ON THE EFFECTS OF FOOD DEPRIVATION AND COMPONENT REINFORCER RATES ON MULTIPLE-SCHEDULE PERFORMANCE

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Six pigeons were used to investigate the effects of varying body weight and component reinforcer rates in two-component multiple variable-interval variable-interval schedules. In Parts 1 and 3 of the experiment, unequal component reinforcer rates were arranged, and body weights were respectively increased and decreased. At 80% ad lib weight, response-rate ratios were closer to unity than reinforcer-rate ratios, but at 100% or more of ad lib weight, response-rate ratios generally equaled reinforcer-rate ratios. In Part 2, component reinforcer-rate ratios were varied over five conditions with the subjects maintained at 100% or more of their ad lib weights, and response-rate ratios matched reinforcer-rate ratios. The data thus support the empirical finding that response allocation in multiple schedules is a function of deprivation. Although this qualitative result is predicted by three models of multiple-schedule performance, only a model that assumes no direct component interaction adequately describes the data.

Key words: multiple schedules, variable-interval schedules, sensitivity to reinforcement, food deprivation, pigeons

Herrnstein (1970) offered the following equation to describe the relationship between response and reinforcer rates in components of multiple VI schedules:

$$B_1 = \frac{kR_1}{R_1 + mR_2 + R_o} \quad (1)$$

B and R refer to response and reinforcer rates, k is the maximum response rate, and m is an interaction parameter that ranges from zero when there is no interaction between the components to unity when interaction is maximal. R_o measures the reinforcer rate for behavior not measured by the experimenter. The equation predicts that when R_o becomes a relatively larger part of the denominator (and the scheduled reinforcer becomes relatively smaller), the response rate will drop. Equation 1 may be written for B_2 also, and thus the ratio of response rates in the two components is given by:

$$\frac{B_1}{B_2} = \frac{R_1}{R_2} \cdot \frac{R_2 + mR_1 + R_o}{R_1 + mR_2 + R_o} \quad (2)$$

As Herrnstein and Loveland (1974) pointed out, when R_o becomes larger relative to R_1 and R_2 , Equation 2 predicts a movement toward an equality of response and reinforcer ratios. This, Herrnstein and Loveland suggested, would occur when the subject was made less deprived of the reinforcers delivered as R_1 and R_2 . In their experiment, Herrnstein and Loveland maintained constant but different schedules in the two components of a multiple VI VI schedule. They found that as deprivation was decreased, the difference between relative response and reinforcer rates decreased. At minimum deprivation (maximum body weight) the difference was zero, that is, response-rate and reinforcer-rate ratios were equal.

However, Herrnstein and Loveland's (1974) result does not necessarily entitle us to conclude that strict matching (an equality of response- and reinforcer-rate ratios for all reinforcer-rate ratios) occurs under no deprivation, because no reinforcer-ratio changes were made in the experiment. For example, Charman and Davison (1982) showed that the equality of response- and reinforcer-rate ratios in short-component multiple VI VI schedules did not imply matching. Charman and Davison ob-

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tained the same short-component effect as reported by Shimp and Wheatley (1971) and by Todorov (1972). In all three studies, an approach to the equality of response- and reinforcer-rate ratios was obtained as component durations were reduced. However, when Charman and Davison reversed reinforcer schedules in the short components, preference did not completely reverse. Rather, postreversal response-rate ratios were closer to indifference. A parametric manipulation of reinforcer ratios in short components gave the same behavior changes as were found in long components (considerable undermatching). Likewise, it is possible that Herrnstein and Loveland's results did not indicate a movement toward matching under decreased deprivation as no parametric data were reported to support such an interpretation. The present experiment was designed first to replicate Herrnstein and Loveland's finding, and second, while the birds were maintained at maximum body weights, to carry out a parametric variation of component reinforcer ratios to determine whether systematic matching occurred.

Herrnstein's (1970) quantitative description of performance on multiple VI schedules (Equations 1 and 2) has recently been challenged on a number of grounds. It does not adequately deal with behavioral contrast, absolute response-rate changes when component durations are decreased, nor the effects of alternate reinforcer sources on contrast. The logical consistency of Herrnstein's approach to multiple-schedule performance has also been questioned (see reviews by McLean & White, 1983, and Williams, 1983). Both Williams and McLean and White have provided alternate quantitative expressions. Williams' equation for absolute response rates is:

$$B_1 = \frac{kR_1}{\frac{R_1 + mR_2}{1 + m} + R_o}, \quad (3)$$

where k and m are the same as in Equation 1. This equation may be rearranged to give:

$$B_1 = \frac{k'R_1}{R_1 + mR_2 + R_o'}, \quad (4)$$

where $k' = k(1 + m)$ and $R_o' = R_o(1 + m)$. Thus, the expression for the ratio of response rates is:

$$\frac{B_1}{B_2} = \frac{R_1}{R_2} \cdot \frac{R_2 + mR_1 + R_o'}{R_1 + mR_2 + R_o'}. \quad (5)$$

The similarity between Williams' approach and that taken by Herrnstein (1970) can easily be seen by comparing Equations 1 and 4, and 2 and 5.

