedules, logarithms of response ratios in two successive components are linear functions of logarithms of reinforcement ratios (McLean & White, 1983):

$$\log(P_{11}/P_{22}) = m \log(R_1/R_2) + \log q. \quad (8)$$

Equation 8 has the same form as the logarithmic version of Equation 3, but m is used to describe sensitivity to reinforcement rather than a , because a applies to the concurrent choice, whereas m describes sensitivity of response ratios in successive components. The constant $\log q$ describes a constant tendency to respond at a higher rate during one or the other of the successive stimuli.

Figure 3 shows logarithms (base 10) of ratios of correct responses as a function of log-

Fig. 3. Logarithms of ratios of correct responses as a function of logarithms of ratios of reinforcers produced by correct responses in Experiment 2. Best fitting straight lines are shown along with values for their slopes (m) and intercepts ($\log q$) according to Equation 8. The standard error of the estimate is given for each function. The large crosses are the origins for each function.

arithms of the R_1/R_2 reinforcement ratio. Straight lines given by Equation 8 were fitted to the data by the method of least squares. The small values for the standard error of the estimate (se) given in Figure 3 show that the fits of Equation 8 to the data were satisfactory. The most interesting feature of the data in Figure 3 is that sensitivity to reinforcement (m) was greater for the 45°/60° discrimination than for the 0°/90° discrimination. In simple multiple schedules, the opposite effect is typical—sensitivity to differing rates of reinforcement increases with increasing stimulus dis-

parity (White, Pipe, & McLean, 1983, 1984; White & Redman, 1983).

Although greater sensitivity (m) for the 45°/60° discrimination than for the 0°/90° discrimination (Figure 3) may seem unusual, it is predicted by the model proposed by McLean and White (1983), adjusted to take into account the generalized effects of temporally distant reinforcement as described by Equations 6 and 7. The resulting modification to McLean and White's model is described by Equation 9:

$$P_{11}/P_{22} = (R_1/R_2)^a \left[\frac{R_1^{a(1-n)} + R_2^a + R_o^a}{R_1^a + R_2^{a(1-n)} + R_o^a} \right] \quad (9)$$

Ratios of correct responses were predicted by Equation 9 by using the values of a and n from Table 6, and by holding R_o , reinforcers per hour produced by behavior other than key pecking, constant at 38, 46, 48, 56, and 64 for Birds M1 through M5, respectively, for both levels of stimulus disparity. Equation 9 accounted for between 90 and 99% of the variance in the data for individual functions in Figure 3. In particular, the predictions accounted for the difference in slopes (m) for the two levels of stimulus disparity. The slope differences were due to differences in a and n (Table 6) because only these parameters differed between the 0°/90° and 45°/60° conditions. In this regard, the predictions from Equation 9 for ratios of correct responses corroborate the description of concurrent choice responses by Equations 6 and 7.

GENERAL DISCUSSION

In Experiment 1, the measure of discriminability between successively presented line orientations depended on the wavelength difference for the simultaneous discrimination that was in conditional relation to the successive discrimination. Thus, performance in the conditional discrimination was jointly determined by disparity of the successive and simultaneous stimuli. Further, the interaction between orientation disparity and wavelength disparity indicated that conjoint control of performance involved a multiplicative relation between the stimulus dimensions. In Experiment 2, the difference between successive line orientations influenced the extent of sensitiv-

ity to relative rate of reinforcement in the simultaneous discrimination. That is, stimulus discriminability and response bias induced by varying relative rates of reinforcement were not independent. Taken together, these results suggest that a single measure of discriminability in conditional discriminations or signal-detection procedures such as $\log d$ or d' (Davison & Tustin, 1978; Green & Swets, 1966; Nevin, 1981) is not simply a measure of the subject's ability to discriminate between the successive stimuli, but quantifies the extent to which performance in the conditional discrimination is under *conjoint* control by both successive and simultaneous discriminations.

The results of Experiment 2 indicate that the effects of reinforcement in the temporally distant component may depend on the discriminability of the stimuli that delineate successive components. Differing values of the parameters obtained for fits of Equations 6 and 7 to the data suggest that the effects of the R_1 and R_2 reinforcers on response ratios in one component were not equivalent, and that their effects differed as a function of stimulus disparity. Further research is needed to quantify the interaction between stimulus and reinforcement effects in conditional discriminations in order to advance the development of a bias-free index of stimulus effects.

