EFFECTS OF THE DISCRIMINABILITY OF ALTERNATIVES IN THREE-ALTERNATIVE CONCURRENT-SCHEDULE PERFORMANCE

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Six pigeons were trained on two- and three-alternative concurrent schedules in which the alternatives were signaled by different wavelengths of light on the main pecking key. The schedules were arranged according to a switching-key procedure in which pecks on a white side key produced a 3-s blackout and, intermittently, a change in the variable-interval schedule of food programmed on the main (center) key after the blackout. In Part 1, a two-alternative concurrent variable-interval schedule was arranged in which the alternatives were signaled by 560 nm and 630 nm. Parts 2 and 3 arranged three-alternative concurrent variable-interval schedules with the alternatives signaled by 560 nm, 600 nm, and 630 nm (Part 2) and 560 nm, 623 nm, and 630 nm (Part 3). Within each part, the relative rate of food reinforcers available on the alternatives was varied across a wide range. In all parts of the experiment, the ratios of responses emitted between pairs of alternatives were more extreme than the ratios of reinforcers obtained on the pairs of alternatives, a result termed overmatching. In Parts 2 and 3, generalized matching sensitivities between pairs of alternatives were found to be higher when the reinforcer rate on the third alternative was low than when it was high—an apparent failure of the constant-ratio rule. The data were well described by an extension of the Davison and Jenkins (1985) model, which assumes differing discriminabilities between concurrent-schedule alternatives in combination with a punishing effect of blackout following changeovers.

Key words: concurrent schedules, number of alternatives, discriminability of alternatives, constant-ratio rule, matching, key peck, pigeons

J. Miller, Saunders, and Bourland (1980) reported an experiment in which pigeons responded on two-alternative concurrent variable-interval (VI) schedules. Three groups of 2 subjects were trained under conditions in which the discriminability of the alternatives differed: For one group, two line orientations differing by 45° were used as discriminative stimuli. For another group, the orientations differed by 15°, and for the third, the orientations differed by 0°. For each group, the relative frequency of reinforcers for responding on the two alternatives was varied over a wide range. Miller et al. carried out generalized matching analyses (Baum, 1974) of their data by fitting them to the following equation:

$$\frac{B_1}{B_2} = c \left(\frac{R_1}{R_2} \right)^a, \quad (1)$$

where B refers to responses emitted, R to reinforcers obtained, and the subscripts 1 and 2 refer to the alternatives. So that linear regression can be used to determine the values of the parameters, Equation 1 is often transformed into its logarithmic equivalent [$\log(B_1/B_2) = a \log(R_1/R_2) + \log c$], and hence it is usual to report $\log c$, rather than c , as the estimate of bias. The parameter a is called sensitivity to reinforcement (Lobb & Davison, 1975); it measures the relative change in the log response ratio as a function of changes in the log obtained reinforcer ratio. The parameter c is called bias, and measures a proportional preference for one alternative that is constant independent of the reinforcer-rate manipulation. For the 45° difference, sensitivity values for pairs of birds were 0.97 and 1.00, for the 15° difference they were 0.28 and 0.37, and for the 0° difference they were both 0.17. Thus, the degree to which performance was sensitive to changes in relative reinforcer frequency depended on how well the birds could discriminate between the sources of reinforcers. (The greater than zero sensitivity in the 0° conditions probably represents the development of a “win-stay lose-shift” strategy; see Alsop & Davison, 1992; Davison & Jenkins, 1985.)

A quantitative model for the performance

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of the subjects in the study by J. Miller et al. (1980) was offered by Davison and Jenkins (1985). This model assumes that, when alternatives are difficult to discriminate, animals can make errors in discriminating the contingencies of reinforcement on the alternatives. At one limit, when the contingencies are fully discriminable, all obtained reinforcers will be accurately allocated to the correct alternative. At the other limit, when the contingencies are not at all discriminable, the animals will emit many errors in allocating reinforcers to response classes. Their model is written

$$\frac{B_1}{B_2} = c \left(\frac{d_r R_1 + R_2}{d_r R_2 + R_1} \right). \quad (2)$$

The independent and dependent variables and subscripts are the same as in Equation 1. The parameter c is bias, but a in Equation 1 is replaced by d_r , which is termed contingency discriminability. A value of $d_r = 1$ represents zero discriminability, in which case $B_1/B_2 = c$, and a value of $d_r = \infty$ is maximal discriminability, in which case $B_1/B_2 = cR_1/R_2$, which is equivalent to Equation 1 with $a = 1$, and is called biased strict matching. A value of $d_r = 1$ corresponds to a sensitivity (a) of 0, and a value of ∞ corresponds to a sensitivity of 1.0. Davison and Jenkins reanalyzed J. Miller et al.'s (1980) data and found d_r values of 1.49 and 1.53, 1.83 and 3.06, and 57.78 and 19.54 for the 0°, 15°, and 45° separations, respectively. Conceptually or structurally similar equations for concurrent-schedule performance have been suggested by Burgess and Wearden (1986), Vaughan and Herrnstein (1987), and Wearden (1983).

Support for Equation 2 as an effective concurrent-schedule model was provided by Alsop and Davison (1992). They studied concurrent VI performance in pigeons over a series of seven light-intensity differences, and showed that estimates of d_r increased systematically as the physical stimulus difference was increased. They also showed no systematic changes in the estimated value of c . Alsop and Davison also introduced a procedure designed to eliminate any possibility that the schedules could be discriminated on the basis of the reinforcer rate that they provided (win-stay lose-shift strategy). They arranged that, after each reinforcer, the schedule and associated stimulus in oper-

ation were determined by a probability gate set at .5. This procedure resulted in no differential reinforcement effects when identical discriminative stimuli were arranged ($d_r = 1$, $a = 0$).

Although Equation 2 has received good support in accounting for two-alternative concurrent-schedule performance, can it describe performance when there are three alternatives? This is the question posed in the present research. Previous research has shown that if performance on VI schedules with more than two alternatives is analyzed pairwise, Equation 1 fits well, and there is no effect of the presence, absence, or value of any third alternative on the preference or sensitivity between the other two (Davison & Hunter, 1976; H. Miller & Loveland, 1974; Pliskoff & Brown, 1976). This finding is known as the constant-ratio rule or the principle of indifference from irrelevant alternatives (Luce, 1959). The present research, then, also asks whether the constant-ratio rule applies when stimulus disparity is varied. There are no previous data on this question.

The subjects were initially trained on a two-alternative concurrent VI VI schedule in which the alternatives were signaled by two widely separated wavelengths, 560 nm and 630 nm. The relative rate of reinforcers available on the alternatives was varied over five conditions. These conditions (Part 1) comprise a control for later manipulations. In Part 2, a third alternative, signaled by a 600-nm color, part way (physically) between the original colors, was added, and the relative rate of reinforcers on all three alternatives was varied over 13 conditions. In Part 3, the central stimulus was changed to a color (623 nm) only partially distinguishable from one of the other discriminative stimuli, and relative reinforcer manipulations similar to those in Part 2 were carried out. Thus, performance in Part 1 can be compared with that in Parts 2 and 3 as a test of Equation 2, under the expectation that d_r for the most disparate colors will remain constant, and performance in Part 2 can be compared with performance in Part 3, with the same expectation, but also with the expectation of a low d_r value between the physically close colors. Initially, the data analysis will be carried out using the simpler Equation 1 (as a is correlated with d_r), but an appropriate version of Equation 2 is fitted in the Discussion.

METHOD

Subjects

The subjects were 6 homing pigeons, numbered 101 to 106, maintained at $85\% \pm 15\%$ g of their free-feeding body weights. They had previously been trained on color discriminations using signal-detection procedures (Davison & McCarthy, 1989). Note that the numbering of the subjects had been changed since the previous experiment. Bird 104 provided no data in Condition 31 because of illness.

Apparatus

The apparatus was the same as that used by Davison and McCarthy (1989). The experimental chamber was 310 mm wide, 340 mm deep, and 310 mm high, and was fitted with an exhaust fan for ventilation and to help mask external noise. On one wall of the chamber were three response keys, 20 mm in diameter, 150 mm apart, and 250 mm from the grid floor. The keys required about 0.1 N for an effective peck. Centered beneath the center key was a food hopper, 70 mm from the floor. The hopper contained wheat, and during reinforcement the hopper was raised and illuminated for 3 s, with all other chamber lights extinguished. Only the left and center keys were used in this experiment. The left key, when available, was illuminated white. The center key, which was transparent, had a light-fiber termination 2 mm behind the key that provided a 3-mm patch of light of selected colors. A houselight (0.1 A, 28 VDC) provided general illumination.

