

*ON THE EFFECTS OF COMPONENT DURATIONS AND
COMPONENT REINFORCEMENT RATES IN
MULTIPLE SCHEDULES*

LESLE CHARMAN AND MICHAEL DAVISON

UNIVERSITY OF AUCKLAND, NEW ZEALAND

Four experiments, each using the same six pigeons, investigated the effects of varying component durations and component reinforcement rates in multiple variable-interval schedules. Experiment 1 used unequal component durations in which one component was five times the duration of the other, and the shorter component was varied over conditions from 120 seconds to 5 seconds. The schedules were varied over five values for each pair of component durations. Sensitivity to reinforcement rate changes was the same at all component durations. In Experiment 2, both component durations were 5 seconds, and the schedules were again varied using both one and two response keys. Sensitivity to reinforcement was not different from the values found in Experiment 1. In Experiment 3, various manipulations, including body-weight changes, reinforcer duration changes, blackouts, hopper lights correlated with keylights, and overall reinforcement rate changes were carried out. No reliable increase in reinforcement sensitivity resulted from any manipulation. Finally, in Experiment 4, reinforcement rates in the two components were kept constant and unequal, and the component durations were varied. Shorter components produced significantly increased response rates normally in the higher reinforcement rate component, but schedule reversals at short component durations eliminated the response rate increases. The effects of component duration on multiple schedule performance cannot be interpreted as changing sensitivity to reinforcement nor to changing bias.

Key words: multiple schedules, component duration, reinforcement rate, reinforcement sensitivity, pecking, pigeons

The generalized matching law (Baum, 1974) provides a convenient description of response allocation as a function of reinforcements obtained in both concurrent and multiple variable-interval (VI) schedules. In logarithmic form, the law states:

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

where P denotes responses, R denotes obtained reinforcements, and the subscripts refer to the two choices or components. The constant a is called sensitivity to reinforcement, and it describes the relation between changes in response and reinforcement ratios. The constant $\log c$ is called bias and describes a con-

stant proportional preference for one choice or component over all experimental conditions. For concurrent VI VI schedules, the value of a typically falls in the range .8 to 1.0 (Baum, 1979; Lobb & Davison, 1975). Lander and Irwin (1968) and Lobb and Davison (1977) showed that performance in multiple VI VI schedules was characterized by considerable undermatching ($a < 1$). Lander and Irwin used 3-min components and suggested that $a = .3$. Lobb and Davison used a procedure in which components terminated in reinforcement (that is, component duration was inversely related to component reinforcement rate) and found an average value of a of .45 (range .12 to .69 over six birds).

Shimp and Wheatley (1971) and Todorov (1972) reported that response distributions between unequal reinforcement rate components of multiple VI VI schedules became more extreme when the equal component durations were decreased from conventional values (2 or 3 min) to 5 or 10 sec. As 5- 10-sec components or durations of responding to a schedule are

The experiments reported here will form part of a doctoral dissertation by Lesle Charman. We thank the University Grants Committee for equipment grants to Michael Davison, and the cooperative of Masters and Doctoral students who helped run the experiments. Lesle Charman also thanks Eric Charman for his support and encouragement. Reprints may be obtained from either author, Department of Psychology, University of Auckland, Private Bag, Auckland, New Zealand.

characteristic of concurrent VI VI schedules, these results were interpreted as showing that response distributions in multiple schedules became closer to response distributions in concurrent schedules when the component durations were of a similar magnitude. The implication is that Equation 1 with $a = .8$ to 1.0 characterizes short-component multiple schedule performance. This interpretation has become widely accepted, but it goes considerably beyond the reported data. An interpretation of matching requires that the component reinforcement schedules are varied to produce a range of relative reinforcement rates. But Shimp and Wheatley reversed schedules between components only twice in 15 conditions, and Todorov carried out no reversals. The data from short components were interpreted as matching because of an approximate equality between relative response and reinforcement rates in those conditions. An alternative explanation could be that there was an increase in bias, $\log c$, with shorter components. The data and discussions provided by Shimp and Wheatley and by Todorov suggest that the most parsimonious interpretation is an increase in a at shorter component durations, but they cannot rule out a change in bias.