McLean and White (1983) took a very different approach. They assumed that the response rates in each multiple-schedule component were a function of only the reinforcer rates in that component, and thus that no explicit component-interaction parameter (m) was necessary. They also took a generalized, rather than a strict, matching approach and added both sensitivity to reinforcer rate (a) and bias (b) (Baum, 1974) to their basic equation:

$$B_1 = \frac{kR_1^a}{R_1^a + bR_{o1}^a}, \quad (6)$$

where R_{o1} is the extraneous or alternate reinforcer rate in Component 1. Thus, the response-rate ratio is given by:

$$\frac{B_1}{B_2} = \left(\frac{R_1}{R_2}\right)^a \cdot \frac{R_2^a + bR_{o2}^a}{R_1^a + bR_{o1}^a}. \quad (7)$$

If, as suggested by Herrnstein and Loveland (1974), decreasing food deprivation decreases the value of the food reinforcer rates (R_1, R_2), then all three models make qualitatively similar predictions regarding deprivation effects. When deprivation is severe, response-rate ratios will change little with component reinforcer-rate ratios. But when deprivation is low or absent, response- and reinforcer-rate ratios will tend to change equal amounts (strict matching) in the Herrnstein and the Williams models, and, because of the sensitivity to reinforcement parameter a , with a little less sensitivity in the McLean and White models. The quantitative predictions of the models are, however, different, and the present data may help choose among them.

METHOD

Subjects

The six homing pigeons, numbered 151 to 156, had previously served in studies of component duration in multiple VI VI schedules (Charman & Davison, 1982). Water and grit were always available in their home cages.

Birds were fed mixed grain and pellets after each training session to maintain the designated weight, and data were used if the birds were within 15 g of this weight.

Apparatus

The sound-attenuated experimental chamber, in which noise was masked by an exhaust fan, was situated remotely from solid-state control equipment. The three keys were translucent, 2 cm in diameter, 9 cm apart, and 26 cm from the grid floor. Each key could be illuminated by red or green lights, and no further illumination was provided in the chamber. A hopper containing wheat was situated below the center key and 9 cm from the grid floor.

Procedure

As all six birds had extensive histories of responding on multiple schedules, no key-peck or schedule training was necessary and they were placed directly on the first experimental condition (Table 1). The two components of the multiple VI VI schedule were signaled by the color (red or green) of the center key, and all reinforcers were obtained for pecks on that key. During reinforcement the key was darkened, the hopper was raised for 3 sec, and the wheat was illuminated. The side keys remained dark and inoperative throughout the experiment. Each component was presented 11 times per session, which began and ended in blackout. Component durations were 120 sec. The schedules and the body weights arranged in each condition are shown in Table 1.

Training continued on each experimental condition until all birds had met a stability criterion. The criterion required that the median relative number of responses emitted in the red component over five sessions differed by not more than .05 from the median of the immediately preceding five sessions. When all birds had met this criterion five, not necessarily consecutive, times, the experimental contingencies were changed for all birds. Each schedule comprised intervals randomized from the first 12 terms of an arithmetic progression in which the smallest interval was one twelfth the mean interval.

In the first part of the experiment, the reinforcement schedules were VI 90-sec in the red

component and VI 30-sec in the green component. Over five experimental conditions (Table 1), we raised the birds' body weights from 80% of free-feeding weight to 100%. For birds that could maintain body weights higher than the designated 100% values, the weights were then progressively increased to 105%, 110%, and even to 115% (Bird 152) of their free-feeding weights. The last five days of stable data at maximum weights are represented in Condition 6 (Table 1). Some birds' weights initially rose above 100% in Condition 6 and then settled at approximately 100%, although Bird 152's weight continued to rise. All birds continued with daily experimental sessions throughout these changes. The number of sessions training (Table 1) in Condition 6 includes all sessions after Condition 5 while maximum body weights stabilized. The weights of Birds 151, 152, and 154 sometimes varied markedly because at high weights they often laid eggs.