The center-key color was produced by a monochromator (Oriel Corp. Model 7240) with a 100-W quartz-halogen bulb, a 1,200 lines/mm grating, and a 280- μ fixed slit. This provided an approximate bandpass of 2 nm. There was no control of light intensity. The monochromator setting was controlled by a dedicated microprocessor that controlled a stepping motor.

Procedure

Schedules were arranged according to a switching-key procedure, with the white side key as the switching key and the center key as the main key. Two (Part 1) or three (Parts 2 and 3) colors could be displayed on the center key, and each color was associated with a VI reinforcement schedule. The colors on the cen-

ter key were 560 nm and 630 nm for Part 1 (Conditions 1 through 5) and for two of the schedules in Parts 2 and 3. The third alternative in Part 2 (Conditions 6 through 18) was signaled by 600 nm, and in Part 3 (Conditions 20 through 31) by 623 nm. The schedules were arranged using a procedure in which a reinforcer was programmed with a fixed probability per second (an exponential VI schedule), and the reinforcer was allocated according to set probabilities to one of the alternative schedules. The probability of schedule allocation is shown in Table 1 for each experimental condition. A response to the white changeover key immediately turned off the white key and the color on the center key, and they remained off for 3 s. This period was required to allow the monochromator to select the next center-key color. Following the blackout of the keys (not the houselight), a new stimulus and associated schedule were provided. In all parts of the experiment, the new color and schedule were selected randomly in order that, in Parts 2 and 3, there could be no control of performance by the current, or expected, reinforcer rate. Thus, in all parts, there was a .5 (Part 1) or .33 (Parts 2 and 3) probability that the same stimulus/schedule combination would be presented after a side-key peck. Exactly the same procedure was used to select the stimulus and schedule after a reinforcer had been obtained; that is, after a reinforcer, the prevailing stimulus and schedule were selected with the same probabilities as above.

Sessions were arranged daily and ended in blackout after 45 min had elapsed or after 40 reinforcers had been collected, whichever event occurred first. The sequence of experimental conditions is shown in Table 1. In Part 1, the overall probability of reinforcement per second was .022 (one reinforcer every 45.5 s), and the probability that this reinforcer was allocated to either of the two schedules was varied over five experimental conditions in an irregular order, spanning reinforcer ratios of 1:9 to 9:1. The overall reinforcer probability in Part 2 was increased in Condition 7 to .028 per second (VI 35.7 s) in order to maintain an overall reinforcer rate similar to that obtained in Part 1. The design in Parts 2 and 3 covered the same range of reinforcer ratios for each pairwise selection of schedules. By mistake, but fortunately, twice as many conditions as originally required were arranged, with, for each

Table 1

Sequence of experimental conditions, number of sessions in each condition, overall probability of reinforcement per second, and arranged relative reinforcer frequency for each option. "X" refers to the wavelength, in nanometers, of the stimulus accompanying the third schedule alternative (when available).

Condi- tion	Sessions	Overall <i>p</i> (R/s)	Relative reinforcer frequencies		
			560 nm	630 nm	X nm
Part 1: Concurrent VI VI. X not available					
1	23	.022	.5	.5	—
2	21	.022	.9	.1	—
3	21	.022	.2	.8	—
4	23	.022	.8	.2	—
5	24	.022	.1	.9	—
Part 2: Concurrent VI VI VI. X is 600 nm					
6	22	.022	.333	.333	.333
7	23	.028	.444	.444	.111
8	20	.028	.111	.444	.444
9	22	.028	.444	.111	.444
10	20	.028	.091	.091	.818
11	23	.028	.818	.091	.091
12	24	.028	.091	.818	.091
13	21	.028	.167	.167	.667
14	22	.028	.667	.167	.167
15	20	.028	.167	.667	.167
16	28	.028	.474	.474	.053
17	26	.028	.053	.474	.474
18	21	.028	.474	.053	.474
Part 3: Concurrent VI VI VI. X is 623 nm (620 in Con- dition 19)					
19	21	.028	.474	.053	.474
20	21	.028	.053	.474	.474
21	21	.028	.474	.053	.474
22	23	.028	.444	.444	.111
23	20	.028	.111	.444	.444
24	24	.028	.444	.111	.444
25	24	.028	.091	.091	.818
26	23	.028	.818	.091	.091
27	25	.028	.091	.818	.091
28	23	.028	.167	.167	.667
29	28	.028	.667	.167	.167
30	22	.028	.167	.667	.167
31	25	.028	.474	.474	.053

pair, a particular reinforcer ratio replicated with a different reinforcer rate on the third alternative. Thus, for example, both Conditions 8 and 15 arranged a 1:4 reinforcer ratio on the 560-nm and 630-nm alternatives, but Condition 8 had a higher probability of reinforcement on the 600-nm alternative than did Condition 15. In view of the results from Part 2, Part 3 used the same set of conditions. Condition 19 used 620 nm as the color of the third alternative, but this did not produce a sufficient decrement in the choice between the 620-nm and 630-nm alternatives for our pur-

poses. The color of the third alternative was changed to 623 nm in Condition 20, and the data from Condition 19 are not analyzed here.

Sessions were conducted in each experimental condition until two stability criteria had been met. The first criterion required that the median relative response rate to 560 nm (pecks on the 560-nm alternative divided by total pecks to all alternatives) over five sessions was not more than 5% different from the median from the previous set of five nonoverlapping sessions. When this criterion had been met five, not necessarily consecutive, times, that subject had met the second criterion. When all subjects had met the second criterion, the experimental condition was changed. Stability thus required 14 sessions at minimum, although more were normally required (Table 1).

In each session, the number of responses to the alternatives, the time spent responding to the alternatives (from changeover to changeover, excluding blackout time), and the numbers of obtained reinforcers were recorded. The data analyzed were from the last five sessions of each experimental condition. Although time-allocation data were recorded (and are provided in the Appendix), the random-switching procedure used here makes the time data from the present experiment rather different from those from standard concurrent schedules. Thus, an analysis of these data is not reported here.

RESULTS

The number of responses emitted, seconds spent responding, and reinforcers obtained on each alternative are given in the Appendix for each subject and condition. These data have been summed over the last five sessions of each condition. Notice that the numbers of changeovers from alternatives were unequal; there were fewer from higher reinforcer-rate alternatives than from lower rate alternatives. This results from the procedure of reselecting the stimuli and schedules after each reinforcer to avoid win-stay lose-shift strategies and discrimination between the alternatives based on obtained reinforcer rates.

Part 1

Part 1 arranged two concurrent schedules signaled by 560 nm and 630 nm, respectively.

Figure 1 shows log response ratios as a function of log obtained reinforcer ratios for all 6 subjects. Straight lines were fitted to the data by the method of least squares to obtain values of a and $\log c$ in the logarithmic form of Equation 1, and these values are shown on the graph. Response-allocation data gave sensitivities to reinforcement (a) for individual subjects that were all greater than 1.0 ($p < .05$, sign test), a result called overmatching (Baum, 1974). These sensitivities ranged from 1.08 (Bird 104) to 1.55 (Bird 101), with a group mean of 1.30. These sensitivities were precisely estimated as shown by standard errors ranging from 0.06 to 0.19, with a median of 0.08. Bias values were close to 0, and a sign test across subjects showed no statistically significant difference from 0.

The overmatching in response allocation is consistent with the finding that punishment of changing over between concurrent schedules increases sensitivity to log obtained reinforcer ratios. This was demonstrated by Todorov (1971), using both electric shock and timeout as the punisher. His Experiment 3 used concurrent VI 60-s VI 180-s schedules, with an arranged log reinforcer ratio of 0.48. With a 3-s timeout on changing over (the same duration of the blackout on changeover as used here), the log response ratios for his 3 subjects were 0.81, 1.19, and 1.38. Calculated sensitivity values from single points (thus neglecting any bias) were 1.61, 2.13, and 2.51. Although the present sensitivity values were less than those obtained by Todorov, they were in the same direction of overmatching. Many other experiments (de Villiers, 1980; Farley, 1980; Farley & Fantino, 1978) have shown that shock punishment increases sensitivity to reinforcement.