The analysis of ratios of correct responses suggests that a conditional discrimination cannot be treated in the same way as a simple successive discrimination. In a successive discrimination, or multiple schedule, the exponent of the power function relating ratios of responses during the successive stimuli to reinforcement ratios (m in Equation 8) increases systematically with increasing disparity between dimensional values of the discriminative stimuli (White et al., 1983, 1984). In the conditional discrimination, however, the exponents obtained when ratios of correct responses were plotted against ratios of reinforcement (Figure 3) were smaller for the $0^\circ/90^\circ$ discrimination than for the $45^\circ/60^\circ$ discrimination, the reverse of the case for simple multiple schedules. That is, ratios of correct responses in conditional discriminations, where they are topographically separated from errors, do not behave in the same way as ratios of responses in multiple schedules. If a measure of stimulus control is required for multiple schedules or successive discriminations,

unconfounded by the effects of variation in rate of reinforcement, the best measure is probably the power-function exponent, m , as proposed by White et al. (1983, 1984). A discriminability measure such as $\log d$ or d' in the conditional discrimination or detection procedure reflects the influence of both successive- and simultaneous-stimulus disparity, and may not easily be separated from reinforcement effects.

REFERENCES

- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, **22**, 231-242.
- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, **32**, 269-281.
- Blough, D. S. (1972). Recognition by the pigeon of stimuli varying in two dimensions. *Journal of the Experimental Analysis of Behavior*, **18**, 345-367.
- Blough, D. S., & Blough, P. M. (1977). Animal psychophysics. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 514-539). Englewood Cliffs, NJ: Prentice-Hall.
- Boneau, C. A., & Honig, W. K. (1964). Opposed generalization gradients based upon conditional discrimination training. *Journal of Experimental Psychology*, **68**, 89-93.
- Bourland, G., & Miller, J. T. (1981). The role of discriminative stimuli in concurrent performances. *Journal of the Experimental Analysis of Behavior*, **36**, 231-239.
- Carter, D. E., & Eckerman, D. A. (1975). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science*, **187**, 662-664.
- Carter, D. E., & Werner, T. J. (1978). Complex learning and information processing by pigeons: A critical analysis. *Journal of the Experimental Analysis of Behavior*, **29**, 565-601.
- Chase, S., & Heinemann, E. G. (1972). Choices based on redundant information: An analysis of two-dimensional stimulus control. *Journal of Experimental Psychology*, **92**, 161-175.
- Cumming, W. W., & Berryman, R. (1965). The complex discriminated operant: Studies of matching-to-sample and related problems. In D. I. Mostofsky (Ed.), *Stimulus generalization* (pp. 284-330). Stanford, CA: Stanford University Press.
- Davison, M. C., & Tustin, R. D. (1978). The relation between the generalized matching law and signal-detection theory. *Journal of the Experimental Analysis of Behavior*, **29**, 331-336.
- Goldiamond, I. (1966). Perception, language, and conceptualization rules. In B. Kleinmuntz (Ed.), *Problem solving: Research method and theory* (pp. 183-224). New York: Wiley.
- Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.
- Heinemann, E. G., & Chase, S. (1970). Conditional