In the second part of the experiment (Conditions 6 to 10), the birds were maintained at their maximum body weights, and the reinforcer rates in the two components were varied over five experimental conditions (Table 1). In the third part of the experiment (Conditions 10 to 15), we reduced the birds' body weights from maximum to 80% ad lib over six experimental conditions. In this part of the

Table 1

Sequence of experimental conditions, and number of sessions training under each condition. Body weight is given as the percentage of the initial free-feeding weight, and schedule values are in seconds. Both components were 2 min in duration.

Condition	VI Schedules		Percentage	Sessions
	Red	Green	Body Weight	
1	90	30	80	23
2	90	30	85	21
3	90	30	90	20
4	90	30	95	19
5	90	30	100	23
6	90	30	max	54
7	30	90	max	35
8	45	45	max	24
9	135	27	max	25
10	27	135	max	51
11	27	135	100	25
12	27	135	95	18
13	27	135	90	16
14	27	135	85	17
15	27	135	80	16

experiment, the reinforcement schedules were VI 27-sec in the red component and VI 135-sec in the green component.

RESULTS

Figure 1 shows the relative rates of responding (response rate in the red component divided by the sum of the rates in the two components) in Conditions 1 to 6 calculated from the mean data given in Appendix 1. Over Conditions 1 to 6, when the schedules in the red and green components were respectively VI 90-sec and VI 30-sec (an arranged relative reinforcer rate of .25) and body weights were increased from 80% ad lib to maximum, the mean relative response rate to the red key decreased from .40 (SD .05) to .21 (SD .08). A nonparametric trend test (Ferguson, 1965) showed that the trend toward more extreme relative response rates (more different from .5) as deprivation decreased was significant ($N =$

6 birds, $k = 5$ conditions, $z = 1.9$, $p < .05$). In Conditions 10 to 15 (Figure 2), when the schedules were VI 27-sec and VI-135 sec (relative reinforcer rate .83) and body weights were reduced from maximum to 80% ad lib, the average relative response rate fell from .87 (SD .06) to .65 (SD .09). Again, there was a significant trend for relative response rate to become more extreme at higher body weights ($N = 6$ birds, $k = 5$ conditions, $z = 2.7$, $p < .05$).

Between these two parts of the experiment, when the birds were maintained at maximum body weight and the reinforcer schedules were varied over five experimental conditions (6 to 10), the sensitivity of the behavior distribution to the distribution of reinforcers between the two components remained high. For this analysis, data from each of the last five sessions of each condition at maximum obtained body

Fig. 1. Part 1, Conditions 1 to 6. The relative rates of responding in the red component (red response rates divided by the sum of the response rates in the two components) as a function of percent ad lib body weight. The schedules were multiple VI 90-sec VI 30-sec. The data are means of the last five sessions of each condition.

Fig. 2. Part 3, Conditions 10 to 15. The relative rates of responding in the red component (red response rate divided by the sum of the response rates in the two components) as a function of percent ad lib body weight. The schedules were multiple VI 27-sec VI 135-sec. The data are means of the last five sessions of each condition.

weights were used. These data are given in Appendix 2 and include sessional data from Conditions 6 and 10. (Mean data [Appendix 1] from Conditions 6 and 10 were also used in Figures 1, 2, 4, and 5 in the analysis of Parts 1 and 3 of this experiment.) The analysis of the data from Conditions 6 to 10 used the generalized matching law (Baum, 1974; Charman & Davison, 1982). This is written:

$$\frac{B_1}{B_2} = c \left(\frac{R_1}{R_2} \right)^a, \quad (8)$$

where a is the sensitivity of response-rate ratios to reinforcer-rate ratios, and c measures bias between the components. When transformed logarithmically, Equation 8 is linear with a slope of a and an intercept of $\log c$. Strict matching is the case in which $a = 1$ and $\log c = 0$.

Figure 3 shows log response-rate ratios as a function of the obtained log reinforcer-rate ratios (Equation 1) for each bird. Straight lines were fitted by the method of least squares and the equations of these lines together with the standard deviations of the slopes and intercepts are shown on the graph. Data were plotted for each of the last five sessions. In Condition 10, when the schedules in the red and green components were respectively VI 27-sec and VI 135-sec, Bird 156 did not always respond in the green component. Performance in the last five sessions of that condition for this bird was averaged and the mean is shown on the graph as a square. Mean sensitivity of response-rate ratios to reinforcer-rate ratios for the six birds was .97 and ranged from .64 (SD .11, Bird 156) to 1.28 (SD .12, Bird 155). The a values for Birds 154 and 156 were more than two standard deviations below 1, but the estimate for Bird 155 was more than two standard deviations greater than 1. None of the estimates of bias ($\log c$ in Equation 8) were more than two standard deviations from zero.