Part 2

Part 2 arranged three schedules signaled by 560 nm, 600 nm, and 630 nm, respectively. The group-average response-allocation results (from summing the raw data across subjects) obtained in Part 2 are shown in Figure 2. It was immediately evident from a scatter plot that the response-allocation data did not fit naturally onto a single straight line of the form described by the logarithmic form of Equation 1. The problem appeared to be that conditions with the same pair of arranged reinforcer rates, with differing reinforcer rates on the third al-

ternative, gave different choice proportions. For example, both of the rightmost sets of three data points came from a 9:1 reinforcer-ratio condition, but they clearly did not fall on the same fitted line. These results, which indicate a failure of the constant-ratio rule, were unexpected and clearly deserved further analysis.

The following analysis was then carried out. The sets of conditions for each pairwise combination of schedules were sorted according to the ratio of the arranged reinforcer rate on the third alternative divided by the sum of the arranged reinforcer rates on the pair of alternatives analyzed. Thus, the choices between, for example, 560 nm and 630 nm were sorted according to the reinforcer rate on the 600-nm key divided by the sum of the reinforcer rates on the 560-nm and 630-nm keys. The conditions were then divided into two groups: a group in which this ratio was less than 0.5 (the low-other-reinforcer-rate group) and a group in which the ratio was greater than 0.5 (the high-other-reinforcer-rate group). The data from Condition 6, in which all the schedules were equal, were used in both groups. Least squares linear regressions of log response ratios against log obtained reinforcer ratios were carried out for both groupings of data, and the equations of the fitted lines for group response allocation are shown in Figure 2. It is evident that each straight line fits the categorized data much better than would a single straight line.

Figure 3 shows the sensitivity values (a) that resulted from fitting straight lines to the categorized response-allocation data for all 6 subjects; more detail on these fits is shown in Table 2. It is evident from Figure 3 that the slopes of the regressions for the low-other-reinforcer-rate conditions were much greater than those for the high-other conditions. This difference occurred for all 18 comparisons for response measures and is, on a binomial test, statistically significant at $p < .01$. Group mean sensitivities for response measures were 1.16 and 0.62, respectively, for low-other and high-other-reinforcer-rate conditions.

These results show, then, that the sensitivity of choice between alternatives was affected by the reinforcer rate on these alternatives in comparison with the reinforcer rate of the other alternative. For example, in concurrent VI 6 s VI 60 s VI 600 s with the present procedure, the response ratio between VI 6 s and VI 60

LOG RESPONSE RATIO

LOG OBTAINED REINFORCER RATIO

Fig. 2. Part 2. Group data—the logarithm of response ratios as a function of the logarithm of the obtained reinforcer ratio for pairwise combinations of schedules when the ratio of the arranged reinforcer rate on the third alternative divided by the sum of the arranged reinforcer rates on the pair of analyzed alternatives was less than .5 (the low-other-reinforcer-rate group, filled circles) or greater than .5 (the high-other-reinforcer-rate group, filled triangles). Straight lines were fitted to the group data (summed across birds) by the method of least squares. The equations of the fitted lines, together with the percentage of data variance accounted for, are shown for both low-other and high-other groupings.

s would be greater than 10:1, because the third alternative arranged a low (VI 600 s) reinforcer rate. By comparison, the response ratio between VI 60 s and VI 600 s would be less than 10:1, because the third alternative arranged a high (VI 6 s) reinforcer rate. This result is quite contrary to the extensive previous research done on preference among more than two alternatives (Davison & Hunter, 1976; H. Miller & Loveland, 1974; Pliskoff & Brown, 1976). We will discuss some reasons for this finding in the Discussion. At this point, though, it was evident that the design of the experiment had been compromised, because no single sensitivity value for each pairwise stimulus alternative had been obtained. However, the design could be saved by arranging exactly the same experimental conditions in Part 3.

Fig. 3. Part 2. Individual birds' sensitivity values (a) resulting from least squares linear regression fits between log response ratios and log obtained reinforcer ratios for pairwise combinations of schedules when the ratio of the arranged reinforcer rate on the third alternative divided by the sum of the arranged reinforcer rates on the pair of analyzed alternatives was less than .5 (low-other; B-Lo) or greater than .5 (high-other; B-Hi).

Rather than follow up the unexpected failure of the constant-ratio rule here, we continued with Part 3 of the originally designed experiment.

Comparison of Parts 1 and 2

Response-allocation measures of sensitivity to reinforcement between the 560-nm and 630-nm stimuli did not differ reliably between Part 1 and the conditions in Part 2 in which there was a lower reinforcer rate on the 600-nm

Fig. 1. Part 1. The logarithm of response ratios as a function of the logarithm of the obtained reinforcer ratio for all subjects. Straight lines were fitted to the data by the method of least squares to obtain values of a and $\log c$ in the logarithmic form of Equation 1. These values are shown for each bird.

Table 2

The results of linear regressions of pairwise log response ratios against log obtained reinforcer ratios for Part 2 of the experiment. The fits were differentiated according to whether the arranged third alternative reinforcer rate was greater (hi) or lower (lo) than the sum of the arranged rates of the schedules in question. Shown are the slopes of the regression lines (*a* in Equation 1), the standard error (*SE*) of the slope estimate, the constant intercept of the line (the logarithm of *c* in Equation 1), and the percentage of the data variance accounted for (%VAC).

Bird	Third alternative (nm)	Lo/hi	Slope (<i>SE</i>)	Constant	%VAC
101	600	lo	1.55 (0.14)	0.01	96
101	600	hi	0.94 (0.12)	-0.19	92
102	600	lo	0.94 (0.05)	-0.04	99
102	600	hi	0.51 (0.13)	-0.09	76
103	600	lo	1.35 (0.09)	-0.01	98
103	600	hi	0.50 (0.08)	-0.05	89
104	600	lo	0.99 (0.07)	0.02	98
104	600	hi	0.44 (0.05)	-0.07	94
105	600	lo	1.28 (0.08)	-0.09	98
105	600	hi	0.63 (0.07)	-0.06	94
106	600	lo	1.07 (0.08)	-0.10	97
106	600	hi	0.53 (0.05)	-0.03	96
101	630	lo	1.44 (0.16)	-0.03	94
101	630	hi	1.01 (0.15)	0.09	91
102	630	lo	0.83 (0.07)	-0.02	96
102	630	hi	0.56 (0.06)	0.00	95
103	630	lo	1.20 (0.11)	-0.01	96
103	630	hi	0.58 (0.10)	0.08	87
104	630	lo	1.10 (0.06)	0.06	99
104	630	hi	0.33 (0.04)	0.02	93
105	630	lo	1.36 (0.05)	0.06	99
105	630	hi	0.67 (0.06)	0.09	96
106	630	lo	0.83 (0.08)	-0.08	95
106	630	hi	0.51 (0.08)	0.06	90
101	560	lo	1.48 (0.11)	0.18	98
101	560	hi	0.94 (0.21)	0.06	80
102	560	lo	0.86 (0.06)	0.07	98
102	560	hi	0.53 (0.10)	0.04	84
103	560	lo	1.21 (0.12)	0.07	96
103	560	hi	0.63 (0.15)	0.03	77
104	560	lo	0.98 (0.06)	0.08	98
104	560	hi	0.36 (0.04)	0.04	95
105	560	lo	1.30 (0.11)	0.11	97
105	560	hi	0.77 (0.09)	0.21	94
106	560	lo	1.04 (0.06)	0.11	98
106	560	hi	0.76 (0.18)	0.00	78

alternative. The group mean for Part 1 was 1.30, and that for Part 2 (low-other) was 1.20. However, in comparisons between Part 1 and the conditions in Part 2 with a higher reinforcer rate on the 600-nm alternative, all 6 birds showed lower sensitivity in Part 2 (sign test, *p* < .05). The group mean for Part 2 (high-other) was 0.59. There were no reliable differences between Parts 1 and 2 on bias measures.