- stimulus control. *Journal of Experimental Psychology*, **84**, 187-197.
- Heinemann, E. G., Chase, S., & Mandell, C. (1968). Discriminative control of "attention." *Science*, **160**, 553-554.
- Honig, W. K. (1965). Discrimination, generalization, and transfer on the basis of stimulus differences. In D. I. Mostofsky (Ed.), *Stimulus generalization* (p. 218-254). Stanford, CA: Stanford University Press.
- Looney, T. A., Cohen, L. R., Brady, J. H., & Cohen, P. S. (1977). Conditional discrimination performance by pigeons on a response-independent procedure. *Journal of the Experimental Analysis of Behavior*, **27**, 363-370.
- Luce, R. D. (1963). Detection and recognition. In R. D. Luce, R. R. Bush, & E. Galanter (Eds.), *Handbook of mathematical psychology* (Vol. 1, pp. 103-189). New York: Wiley.
- McCarthy, D., & Davison, M. (1980). Independence of sensitivity to relative reinforcement rate and discriminability in signal detection. *Journal of the Experimental Analysis of Behavior*, **34**, 273-284.
- McCarthy, D., & Davison, M. (1981). Matching and signal detection. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 393-417). Cambridge, MA: Ballinger.
- McCarthy, D., & Davison, M. (1984). Isobias and alloibias functions in animal psychophysics. *Journal of Experimental Psychology: Animal Behavior Processes*, **10**, 390-409.
- McCarthy, D., Davison, M., & Jenkins, P. E. (1982). Stimulus discriminability in free-operant and discrete-trial detection procedures. *Journal of the Experimental Analysis of Behavior*, **37**, 199-215.
- McLean, A. P., & White, K. G. (1983). Temporal constraint on choice: Sensitivity and bias in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 405-426.
- Medin, D. L., & Dewey, G. I. (1984). Learning of ill-defined categories by monkeys. *Canadian Journal of Psychology*, **38**, 285-303.
- Miller, J. T., Saunders, S. S., & Bourland, G. (1980). The role of stimulus disparity in concurrently available reinforcement schedules. *Animal Learning & Behavior*, **8**, 635-641.
- Nevin, J. A. (1969). Interval reinforcement of choice behavior in discrete trials. *Journal of the Experimental Analysis of Behavior*, **12**, 875-885.
- Nevin, J. A. (1970). On differential stimulation and differential reinforcement. In W. C. Stebbins (Ed.), *Animal psychophysics* (pp. 401-423). New York: Appleton-Century-Crofts.
- Nevin, J. A. (1981). Psychophysics and reinforcement schedules: An integration. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 3-27). Cambridge, MA: Ballinger.
- Nevin, J. A., Jenkins, P., Whittaker, S., & Yarensky, P. (1982). Reinforcement contingencies and signal detection. *Journal of the Experimental Analysis of Behavior*, **37**, 65-79.
- Reynolds, G. S., & Limpo, A. J. (1969). Attention and generalization during a conditional discrimination. *Journal of the Experimental Analysis of Behavior*, **12**, 911-916.
- Richards, R. W. (1979). Stimulus control following training on a conditional discrimination. *Animal Learning & Behavior*, **7**, 309-312.
- Schrier, A. M., & Thompson, C. R. (1980). Conditional discrimination learning: A critique and amplification. *Journal of the Experimental Analysis of Behavior*, **33**, 291-298.
- Sidman, M. (1980). A note on the measurement of conditional discrimination. *Journal of the Experimental Analysis of Behavior*, **33**, 285-289.
- Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, **37**, 5-22.
- Staddon, J. E. R. (1968). Spaced responding and choice: A preliminary analysis. *Journal of the Experimental Analysis of Behavior*, **11**, 669-682.
- Taylor, R., & Davison, M. (1983). Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 191-198.
- White, K. G. (1974). Temporal integration in the pigeon. *British Journal of Psychology*, **65**, 437-444.
- White, K. G., Pipe, M-E., & McLean, A. P. (1983). Dimensional stimulus control of multiple schedule performance. *Behaviour Analysis Letters*, **3**, 51-57.
- White, K. G., Pipe, M-E., & McLean, A. P. (1984). Stimulus and reinforcer relativity in multiple schedules: Local and dimensional effects on sensitivity to reinforcement. *Journal of the Experimental Analysis of Behavior*, **41**, 69-81.
- White, K. G., Pipe, M-E., & McLean, A. P. (1985). A note on the measurement of stimulus discriminability in conditional discriminations. *Bulletin of the Psychonomic Society*, **23**, 153-155.
- White, K. G., & Redman, S. (1983). Free-operant forgetting: Delayed stimulus control of multiple-schedule performance. *Journal of the Experimental Analysis of Behavior*, **39**, 129-133.
- Williams, B. A. (1984). Relative stimulus validity in conditional discrimination. *Animal Learning & Behavior*, **12**, 117-121.
- Wright, A. A. (1974). Psychometric and psychophysical theory within a framework of response bias. *Psychological Review*, **81**, 322-347.
- Wright, A. A., & Cumming, W. W. (1971). Color-naming functions for the pigeon. *Journal of the Experimental Analysis of Behavior*, **15**, 7-17.
- Zuckerman, D. C. (1973). Steady state responding based upon simple and compound stimuli. *Journal of the Experimental Analysis of Behavior*, **20**, 209-218.

Received December 28, 1984

Final acceptance December 5, 1985