The numbers of responses emitted per minute in each component in Conditions 1 to 6, and in Conditions 10 to 15, are shown in Figures 4 and 5. The decrease in response rate in both components with decreasing deprivation is clearly evident in both sets of data. When the schedules were multiple VI 90-sec VI 30-sec, the fall in mean responses per minute in the red (VI 90-sec) component was from 34 to 7, and in the green (VI 30-sec) component from

51 to 20. When the schedules were VI 27-sec in the red component and VI 135-sec in the green component, the mean responses per minute for the six birds fell respectively in the two components from 51 to 15, and from 31 to 3.

DISCUSSION

Parts 1 and 3 of this experiment constituted a direct replication of Herrnstein and Loveland's (1974) experiment. In Part 1, absolute response rates fell as deprivation was decreased and body weight rose. Again, in Part 3, when we reversed the procedure and increased deprivation, absolute response rates rose as body weight fell. Relative response rates tended toward equality with relative reinforcer rates as deprivation was reduced, and moved away from the strict matching relation as deprivation was once more increased. These results are all predicted by the three models of multiple-schedule performance discussed in the introduction.

In Part 2, we extended this finding and showed that, unlike the short-component duration effect (Charman & Davison, 1982), the increase in sensitivity to reinforcer ratios under decreased deprivation withstood a wide variation of the component-reinforcer ratios.

It is difficult to check quantitatively the accuracy of predictions from Herrnstein's (1970), McLean and White's (1983), and Williams' (1983) models, as the functions relating R_o to deprivation have not been directly specified. However, for Equation 2 (Herrnstein's model), if we assume that m and R_o are constant between the two experimental conditions at each body weight in Parts 1 and 3, the values of these parameters may be algebraically estimated. Equation 2 should apply to each component in each pair of conditions, and thus m and R_o for each deprivation level can be obtained using simultaneous equations. To do this, we applied Equation 2 to the performance at each deprivation level in the ascending and descending (subscripts a and d) body-weight conditions. Thus,

$$\frac{B_{1a}}{B_{2a}} = \frac{R_{1a}}{R_{2a}} \cdot \frac{R_{2a} + mR_{1a} + R_o}{R_{1a} + mR_{2a} + R_o}, \text{ and}$$

$$\frac{B_{1d}}{B_{2d}} = \frac{R_{1d}}{R_{2d}} \cdot \frac{R_{2d} + mR_{1d} + R_o}{R_{1d} + mR_{2d} + R_o},$$

Fig. 3. Part 2, Conditions 6 to 10. The logarithm of the ratio of response rates in the red and green components as a function of the logarithm of the obtained reinforcer rates. The data are for each of the last five sessions of each condition. Data points sometimes overlay each other. The square displayed in the data for Bird 156 is the mean of the last five sessions for that condition (see text). The data for each bird are displaced downward from those of the previous bird by 1.5 log units, and crosses show the origin for each bird's data. For each bird, the least-squares line, its equation, and the standard deviation of the slope and intercept are shown.

Fig. 4. Part 1, Conditions 1 to 6. The number of responses per minute in the red and green components as a function of percent ad lib body weight. The schedules were multiple VI 90-sec VI 30-sec. The data are means of the last five sessions of each condition.

where R_1 and R_2 are the component reinforcer rates measured at each deprivation level. The values of the unknowns, m and R_0 , are found by substitution.

Figure 6 shows the calculated values of m and R_0 for each of the six birds at each level of deprivation. There was no trend in R_0 as deprivation was changed ($N = 6$ birds, $k = 5$ conditions, $z = .3$), nor in the parameter m ($z = .9$). The median data across the six subjects for each level of deprivation are also

Fig. 5. Part 3, Conditions 10 to 15. The number of responses per minute in the red and green components as a function of percent ad lib body weight. The schedules were multiple VI 27-sec VI 135-sec. The data are means of the last five sessions of each condition.

shown in Figure 6. The mean values of these medians were: $m = .95$, and $R_0 = -2.54$ reinforcers per minute. There are two ways in which Equation 2 can predict a trend toward equality of response and reinforcer ratios with decreasing deprivation. First, m may change from a value less than 1 at 80% body weight to a value close to 1 at 100% body weight, an explanation originally given for the short-component multiple-schedule matching effect

Fig. 6. Estimates of the parameters R_o and m obtained using Equation 3 applied simultaneously to pairs of experimental conditions at the same percentage body weight. The data were obtained from means of the last five sessions of each condition. The median values of R_o and m across birds for each level of deprivation are also shown.