Fig. 4. Part 3. Individual birds' sensitivity values (*a*) resulting from least squares linear regression fits between log response ratios and log obtained reinforcer ratios for pairwise combinations of schedules when the ratio of the arranged reinforcer rate on the third alternative divided by the sum of the arranged reinforcer rates on the pair of analyzed alternatives was less than .5 (low-other; B-Lo) or greater than .5 (high-other; B-Hi).

Part 3

Part 3 consisted of Conditions 20 to 31, and was identical to Part 2 in all respects except one: The third alternative was signaled by 623 nm rather than by 600 nm. Condition 19 (in which 620 nm was arranged as the third alternative) was not used, because 620 nm was found not to be sufficiently indiscriminable from 630 nm. Thus, from Condition 20, a 623-nm color was arranged to signal the third alternative. The data were analyzed in the same way as in Part 2. The slopes of the best fitting lines for the response-allocation data are shown in Figure 4 for all subjects; more detail on the fits is given in Table 3. The pattern of results was similar to that in Part 2: When the reinforcer rate on the third alternative was high,

pairwise sensitivity values were lower than when the reinforcer rate on the third alternative was low. It was also the case, as we would expect on the basis of stimulus discriminability, that the sensitivity values for 560 nm versus 630 nm and 560 nm versus 623 nm were higher than those for 630 nm versus 623 nm, when the reinforcer rate on the third alternative was high or low.

As can be seen from Figure 4 and Table 3, sensitivity values were greater for low-other reinforcer rates than for high-other reinforcer rates for all 6 subjects for the 560-nm versus 630-nm and the 560-nm versus 623-nm alternatives. For the 630-nm versus 623-nm alternatives, response sensitivities differed in the same direction for 5 of the 6 subjects.

Bias measures. Table 3 suggests a further interesting result: There appears to be a considerable bias towards responding to the 560-nm stimulus in the 560-nm versus 630-nm choice when the 623-nm alternative provided a lower reinforcer rate, and a bias in the opposite direction when the 623-nm alternative provided a higher reinforcer rate. Bias measures are shown for each individual subject in Figure 5. In the choice between the 560-nm and 630-nm stimuli, response measures were biased to the 560-nm alternative when the 623-nm alternative provided a low reinforcer rate and to the 630-nm alternative when the 623-nm alternative provided a high reinforcer rate. A similar pattern of results, but at lower absolute values and with a reversal for Bird 102, can be seen in the choice between 560 nm and 623 nm according to whether the 630-nm alternative had a higher or lower reinforcer rate. For the choice between 630 nm and 623 nm, there seemed to be no consistent pattern. No such biases were found in Part 2. An explanation of these bias findings will be offered in the Discussion.

Comparison of Parts 2 and 3

In the choice between 560 nm and 630 nm, for both high and low 623-nm reinforcer rates, sensitivity values for every bird in Part 3 were lower than in Part 2, in which the third alternative was signaled by 600 nm ($p < .05$, sign test). Group means were 0.59 and 1.20 for high-other and low-other, respectively, in Part 2 and were 0.43 and 0.90 for high-other and low-other, respectively, in Part 3. As expected, it was also the case that the choice between 630 nm and 623 nm (Part 3) showed

Table 3

The results of linear regressions of pairwise log response ratios against log obtained reinforcer ratios for Part 3 of the experiment. The fits were differentiated according to whether the arranged third alternative reinforcer rate was greater (hi) or lower (lo) than the sum of the arranged rates of the schedules in question. Shown are the slopes of the regression lines (a in Equation 1), the standard error (SE) of the slope estimate, the constant intercept of the line (the logarithm of c in Equation 1), and the percentage of the data variance accounted for (%VAC).

Bird	Third alternative (nm)	Lo/hi	Slope (SE)	Constant	%VAC
101	623	lo	1.17 (0.10)	0.49	97
101	623	hi	0.63 (0.11)	-0.31	89
102	623	lo	0.66 (0.06)	0.20	97
102	623	hi	0.32 (0.11)	-0.25	66
103	623	lo	1.08 (0.08)	0.10	98
103	623	hi	0.41 (0.08)	-0.17	87
104	623	lo	0.53 (0.08)	0.22	93
104	623	hi	0.20 (0.05)	-0.19	83
105	623	lo	1.21 (0.12)	0.18	96
105	623	hi	0.59 (0.08)	-0.12	94
106	623	lo	0.74 (0.08)	0.12	96
106	623	hi	0.44 (0.14)	-0.09	70
101	630	lo	1.44 (0.12)	0.23	97
101	630	hi	0.98 (0.09)	-0.02	97
102	630	lo	0.81 (0.08)	-0.07	96
102	630	hi	0.66 (0.05)	0.10	98
103	630	lo	0.92 (0.10)	0.06	96
103	630	hi	0.43 (0.14)	-0.24	71
104	630	lo	0.50 (0.03)	0.06	99
104	630	hi	0.24 (0.04)	-0.18	93
105	630	lo	1.03 (0.08)	0.07	98
105	630	hi	0.71 (0.07)	0.03	97
106	630	lo	0.87 (0.14)	0.09	91
106	630	hi	0.59 (0.06)	-0.03	97
101	560	lo	0.51 (0.06)	-0.04	95
101	560	hi	-0.19 (0.15)	0.00	28
102	560	lo	-0.06 (0.04)	-0.06	42
102	560	hi	0.04 (0.02)	-0.05	46
103	560	lo	0.45 (0.03)	-0.01	99
103	560	hi	-0.21 (0.08)	-0.07	65
104	560	lo	0.03 (0.01)	-0.03	44
104	560	hi	0.00 (0.04)	-0.04	0
105	560	lo	0.77 (0.07)	0.02	97
105	560	hi	-0.21 (0.20)	-0.03	21
106	560	lo	0.55 (0.07)	-0.02	94
106	560	hi	-0.20 (0.16)	0.01	27

a lower sensitivity than the choice between 630 nm and 600 nm (Part 2) for both low and high 560-nm reinforcer rates ($ps < .05$, sign test). Group means were -0.13 and 0.38 for high-other and low-other, respectively, in Part 3 and were 0.67 and 1.15 for high-other and low-other, respectively, in Part 2. However, there was no consistent difference in sensitivity in the choice between 560 nm and 600 nm (Part 2) and between 560 nm and 623 nm

Fig. 5. Part 3. Bias values ($\log c$) for individual birds resulting from least squares linear regression fits between $\log$ response ratios and $\log$ obtained reinforcer ratios for pairwise combinations of schedules when the ratio of the arranged reinforcer rate on the third alternative divided by the sum of the arranged reinforcer rates on the pair of analyzed alternatives was less than .5 (low-other; B-Lo) or greater than .5 (high-other; B-Hi). Positive logarithmic values denote a bias toward the first alternative in a pair. Negative bias values denote a bias toward the second alternative in a pair.

(Part 3) for either low or high 630-nm reinforcer rates. Group means were 0.61 and 0.96 for high-other and low-other, respectively, in Part 2 and were 0.60 and 0.93 for high-other and low-other, respectively, in Part 3.

Response measures were more biased towards 560 nm (Figure 5) in Part 3 than in Part 2 for the 560-nm versus 630-nm choice with a lower 623-nm (Part 3) or 600-nm (Part 2) reinforcer rate ($p < .05$, sign test), and more biased towards the 630-nm alternative in Part 3 than in Part 2 ($p < .05$, sign test) on the same choice when there was a high 623-nm

or 600-nm reinforcer rate (see Tables 3 and 4). Performance was more biased towards the 630-nm alternative in Part 2 for the choice between 630 nm and 600 nm than it was in Part 3 for the choice between 630 nm and 623 nm ($p < .05$, sign test) for lower reinforcer rates on the 560-nm alternative. Indeed, these bias values in Part 3 were not significantly different from 0 on a sign test ($p > .05$).

Comparison of Parts 1 and 3

For the choice between the 560-nm and 630-nm alternatives, sensitivity values for both high-other and low-other were lower ($ps < .05$, sign test) for each individual subject in Part 3 than in Part 1 (Figure 1 and Table 3). There were also differences in bias values between Parts 1 and 3. For the low-other reinforcer rate, the intercepts in Part 3 were all higher (more towards the 560-nm alternative) than in Part 1 ($p < .05$, sign test). But for the high-other reinforcer rate, the intercepts in Part 3 were more towards 630 nm ($p < .05$, sign test) than they were in Part 1.

Summary

Consider the 560-nm versus the 630-nm choice of Part 1. In Part 2, a 600-nm alternative was added. When this provided a low reinforcer rate, sensitivity between the 560-nm and 630-nm alternatives was unchanged. When the 600-nm alternative provided a high reinforcer rate, however, sensitivity decreased. In Part 3, a 623-nm stimulus replaced the 600-nm stimulus. Compared with Part 1, sensitivity between the 560-nm and 630-nm alternatives decreased when the 623-nm alternative provided either a low or a high reinforcer rate. In addition, there was a significant bias toward the 560-nm alternative when the 623-nm alternative provided a low reinforcer rate, and there was a significant bias toward the 630-nm alternative when the 623-nm alternative provided a high reinforcer rate.

DISCUSSION

A first, didactic, approach to the present data is to consider what performance might result if pigeons were exposed to the present set of conditions (e.g., Part 3) if two of the discriminative stimuli (623 nm and 630 nm) were completely indiscriminable. Under these

conditions, there would appear to be a two-alternative choice available between 560 nm and a color that we will, for convenience, call v nm. The experimenter, though, would analyze the data as a three-alternative choice. The subject would thus respond equally to the two schedules signaled by v (with $a = 0$ in Equation 1), while the reinforcer rates on these schedules, and between these schedules and that signaled by 560 nm, were varied. The performance would no doubt look like a two-alternative concurrent VI VI schedule from the subject's viewpoint, but what would the performance look like when analyzed by the experimenter? Assuming strict matching (Equation 1 with $a = 1$) on the "apparent" two-alternative concurrent VI VI signaled by 560 nm and v nm, the predicted performance as analyzed by the experimenter would look like the theoretical data shown in Figure 6. This figure was produced using the group average obtained reinforcer rates in Part 3, but assuming that the subject could not discriminate the 623-nm and 630-nm stimuli. Thus, for example, if 80 reinforcers per session were obtained in the presence of 560 nm, 100 in the presence of 623 nm, and 10 in the presence of 630 nm, then because 623 nm and 630 nm were assumed to be indiscriminable, an average of 55 reinforcers per session were assumed to be obtained in each of the components of v . Thus, the predicted response allocation between 560 nm and 623 nm, and between 560 nm and 630 nm, is 80:55; between 623 nm and 630 nm, it is 55:55. When analyzed in the same categorical way as in Figures 3 and 4, the data in Figure 6 show a greater sensitivity to reinforcement for the low-other category than for the high-other category and a much larger negative bias for the high-other than for the low-other category. Thus, all the findings of Part 3, at least in terms of directions of effects if not their quantitative values, can be produced simply by assuming that the experimenter and the subject are approaching the data from differing viewpoints. Both the bias and sensitivity effects, therefore, are due to differences between the obtained reinforcer rates apparent to the subject and those apparent to the experimenter and plotted in an experimental data analysis. Of course, when some of the discriminative stimuli are only partly discriminable, rather than wholly indiscriminable, prediction is much more difficult. How-

Fig. 6. Log predicted response ratios as a function of log obtained reinforcer ratios (as obtained in Part 3) between the 560-nm and 630-nm alternatives when the third alternative is not discriminable from the 630-nm alternative. Please see the text for further explanation.

ever, if Equation 2 is extended appropriately, the data should be describable.

Generalized Matching

The present results join a growing number of reports (Alsop & Elliffe, 1988; Davison, 1988; Logue & Chavarro, 1987) that show that the generalized matching relation (Equation 1; Baum, 1974) is not an adequate theory of choice, because the parameters (notably a , the sensitivity to reinforcement) are affected by variables (signaling stimuli) that should, in theory, not affect them. Indeed, the generalized matching law is silent on what might affect a , implying constancy. Equation 2 (Davison & Jenkins, 1985) was an attempt to account for the same data as the generalized matching relation, and additionally to account for situations in which discriminative stimuli were less than perfectly discriminated. As we will show below, an extended Equation 2 does a good job in describing the present data.

Indifference from Irrelevant Alternatives

The present results have clearly shown that the principle of indifference from irrelevant alternatives, or the constant-ratio rule, is not applicable to three-alternative choice when there is a timeout contingent on changing over between the choices. Rather than arguing against the principle per se, the present results can simply be interpreted as showing that re-

inforcer rates for the third alternative are not irrelevant when punishers (i.e., the timeouts) are present; this is consistent with the results of Davison (1991), who showed that the punishment effect was dependent upon the reinforcer rate in the schedule to which a changeover was made. If the magnitude of the punishment effect on performance under one schedule depends on the reinforcers in alternative schedules, the alternative reinforcer rate is clearly relevant, not irrelevant. Also, as we have argued above, relevance of third alternatives results from the third alternative being signaled by a stimulus that is less than completely discriminable from that signaling one of the analyzed pair of alternatives.

Modeling the Results

The Davison and Jenkins (1985) model was designed to take into account differing discriminabilities between alternatives. The model, for the two-alternative case, uses a parameter (d_r , contingency discriminability) that depends upon the discriminability of the stimuli signaling the alternatives. It is clear that the differentiation of two three-term (stimulus-behavior-reinforcement) contingencies will depend upon the discriminability of the stimuli signaling the alternatives. If the different stimulus settings that support different behavior-reinforcement contingencies are only marginally discriminable, then a reinforcer-rate differential between the settings will not be reflected fully in differential behavior. The Davison-Jenkins model should be able to account for the present results, but there is an immediate problem: This model, as originally stated, cannot predict overmatching (more extreme response allocation than the obtained reinforcer ratios). As pointed out by Davison and Jenkins, the model will account for overmatching if the subtractive model of punishment (de Villiers, 1980; Farley, 1980; Farley & Fantino, 1978) is accepted. With a constant punishment magnitude, w , the model given in Equation 2 becomes

$$\frac{B_1}{B_2} = c \frac{d_r R_1 + R_2 - w}{d_r R_2 + R_1 - w}. \quad (3)$$

Equation 3 should describe the data obtained in Part 1 with a value of d_r that is high, because the stimuli (560 nm and 630 nm) were easily discriminated. The value of w , which depends presumably on the duration of the blackout following changeovers in combination with current and alternative reinforcer rates, should be constant (see below) throughout Part 1, and indeed, throughout the whole experiment.

Equation 3 becomes more difficult when applied to three-alternative choice. It can be approached in this way. For purposes of easily fitting the model, replace d_r with $d_r = p_r / (1 - p_r)$, and multiply through with $(1 - p_r)$, as in Equation 2b of Davison and Jenkins (1985). We will term p_r *relative discriminabilities*. Equation 3 then becomes

$$\frac{B_1}{B_2} = c \frac{p_r R_1 + (1 - p_r) R_2 - w}{p_r R_2 + (1 - p_r) R_1 - w}, \quad (4)$$

which has the better properties of the reinforcers in the numerator and denominator summing to the total number of reinforcers in the situation, $R_1 + R_2$. The smallest value of p_r will be .5 (equivalent to $d_r = 1$, no discrimination), and the greatest value will be 1 (equivalent to $d_r = \infty$, maximal discrimination). It can be seen that of the R_1 reinforcers obtained, p_r of them remain in the numerator (and are allocated to B_1 responding) and $(1 - p_r)$ of them are allocated to B_2 responding. $p_r R_1$ is, of course, $R_1 - (1 - p_r) R_1$. In the three-alternative case, there will be a further loss of R_1 reinforcers to the third alternative, B_3 . Thus, with i, j , and k representing three discriminative stimuli, the appropriate equation for Parts 2 and 3 is Equation 5, shown at the bottom of the page. Equation 5 was fitted to the data on the obtained choice between 560 nm and 630 nm for Parts 1 to 3. In order not to have the fits unduly influenced by extreme B_1/B_2 ratios, the dependent variable used was the relative choice, $B_1/(B_1 + B_2)$, and the predictions were naturally of the same form. Notice that the discriminability (p_{ij}) between two stimuli is symmetrical. The data input into this equation were the reinforcer rates obtained on each alternative in each condition

$$\frac{B_i}{B_k} = \frac{R_i - (1 - p_{ik}) R_i - (1 - p_{ij}) R_i + (1 - p_{ik}) R_k + (1 - p_{ij}) R_j - w}{R_k - (1 - p_{ik}) R_k - (1 - p_{jk}) R_k + (1 - p_{jk}) R_j + (1 - p_{ik}) R_i - w}. \quad (5)$$

Table 4

Parameter values for Equation 5 for each individual subject obtained from the data on the choice between the 560- and 630-nm alternatives in Parts 1 to 3. The value for w , the subtractive-punishment factor, is given as reinforcers per minute.