(Shimp & Wheatley, 1971; Todorov, 1972; but see Charman & Davison, 1982). The present results indicate that this did not happen and that the degree of interaction between the components remained high and constant. Second, as Herrnstein and Loveland (1974) suggested, R_o might increase relative to R_1 and R_2 as deprivation decreased. Again, this apparently did not occur, and the present data argue against this explanation of the relationship between deprivation and matching, at

least within Herrnstein's (1970) equation. In the present experiment, the value of R_o was always negative. This is a difficult finding to accommodate or even to conceptualize in relation to Equations 1 and 2 (Davison & Hunter, 1976).

It could be argued that allowing both m and R_o to vary in this analysis is contrary to Herrnstein's (1970) approach, which suggests that m should remain constant when deprivation changes. The possibility that a more realistic, and fixed, value of m would produce appropriate changes in R_o with deprivation was briefly assessed. We assumed that $m = .5$ in Equation 2 and solved for R_o for each bird in Conditions 1 to 6 and 10 to 15. Of the 72 estimates of R_o , 61 were negative, and there was no trend toward larger values of R_o with increasing body weight.

The failure to find a change in m or, more particularly, R_o , with body weight also argues against Williams' (1983) model of multiple-schedule performance (Equations 3 to 5). The calculations done above to obtain m and R_o would give m and R_o' in Williams' model. Thus, m and R_o' were constant with deprivation changes, and as $R_o' = R_o(1 + m)$, the value of R_o in Williams' model was also unchanging. Thus, neither Herrnstein's (1970) nor Williams' models can accommodate the present results.

Although there was no trend in the values of m and R_o , there were changes in both these measures over the range of body weights investigated. The data for each bird shown in Figure 6 reveal a mirror-image relation between m and R_o , and the correlation between these values was, in fact, -1 . There is obviously an algebraic tautology in these results, and this analysis suggests that it is the models (Equations 1 to 5) that are at fault, rather than the explanation that Herrnstein and Loveland gave.

McLean and White's (1983) model, with as many as four free parameters, is inherently more difficult to assess quantitatively. In order to do this, we made two simplifying assumptions about the parameters of Equation 6 at each body weight: First, that a in Equations 6 and 7 was 1.0; and second, that the rate of extraneous reinforcers was the same in the two components ($R_{o1} = R_{o2}$). With these assumptions, it is evident from Equation 7 that the

measure of R_o must increase relative to R_1 and R_2 when the difference between B_1/B_2 and R_1/R_2 becomes smaller.

This result can be shown another way. Using exactly the same assumptions as above, we estimated k and R_o in Equation 6 at each body weight using the Wilkinson (1961) method for fitting a rectangular hyperbola. The data used were the four obtained response- and reinforcer-rate pairs from the ascending and descending body-weight conditions. The obtained estimates of k and R_o are shown in Table 2 with the standard errors of the parameters and the variance accounted for

Table 2

Obtained estimates of k and R_o (both per minute), with the standard errors of each and the percent variance accounted for by the fitted hyperbola. Body weights are given as the percentage of the ad lib body weight.

Body Weight	k (SE)	R_o (SE)	% VAC
<i>Bird 151</i>			
80	94 (20.6)	.87 (.48)	99
85	68 (11.6)	.73 (.34)	99
90	59 (6.7)	.85 (.24)	100
95	55 (24)	1.00 (.80)	90
100	536 (494)	21.91 (13)	22
<i>Bird 152</i>			
80	57 (7.4)	1.09 (.31)	100
85	59 (16)	1.43 (.87)	99
90	66 (15.7)	2.05 (.87)	99
95	148 (455)	8.71 (24)	81
100	37 (17)	1.74 (1.70)	99
<i>Bird 153</i>			
80	53 (1.8)	.28 (.04)	100
85	49 (7.4)	.18 (.16)	99
90	67 (5.4)	.47 (.13)	100
95	53 (10)	.36 (.25)	98
100	108 (198)	4.50 (14)	97
<i>Bird 154</i>			
80	57 (.9)	.26 (.02)	100
85	63 (2.9)	.23 (.06)	100
90	53 (6.5)	.15 (.12)	99
95	50 (16)	.40 (.46)	95
100	45 (13)	1.02 (.60)	97
<i>Bird 155</i>			
80	87 (8.6)	.70 (.20)	100
85	101 (15)	1.03 (.37)	100
90	91 (27)	.72 (.55)	97
95	107 (3.7)	.98 (.08)	100
100	122 (52)	3.03 (1.5)	97
<i>Bird 156</i>			
80	40 (8.1)	.35 (.31)	98
85	42 (17)	.92 (1.02)	97
90	50 (43)	2.28 (2.60)	86
95	38 (19)	1.09 (1.48)	98
100	19 (6.9)	1.46 (.88)	98