Subject	Relative discriminabilities (p_i) for each stimulus pair					w	%VAC
	560/630 p_1	560/600 p_2	600/630 p_3	560/623 p_4	623/630 p_5		
101	1.05	0.90	0.86	0.85	0.21	0.048	95
102	0.97	0.81	0.74	0.79	0.33	0.048	93
103	1.06	0.63	0.59	0.68	0.36	0.020	95
104	0.84	0.78	0.75	0.70	0.42	0.243	96
105	1.06	0.71	0.74	0.79	0.53	0.034	96
106	0.98	0.70	0.72	0.77	0.54	0.049	95
<i>M</i>	0.99	0.75	0.73	0.76	0.40	0.075	

for each subject. Taking i and k as performance on the 560-nm and 630-nm alternatives, then in Part 1, R_j was zero. To fit the data from all conditions of the experiment (excluding Condition 19), six parameters are required, which we defined as p_1 (the discriminability between 560 nm and 630 nm) for Parts 1, 2, and 3; p_2 (560 nm vs. 600 nm) and p_3 (600 nm vs. 630 nm) for Part 2; and p_4 (560 nm vs. 623 nm) and p_5 (623 nm vs. 630 nm) for Part 3; and finally, w . The data were fitted to Equation 5 using a Levenberg-Marquardt nonlinear curve-fitting procedure (Sprott, 1991). We expected that the greatest discriminability would be between 560 nm and 630 nm, the second largest between 560 nm and 623 nm, the third and fourth between 560 nm and 600 nm and 600 nm and 630 nm, and the smallest between 623 nm and 630 nm. Table 4 shows the results of these fits and the percentage of data variance accounted for. Given that 30 data points were used in these fits, the ratio of data points to estimated parameter values was 5:1, twice the ratio usually used in research on generalized matching (Equation 1). The parameter estimates should therefore be accurate.

Our expectations were that the discriminability between 560 nm and 630 nm would be the largest in the set, and that the discriminability between 623 nm and 630 nm would be the smallest. Both these predictions were correct for all 6 subjects (Table 4). We also expected that the discriminability between 560 nm and 623 nm would be greater than that between 560 nm and 600 nm, but this was the case for only 3 of the 6 subjects. There will, of course, be some error in the estimation of

the parameters that could obscure the order in the obtained values. This error is best seen in the estimation of the "probabilities" for the 560-nm versus the 630-nm choice, three of which were greater than 1.0. We could have constrained this parameter to an upper limit of 1.0, but it is a better test of the model to leave the estimate unconstrained. Had the estimated values been significantly greater than 1, the model would have been shown to fail. In any event, the parameter estimates were not significantly greater than 1.

The values of w , the constant punishment factor arising from the 3-s blackout after each changeover, appear to be of the right order of magnitude. It may seem to be an unwarranted assumption to take w as constant, particularly because Davison (1991) showed that the punishing effect of timeout on changing over depended on the reinforcer rates of the schedules to be changed to. However, in the present experiment, the subjects could not switch to a selected alternative stimulus and schedule, but rather entered (or reentered) one of the two (Part 1) or three (Parts 2 and 3) alternatives with equal probability. Thus, it is consistent with Davison's results to assume that the average value of reinforcers lost on the changeover would derive from the overall reinforcer rate, which was kept approximately constant throughout the three parts of the experiment. Although it could well be argued that the molar punishment effect, which w measures, should also be a function of the rates of changing over, assuming a constant value for w is the simplest assumption that we can make. Indeed, given that we measured only changeovers from alternatives, it is difficult to take

the analysis of the present data further. Future research will doubtless show whether the constant w assumption is valid.

Modeling behavioral data always involves trying to understand, and maybe quantify, the relation between the experimenter's idealized perception of physical stimuli (e.g., monochromator settings), arranged contingencies, and response requirements (the details of the computer program) and the subject's "perception" of the results of these as its operating environment. The subject's effective environment contains neither the monochromator dial that sets the stimuli nor the computer program. A further requirement is to discover how these "perceived" events affect behavior. Initial research on concurrent schedules always used highly discriminable stimuli to signal the alternatives. Under such conditions, we can assume that the subject's perception of response requirements, stimulus events, and contingencies of reinforcement may well approximate those of the experimenter, and a relatively pure measure of how reinforcer rates affect response ratios can be obtained. We have assumed, like Baum (1974), that these classical data indicate that the pure relation is strict matching (a sensitivity of 1.0). We have also assumed, following de Villiers (1980), Farley (1980), and Farley and Fantino (1978), that punishing changing over between alternatives changes the subject's perception of the payoffs from the alternatives, leading to overmatching. To these well-known effects, we have added (as did J. Miller et al., 1980) a decreased likelihood of the animal being able to discriminate between the stimuli signaling the alternatives. The general model that we offer for the effects of discrimination variation (Equations 4 and 5; Davison & Jenkins, 1985) is one that attempts to describe logically how the subject might perceive the contingencies of reinforcement when stimulus discrimination is less than perfect. Under these conditions, we have assumed that the subject's behavior still strictly matches obtained reinforcers to what the subject "thinks" it obtains, rather than to what the experimenter measures via his or her equipment. We feel that we need to apologize for this behaviorally imprecise language, and we do not mean to imply that a process of thinking in the subject is in any way a useful intervening variable. But surely we must all accept that the experimenter-specified conditions of an experiment

may not, in many, or most, preparations, be the effective independent variables controlling behavior. There are two transfer functions necessary to understand experimental data: that between what the experimenter physically arranges and what the subject receives, and that between what the subject receives and the behavior the subject emits. The model provided here combines both of these. The first transfer function is provided by the relative discriminability measures; the second is provided by strict matching and the subtractive nature of timeout punishment. Obviously the model requires further testing to determine whether its assumptions—for instance, the constancy of discriminability parameters for unchanged physical stimuli in the face of changes in other available stimuli and overall reinforcer rates—are valid.

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APPENDIX

Numbers of responses emitted, seconds spent responding (excluding blackout periods after changeovers), and reinforcers obtained on each alternative. Also shown are the numbers of changeovers from each alternative and the number of training sessions given in each experimental condition. The data are summed over the last five experimental sessions. "X" refers to the alternative that was either absent (Part 1) or signaled by 600 nm (Part 2) or by 623 nm (Part 3).