by the hyperbolae. Although estimates were often poor at high body weights, the results were clear: k showed no significant trend ($N = 6$ birds, $k = 5$ conditions, $z = .7$), whereas R_o showed a significant increase with increasing body weight ($z = 3.3$). We therefore reach the interesting conclusion that Herrnstein and Loveland's (1974) explanation (decreasing deprivation increases R_o relative to R_1 and R_2) is the correct explanation of the trend toward multiple-schedule matching under increasing body weights. But the model they used in conjunction with this explanation (Equations 1 & 2) appears incorrect. Like McSweeney (1980), we favor the model suggested by McLean and White (Equations 6 & 7) in which there is no explicit interaction parameter m .

It must be stressed that although we have assumed that R_o was the same in both multiple-schedule components, this may not be the case. Indeed, Herrnstein (1970) discussed the possibility that they could be different, and the research reported by Hinson and Staddon (1978) seems to suggest that multiple-schedule component interactions could occur via the reallocation of "other" behavior, and hence possibly "other" reinforcers, between the components. Like Herrnstein, we note that the model quickly becomes intractable if this is allowed. However, research to determine if, and under what conditions, R_o is reallocated is now important. If R_o is reallocated, even overmatching could occur in multiple VI VI schedules.

Last, we used the generalized matching law power value (a in Equation 8) as a metric to display the degree of matching (Figure 3). It is difficult to judge whether the generalized-matching description of multiple-schedule performance is superior to the McLean and White (1983) approach (Equation 7) as they are almost identical functions when appropriate parameter values have been obtained. It may be that a simple functional relationship between a in Equation 8 and percentage body weight would provide a reasonable description of the effect of deprivation on multiple-schedule response allocation. The problem with such a suggestion, though, is the lack of any convincing mechanism for increasing sensitivity to food reinforcement when food deprivation is decreased. The same mechanism would also have to account for the absence of a de-

privation effect in concurrent VI VI schedule performance (McSweeney, 1975). Thus, an explanation in terms of an effect of deprivation directly on sensitivity to reinforcement appears less appealing than one in terms of increasing levels of R_o in Equation 7.

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APPENDIX 1

Responses per minute and obtained reinforcers per minute in each component and experimental condition. Body weights are given as the percentage of the ad lib body weight. Data are means of the last five days of each condition.

Conditions	Body Weight	Responses/ min		Reinf./min		Conditions	Body Weight	Responses/ min		Reinf./min	
		Red	Green	Red	Green			Red	Green	Red	Green
Bird 151						Bird 154					
1	80	36	74	.7	2.2	1	80	42	51	.7	2.1
2	85	36	54	.7	2.2	2	85	47	59	.7	2.1
3	90	23	41	.7	2.1	3	90	37	48	.7	2.1
4	95	30	46	.7	2.2	4	95	23	34	.7	2.0
5	100	9	25	.6	2.0	5	100	12	26	.7	2.1
6	Max	2	15	.4	1.4	6	Max	10	28	.7	2.0
10	Max	9	1	1.2	.2	10	Max	19	6	2.0	.4
11	100	12	2	1.2	.2	11	100	34	17	2.1	.4
12	95	25	5	2.1	.4	12	95	52	34	2.2	.5
13	90	43	23	2.1	.5	13	90	52	45	2.1	.5
14	85	46	24	2.1	.5	14	85	55	44	2.1	.5
15	80	61	39	2.2	.5	15	80	51	36	2.2	.5
Bird 152						Bird 155					
1	80	24	38	.7	2.1	1	80	42	62	.7	2.2
2	85	20	39	.7	2.2	2	85	38	64	.7	2.2
3	90	18	31	.7	2.1	3	90	53	79	.7	2.2
4	95	8	12	.7	2.0	4	95	44	74	.7	2.2
5	100	10	17	.7	2.0	5	100	25	47	.7	2.0
6	Max	3	8	.5	1.4	6	Max	11	35	.6	1.9
10	Max	15	3	1.8	.4	10	Max	18	2	1.5	.3
11	100	23	9	2.1	.5	11	100	27	4	1.2	.3
12	95	37	12	2.2	.5	12	95	73	37	2.2	.5
13	90	37	12	2.3	.5	13	90	57	27	2.3	.5
14	85	32	14	2.2	.5	14	85	74	35	2.3	.5
15	80	36	14	2.1	.5	15	80	70	36	2.2	.5
Bird 153						Bird 156					
1	80	36	47	.7	2.2	1	80	24	29	.7	2.1
2	85	33	43	.7	2.1	2	85	16	24	.7	2.1
3	90	40	52	.7	2.1	3	90	6	13	.6	1.9
4	95	28	42	.7	2.1	4	95	13	20	.7	2.1
5	100	14	28	.6	2.1	5	100	4	9	.5	1.7
6	Max	10	25	.6	2.0	6	Max	3	8	.4	1.2
10	Max	27	5	2.0	.4	10	Max	2	1	.4	.1
11	100	39	8	2.1	.4	11	100	11	5	1.6	.4
12	95	50	35	2.2	.5	12	95	29	12	2.1	.5
13	90	58	34	2.2	.5	13	90	31	13	2.2	.5
14	85	49	41	2.2	.5	14	85	34	15	2.2	.5
15	80	47	35	2.2	.5	15	80	39	25	2.2	.5

APPENDIX 2

Responses per minute and obtained reinforcers per minute, in the red and green components. Data are for each of the last five days of each condition. Body weights are maximum for each bird.

Conditions	Body Weight	Responses/min		Reinf./min		Conditions	Body Weight	Responses/min		Reinf./min	
		Red	Green	Red	Green			Red	Green	Red	Green
Bird 151						Bird 152 (continued)					
Condition 6						Condition 9					
1	103	3.3	17.6	.50	1.69	1	114	.5	4.3	.15	1.35
2	103	1.7	13.5	.45	1.75	2	116	.5	1.2	.15	.50
3	101	3.7	20.7	.50	1.80	3	113	3.1	15.7	.40	2.20
4	104	0.5	6.8	.15	.40	4	112	1.4	8.2	.30	1.92
5	102	2.8	17.7	.50	1.30	5	108	1.4	6.1	.25	1.24
Condition 7						Condition 10					
1	100	3.0	0.4	.71	.25	1	108	19.5	3.2	1.90	.45
2	101	2.2	0.2	.50	.05	2	106	10.8	2.8	1.81	.40
3	102	10.9	3.1	1.14	.30	3	107	13.4	2.8	1.57	.40
4	100	7.5	1.6	1.47	.30	4	108	18.6	5.4	2.01	.45
5	107	4.8	2.8	.60	.30	5	109	12.8	2.6	1.46	.40
Condition 8						Bird 153					
1	102	7.7	7.3	.97	.97	Condition 6					
2	100	8.2	6.0	1.03	.97	1	100	8.1	27.7	.60	2.08
3	104	5.2	5.7	.71	.66	2	99	5.9	22.7	.65	2.10
4	99	5.1	3.4	1.19	.92	3	100	7.3	23.2	.45	1.86
5	95	2.8	3.3	.40	.35	4	100	20.5	26.7	.71	1.92
Condition 9						5	101	5.8	24.4	.50	2.06
1	101	.7	2.4	.20	.76	Condition 7					
2	104	.1	2.3	.05	.40	1	96	19.6	4.5	1.51	.40
3	101	.8	2.5	.25	1.18	2	96	32.3	9.7	2.09	.66
4	98	1.3	3.9	.05	.45	3	97	25.7	9.5	1.75	.60
5	99	.8	3.2	.15	.50	4	96	31.6	18.8	2.27	.66
Condition 10						5	97	32.5	10.6	2.16	.66
1	98	5.7	1.0	1.68	.30	Condition 8					
2	97	8.4	1.3	.97	.35	1	95	22.2	22.3	1.36	1.35
3	98	4.3	1.2	.60	.15	2	98	29.4	32.6	1.29	1.35
4	98	8.5	2.2	1.02	.15	3	97	34.7	38.8	1.35	1.41
5	97	15.9	1.2	1.62	.25	4	97	34.7	32.5	1.32	1.40
Bird 152						5	97	35.3	25.3	1.41	1.35
Condition 6						Condition 9					
1	114	2.5	7.9	.45	1.30	1	97	6.1	25.6	.40	2.09
2	114	1.9	7.0	.35	1.08	2	96	3.2	24.9	.50	2.10
3	114	1.1	6.1	.40	1.24	3	96	20.3	47.1	.45	2.51
4	116	2.2	5.6	.45	1.14	4	96	16.0	44.6	.40	2.44
5	116	5.2	11.5	.61	2.01	5	98	7.9	37.8	.35	2.19
Condition 7						Condition 10					
1	113	5.3	1.5	1.37	.45	1	100	21.8	2.5	2.18	.35
2	113	7.9	3.6	1.63	.55	2	98	32.4	10.4	2.20	.45
3	116	6.7	1.8	1.50	.50	3	98	26.3	2.9	1.86	.45
4	116	8.1	3.7	1.58	.61	4	98	26.3	4.4	1.79	.30
5	118	10.4	5.2	1.93	.50	5	98	27.2	3.6	2.02	.40
Condition 8						Bird 154					
1	113	10.3	7.5	1.24	1.14	Condition 6					
2	117	6.9	6.0	1.08	1.08	1	104	6.9	34.1	.71	2.09
3	118	11.5	10.7	1.19	1.29	2	102	11.2	34.7	.81	2.04
4	113	10.1	5.0	1.20	1.02	3	105	9.0	23.7	.71	1.64
5	112	7.8	5.5	1.35	1.03	4	108	14.6	24.8	.71	2.16
						5	106	6.8	20.9	.55	1.97