Bird	Con- di- tion	Responses			Time (s)			Reinforcers			Changeovers			Ses- sions
		560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	
101	1	2,114	2,967	0	5,179	6,043	0	74	81	0	212	236	0	23
	2	9,781	228	0	8,049	1,849	0	176	18	0	106	248	0	21
	3	1,772	13,232	0	2,512	8,148	0	34	161	0	295	152	0	21
	4	14,606	1,517	0	7,651	1,930	0	161	38	0	220	350	0	23
	5	887	18,268	0	1,411	8,027	0	25	174	0	251	111	0	24
	6	3,546	4,775	1,524	3,680	2,883	2,934	45	62	49	334	311	376	22
	7	3,452	6,673	482	2,221	3,766	1,186	85	94	21	277	262	365	23
	8	665	7,764	2,569	1,247	4,621	2,392	17	95	86	351	280	265	20
	9	3,629	1,005	5,663	3,363	1,568	4,062	88	23	81	277	327	313	22
	10	644	398	11,078	1,083	1,096	7,077	21	13	165	285	290	123	20
	11	11,811	387	727	6,275	994	873	165	18	17	142	290	283	23
	12	525	10,199	511	1,148	6,289	845	15	159	23	278	134	285	24
	13	548	1,300	9,460	1,240	2,017	6252	28	32	132	279	310	182	21
	14	9,325	447	617	5,693	1,197	1,157	146	27	27	163	301	292	22
	15	604	10,107	707	1,167	6,272	1,064	35	133	31	304	217	335	20
	16	5,683	3,487	642	3,678	3,219	1,172	105	83	10	286	290	373	28
	17	612	5,533	4,259	1,055	4,437	2,934	16	99	82	305	261	251	26
	18	3,891	809	5,430	3,335	1,524	3,375	94	6	100	225	319	216	21
	19	5,512	1,194	3,988	3,551	1,510	2,866	91	4	105	292	368	268	21
	20	559	5,091	5,030	1,093	3,490	3,638	7	102	91	313	247	274	21
	21	4,116	1,609	3,183	2,938	2,178	2,335	83	10	107	342	449	318	21
	22	5,339	2,324	1,555	3,924	2,389	2,249	90	83	25	335	299	357	23
	23	734	2,815	3,096	1,767	2,813	2,896	26	87	87	364	289	308	20
	24	3,421	1,978	3,156	2,620	2,317	2,617	81	19	100	365	413	322	24
	25	565	1,732	7,381	1,244	2,250	4,541	19	19	162	307	286	137	24
	26	9,485	307	376	5,555	960	879	164	18	18	109	243	268	23
	27	1,564	6,402	2,530	1,648	3,846	2,429	20	158	21	369	208	352	25
	28	1,039	2,266	4,115	1,365	2,167	2,712	42	19	139	469	491	372	23
	29	9,253	462	432	5,066	899	792	129	36	35	225	350	295	28
	30	2,402	3,149	1,914	1,998	2,378	2,190	39	132	29	472	370	509	22
	31	5,691	1,680	666	3,582	1,495	1,192	83	105	12	356	311	413	25
102	1	4,840	3,523	0	4,276	3,356	0	105	95	0	564	562	0	23
	2	9,731	870	0	8,194	1,140	0	179	18	0	212	357	0	21
	3	1,666	8,037	0	2,077	6,603	0	27	165	0	470	337	0	21
	4	10,448	972	0	8,065	1,368	0	155	42	0	308	387	0	23
	5	567	15,510	0	928	8,822	0	21	175	0	330	171	0	24
	6	1,767	2,273	2,248	2,202	2,549	2,807	68	68	55	506	492	533	22
	7	2,909	3,217	1,133	2,630	2,582	1,242	93	83	24	454	457	503	23
	8	877	3,032	1,893	1,097	2,726	1,855	20	96	84	389	337	312	20
	9	3,842	1,217	2,995	3,546	1,366	2,889	81	29	90	304	337	325	22
	10	725	736	3,952	995	943	4,093	17	23	160	335	348	183	20
	11	5,450	459	484	4,546	669	691	181	11	8	123	298	303	23
	12	858	6,522	866	1,049	5,099	1,024	17	165	18	327	191	347	24
	13	1,009	1,790	5,281	1,078	1,487	3,694	31	27	142	399	408	287	21
	14	5,952	1,243	1,125	4,918	1,275	1,110	143	32	25	277	422	372	22
	15	1,001	5,193	1,364	1,273	4,045	1,355	30	132	38	345	232	353	20
	16	3,086	3,402	805	3,138	2,881	1,206	92	97	11	378	342	439	28
	17	644	2,985	2,272	1,038	2,567	2,261	7	102	91	454	379	379	26
	18	2,167	1,355	2,351	2,151	1,172	2,095	97	11	92	424	493	398	21
	19	1,990	1,117	1,828	1,980	1,239	1,719	110	9	81	417	513	477	21
	20	885	2,993	3,096	1,206	2,870	2,914	10	96	94	401	294	309	21
	21	2,509	1,608	1,922	2,492	1,986	1,960	84	12	104	445	520	429	21

APPENDIX (Continued)

Bird	Con- di- tion	Responses			Time (s)			Reinforcers			Changeovers			Ses- sions
		560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	
	22	2,064	1,755	1,696	2,098	2,096	2,097	89	93	18	421	426	504	23
	23	1,785	3,212	2,948	1,707	2,501	2,374	29	100	71	425	322	346	20
	24	3,002	2,499	2,485	2,601	2,408	2,223	106	12	80	342	451	367	24
	25	1,139	3,224	3,994	1,200	2,757	2,880	20	15	165	353	372	204	24
	26	5,192	803	1,103	4,445	981	1,114	172	17	11	124	309	274	23
	27	965	2,637	3,350	1,051	2,157	3,073	19	159	22	399	276	477	25
	28	1,117	2,705	4,087	1,325	2,414	3,161	39	29	132	402	427	347	23
	29	5,484	1,088	1,349	4,720	1,329	1,484	130	34	36	295	399	414	28
	30	1,771	2,561	2,857	2,058	2,451	2,911	32	134	30	446	328	458	22
	31	2,516	1,960	2,180	2,709	1,929	2,465	76	105	16	409	391	478	25
103	1	3,286	2,744	0	4,795	4,569	0	91	93	0	395	408	0	23
	2	11,541	486	0	7,625	1,811	0	180	20	0	170	336	0	21
	3	1,231	10,347	0	2,303	7,739	0	34	155	0	309	178	0	21
	4	8,509	902	0	6,523	2,088	0	173	27	0	176	328	0	23
	5	691	10,807	0	1,841	7,725	0	18	174	0	297	141	0	24
	6	2,213	2,471	1,504	4,080	3,601	2,845	60	47	54	200	236	195	22
	7	4,292	3,130	1,010	3,994	2,877	1,872	88	80	27	388	359	366	23
	8	1,172	2,972	2,288	2,306	2,434	2,420	20	89	90	439	335	322	20
	9	2,569	1,192	1,877	2,962	1,762	2,350	76	30	92	378	387	338	22
	10	385	500	7,958	955	922	5,523	17	14	167	265	266	129	20
	11	8,239	517	766	5,964	943	1,158	157	23	20	144	254	263	23
	12	590	9,327	634	1,534	5,561	983	18	154	26	326	153	291	24
	13	1,028	1,262	5,373	2,404	2,365	4,334	29	43	125	298	287	200	21
	14	6,252	688	1,327	4,772	1,580	1,749	136	29	35	189	306	307	22
	15	1,314	4,720	1,193	1,926	3,423	1,674	44	125	31	319	245	357	20
	16	2,493	3,261	820	2,742	2,756	1,394	99	90	11	380	391	441	28
	17	1,001	2,643	2,432	3,023	2,389	2,354	16	99	80	385	318	344	26
	18	2,300	1,188	2,771	2,442	1,621	2,459	106	16	78	376	482	401	21
	19	3,017	1,199	2,682	3,019	1,823	2,417	100	16	83	391	437	390	21
	20	731	2,822	2,573	1,388	2,610	2,188	9	95	96	482	473	408	21
	21	2,520	1,182	2,647	2,774	1,532	2,233	85	12	101	378	425	340	21
	22	3,017	1,680	1,895	2,646	1,899	2,445	86	98	16	429	392	547	23
	23	1,039	2,446	2,611	1,622	2,401	2,348	22	88	90	433	437	396	20
	24	1,441	1,826	2,131	1,745	2,201	2,042	92	22	86	360	446	382	24
	25	786	1,705	6,093	1,353	2,093	4,177	11	24	165	384	359	245	24
	26	7,344	441	535	4,688	835	970	169	14	17	190	328	341	23
	27	499	5,338	2,039	970	3,507	2,037	19	163	18	347	214	340	25
	28	1,146	1,668	2,997	1,522	1,974	2,647	36	45	119	464	445	390	23
	29	4,375	960	1,238	3,192	1,295	1,535	126	35	35	354	457	484	28
	30	1,004	4,099	2,303	1,642	2,792	2,196	28	142	30	410	257	389	22
	31	2,203	2,089	1,164	2,133	1,841	1,629	95	94	11	377	449	505	25
104	1	1,648	1,712	0	3,364	4,092	0	96	99	0	548	615	0	23
	2	8,046	694	0	7,823	1,924	0	175	22	0	117	274	0	21
	3	1,149	6,195	0	2,443	6,352	0	37	163	0	404	256	0	21
	4	6,736	1,006	0	6,683	2,167	0	160	37	0	324	484	0	23
	5	527	5,728	0	1,709	5,829	0	14	186	0	292	121	0	24
	6	1,158	1,458	1,151	2,539	3,292	2,858	48	61	64	411	406	402	22
	7	1,462	1,629	1,029	1,812	1,707	1,486	82	89	25	601	524	637	23
	8	837	1,265	1,163	1,628	1,682	1,569	27	79	93	572	515	546	20
	9	1,701	999	1,524	1,854	1,568	1,598	86	24	90	584	565	542	22
	10	520	514	5,072	1,005	991	3,649	17	14	169	411	391	273	20
	11	6,662	561	680	4,804	987	1,177	157	15	28	235	357	351	23
	12	688	7,627	610	1,320	5,870	1,060	15	165	20	344	170	299	24
	13	785	1,352	4,170	1,295	1,638	3,143	32	36	132	434	439	393	21
	14	4,455	850	900	3,127	1,124	1,075	139	32	29	333	474	472	22
	15	985	3,243	831	1,522	2,987	1,263	27	145	28	442	329	417	20
	16	1,534	2,077	747	1,714	1,886	1,501	99	92	9	434	396	532	28

APPENDIX (Continued)

Bird	Con- di- tion	Responses			Time (s)			Reinforcers			Changeovers			Ses- sions
		560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	
105	17	539	1,957	1,451	1,415	2,332	1,735	8	95	97	528	469	416	26
	18	2,000	876	1,599	2,276	1,534	1,867	102	10	88	408	511	428	21
	19	1,501	1,090	1,313	1,610	1,695	1,498	100	10	90	490	609	517	21
	20	731	1,993	2,351	1,338	1,979	2,338	7	96	97	534	440	472	21
	21	1,425	1,407	1,478	1,599	1,918	1,685	84	10	102	473	556	462	21
	22	1,849	1,431	1,455	1,892	1,595	1,862	97	97	6	475	477	607	23
	23	1,052	1,834	1,821	1,588	1,936	1,910	21	108	71	491	384	418	20
	24	1,665	1,614	1,669	1,780	1,803	1,746	92	15	93	440	486	446	24
	25	937	1,979	2,245	1,618	2,079	1,737	16	18	166	507	480	307	24
	26	4,085	573	794	3,569	1,371	1,335	169	21	10	176	344	336	23
	27	1,021	1,624	1,606	1,552	1,593	2,083	21	164	15	655	466	605	25
	28	1,264	2,020	2,220	1,486	2,202	1,920	37	34	129	568	547	401	23
	29	2,664	925	982	2,481	1,311	1,336	143	30	27	414	531	530	28
	30	1,195	1,485	1,556	2,240	2,024	2,557	30	138	30	436	338	452	22
	31	No data												
	1	1,910	1,725	0	3,975	3,894	0	106	94	0	457	448	0	23
	2	5,863	384	0	7,958	1,375	0	183	17	0	176	323	0	21
	3	699	3,385	0	2,388	5,682	0	42	158	0	417	299	0	21
	4	5,620	679	0	6,329	1,978	0	156	41	0	263	392	0	23
	5	356	8,223	0	1,512	7,773	0	20	173	0	380	210	0	24
	6	1,118	1,316	693	3,026	3,452	2,480	69	62	60	336	350	332	22
	7	1,109	2,150	381	2,200	3,078	1,606	87	92	21	366	356	413	23
	8	628	1,524	928	1,986	2,637	2,086	28	86	86	459	408	394	20
	9	1,425	723	922	2,605	1,578	2,130	104	14	82	504	519	510	22
	10	355	354	4,815	1,010	1,127	4,227	22	20	158	378	404	238	20
	11	5,323	334	319	5,696	1,011	949	155	19	24	163	338	298	23
	12	337	4,329	433	1,178	4,255	1,307	19	159	22	322	171	381	24
	13	323	405	2,331	1,885	1,827	3,908	29	31	140	349	359	261	21
	14	1,996	559	370	4,345	2,036	1,350	127	40	33	263	403	342	22
	15	296	2,798	220	1,812	5,281	1,243	30	136	32	379	284	345	20
	16	761	1,195	154	2,566	3,103	1,135	86	96	12	454	469	516	28
	17	229	1,119	966	1,384	2,053	2,068	8	101	91	623	503	501	26
	18	1,445	218	1,626	2,315	1,439	2,379	85	7	108	394	473	393	21
	19	1,361	218	965	2,660	1,595	2,132	95	7	88	482	655	527	21
	20	257	1,093	1,056	1,529	2,469	2,510	8	96	93	546	448	441	21
	21	1,144	412	1,085	2,877	2,002	2,833	81	13	100	387	420	394	21
	22	1,048	848	442	2,944	2,757	2,230	72	104	20	463	396	461	23
	23	397	1,603	1,375	2,033	3,380	3,197	18	99	77	404	296	318	20
	24	1,326	578	924	2,923	2,203	2,721	86	18	88	403	464	424	24
	25	523	557	1,932	1,659	2,263	3,379	32	17	151	373	408	252	24
	26	3,385	169	253	5,220	1,095	1,424	170	15	12	285	390	417	23
	27	601	5,722	578	1,704	4,518	1,937	26	145	22	408	231	425	25
	28	483	937	3,104	1,695	2,363	3,024	29	28	143	436	415	300	23
	29	5,015	570	644	4,604	1,561	1,689	132	37	27	294	345	369	28
	30	1,133	2,293	976	1,966	2,626	2,326	39	126	35	424	307	416	22
	31	2,642	1,454	549	2,932	2,058	1,532	94	90	16	378	388	451	25
106	1	2,305	2,556	0	3,800	4,917	0	124	76	0	375	451	0	23
	2	7,014	257	0	7,751	1,039	0	184	16	0	100	282	0	21
	3	1,042	6,731	0	2,557	7,686	0	45	149	0	342	203	0	21
	4	4,279	551	0	6,161	2,188	0	157	43	0	385	571	0	23
	5	327	5,625	0	1,235	7,751	0	16	182	0	263	112	0	24
	6	411	778	439	2,195	3,624	4,786	28	49	38	239	231	219	22
	7	1,067	1,541	677	2,555	3,127	4,437	69	69	19	241	250	320	23
	8	623	1,601	1,344	2,605	3,214	3,554	15	94	85	328	208	234	20
	9	1,324	449	1,169	3,492	2,038	4,101	85	17	78	232	319	228	22
	10	389	468	4,682	1,746	1,857	6,699	15	15	146	235	225	98	20
	11	4,222	240	813	4,173	1,426	1,649	173	12	15	91	268	263	23

APPENDIX (*Continued*)

Bird	Con- di- tion	Responses			Time (s)			Reinforcers			Changeovers			Ses- sions
		560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	560 nm	630 nm	X nm	
12		483	5,192	414	1,714	6,160	1,649	25	149	15	231	107	262	24
13		746	843	2,327	2,737	3,687	3,965	25	24	108	288	260	174	21
14		3,404	707	1,239	4,384	2,225	2,856	130	21	32	173	280	281	22
15		813	2,840	668	2,350	4,538	2,013	31	119	49	285	174	278	20
16		1,257	1,524	309	3,000	4,308	2,530	94	65	16	223	281	288	28
17		548	1,800	1,527	2,492	3,547	3,496	9	91	85	313	244	237	26
18		1,170	409	1,501	3,127	2,316	3,967	97	10	82	206	271	251	21
19		1,703	379	1,326	3,880	3,121	3,304	76	12	71	218	284	241	21
20		368	1,179	1,446	3,878	2,661	3,200	10	81	80	298	214	194	21
21		1,706	820	1,427	3,287	2,932	2,616	83	12	98	279	373	235	21
22		1,718	1,054	859	2,831	2,776	3,142	86	84	25	317	339	388	23
23		626	1,106	1,265	2,764	2,971	2,897	20	90	83	427	295	292	20
24		853	401	522	2,366	2,856	3,241	73	24	84	304	355	291	24
25		398	930	2,598	2,179	3,907	3,187	13	9	153	236	269	134	24
26		3,082	314	485	4,176	1,807	1,800	179	7	14	119	312	304	23
27		726	4,024	957	1,716	4,172	4,186	12	158	14	269	116	266	25
28		641	924	3,060	1,838	2,852	4,202	31	38	117	250	238	195	23
29		4,419	675	571	5,447	1,558	1,395	135	30	33	217	362	322	28
30		1,033	2,000	907	2,702	3,286	4,212	44	119	21	237	173	275	22
31		1,322	1,224	441	3,966	3,261	3,525	56	66	10	147	182	208	25