APPENDIX 2 (continued)

Conditions	Body Weight	Responses/min		Reinf./min		Conditions	Body Weight	Responses/min		Reinf./min	
		Red	Green	Red	Green			Red	Green	Red	Green
Bird 154 (continued)						Bird 155 (continued)					
Condition 7						Condition 9					
1	95	16.1	8.2	1.87	.61	1	103	12.7	40.3	.35	2.34
2	96	17.7	11.3	1.85	.66	2	102	.1	1.7	.10	.20
3	98	17.7	6.3	1.92	.61	3	103	.2	1.0	.05	.10
4	100	17.5	6.1	1.98	.55	4	104	9.2	36.1	.50	1.86
5	102	10.6	2.4	1.69	.50	5	105	.4	1.8	.15	.40
Condition 8						Condition 10					
1	97	15.2	16.0	1.25	1.29	1	102	12.4	.6	1.41	.25
2	101	11.2	10.0	1.35	1.27	2	101	31.9	4.0	2.22	.35
3	98	10.8	9.1	1.14	1.19	3	102	4.9	.2	.81	.15
4	99	17.3	14.6	1.46	1.36	4	101	17.0	1.7	1.57	.25
5	100	10.9	7.0	1.14	1.13	5	101	22.6	1.4	1.74	.30
Condition 9						Bird 156					
1	103	2.9	11.5	.40	1.80	Condition 6					
2	103	5.2	17.4	.45	2.03	1	100	7.1	11.1	.45	1.35
3	106	2.3	4.7	.20	1.04	2	102	1.2	4.3	.15	.55
4	106	.4	1.6	.15	.50	3	99	3.3	10.0	.45	1.69
5	116	4.9	12.1	.45	1.96	4	100	4.8	13.0	.61	2.03
Condition 10						5	102	.1	.7	.10	.20
1	100	27.2	11.4	1.93	.45	Condition 7					
2	95	18.7	9.6	1.86	.45	1	100	.2	.3	.15	.05
3	98	17.6	3.2	2.08	.40	2	98	6.2	4.3	1.02	.35
4	97	15.5	3.6	1.86	.45	3	100	.2	.2	.20	.10
5	98	16.1	3.3	2.03	.40	4	100	6.6	5.1	.61	.30
Bird 155						5	98	6.1	4.3	1.24	.50
Condition 6						Condition 8					
1	105	3.0	27.2	.61	1.70	1	99	.7	.5	.25	.15
2	105	15.6	34.8	.66	1.96	2	98	3.4	2.7	.86	.92
3	105	1.4	19.7	.40	1.93	3	100	.2	.1	.10	.05
4	104	15.0	43.6	.60	1.91	4	99	3.3	2.7	.35	.56
5	105	17.5	47.3	.55	1.93	5	100	.1	.1	.05	.10
Condition 7						Condition 9					
1	103	28.3	16.2	1.75	.60	1	100	1.6	3.8	.15	.40
2	103	13.8	3.7	.85	.45	2	100	1.3	4.7	.25	1.41
3	102	19.9	8.5	1.52	.40	3	100	.4	4.1	.15	1.13
4	103	24.2	6.7	1.52	.45	4	101	.4	.7	.15	.40
5	103	44.2	25.2	1.9	.66	5	100	1.9	3.9	.10	.91
Condition 8						Condition 10					
1	103	38.3	34.4	1.36	1.31	1	102	.3	0	.20	0
2	103	22.0	18.1	1.30	1.19	2	102	.1	0	0	0
3	102	16.3	15.1	1.21	1.18	3	99	6.2	2.7	1.51	.35
4	103	17.2	16.2	1.10	1.13	4	102	.2	0	.05	0
5	103	13.6	14.0	1.03	.76	5	100	1.0	.3	.45	.66