The role of component duration in producing a change toward matching in short-component multiple VI VI schedules has not been the subject of detailed research. If a relation exists between concurrent and short-component multiple schedule performances (Killeen, 1972), the relative amount of time spent in the two components should also affect behavior allocation. In concurrent schedules, birds also match quite closely the ratio of time spent in the two components to the ratio of reinforcements obtained in the two components (Baum, 1979). We might, then, expect the closest approximation to matching in multiple VI VI schedules when the component-time ratio equals the component reinforcement ratio. Indeed, Killeen (1972) has shown (but, see our final discussion) that relative response frequencies match relative reinforcement frequencies when components were short and had durations that were proportional to the component reinforcement frequencies. Killeen's procedure allocated time to each multiple schedule component in a similar proportion and duration that the bird would produce on a concurrent

schedule. Thus, the available experimental data suggest multiple schedule matching when components are short and equal in duration, or when they are short and proportional in duration to component reinforcement rates. The questions asked initially in this research were these: does short-component multiple schedule matching occur for any relation between component durations and reinforcement rates (e.g., if relative component durations were inversely related to component reinforcement rates); and does the absolute duration of unequal-duration components affect behavior allocation between components?

Thus, in the first experiment, we kept the ratio of the component durations at 5:1 and varied the absolute values of the durations from 10 min/2 min to 25 sec/5 sec. At each absolute component duration value, we varied the VI schedules in each component over a range from VI 480 sec to VI 120 sec.

EXPERIMENT 1

METHOD

Subjects

Six naive homing pigeons, numbered 151 to 156, were maintained at $80\% \pm 15$ g of their free-feeding body weights. Water and grit were always available in their home cages and supplementary feed of mixed grain was given, when necessary to maintain their body weights, immediately after the daily training sessions.

Apparatus

The sound-attenuated experimental chamber, in which noise was masked by an exhaust fan, was situated remotely from solid-state control equipment. The chamber contained three response keys set on one wall. The keys were translucent and were 2 cm in diameter, 9 cm apart, and 26 cm from the grid floor. Each key could be illuminated by colored lights, and no further illumination was provided in the chamber. Pecks on lighted keys were counted and produced an audible click from a relay in the experimental chamber. Pecks on darkened keys were ineffective. A hopper containing wheat was situated below the center key and 9 cm from the floor. During reinforcement the key was darkened, the hopper was raised for 3 sec, and the grain was illuminated.

Procedure

Each bird was autoshaped to peck a white key and then given a small amount of training to respond to green and red keys on VI schedules. The first condition of the experiment (Table 1) was then begun. The two components of the multiple VI VI schedule were signaled by the color (red or green) of the center key, and all reinforcements were obtained for responses on this key. The red component was in effect for 600 sec followed by the green component for 120 sec in simple alternation. Each component was presented four times per session, which began and ended in blackout. The schedules arranged in each condition are shown in Table 1. 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.

Training continued on each experimental condition until all birds had met a defined stability criterion five, not necessarily consecutive, times. The criterion required that the

median relative number of responses emitted in the red component over five sessions was not more than .05 different from the median of the five sessions immediately preceding these. When all birds had met this criterion five times, the experimental contingencies were changed for all birds.

In Conditions 1 to 5, the red and green component durations were 600 and 120 sec respectively; in Conditions 6 to 10 they were decreased to 150 and 30 sec; and in Conditions 11 to 15 they were further decreased to 50 and 10 sec. Conditions 16 to 18 were then carried out to ascertain whether the subjects would indeed show a more extreme response distribution between the components when equal short components were arranged. Finally, Conditions 19 to 23 used component durations of 25 and 5 sec. In each condition the number of components presented per session was varied to maintain a session time of 48 min.

RESULTS AND DISCUSSION

The numbers of responses emitted per minute and the number of reinforcers obtained per hour are shown in Appendix 1. The time-base for the calculation of rates was the component time excluding the time taken up by reinforcement. In general, the reinforcement rates were close to the arranged rates, and the response rates were relatively high compared with the reinforcement rates.

Two questions about the sensitivity of behavior to the distribution of reinforcements between components may be asked of the present data. First, did the value of a in Equation 1 increase as the absolute component durations were decreased? Second, did response ratios more nearly equal reinforcement ratios when component duration ratios were close to reinforcement ratios (as in concurrent schedules)? These questions were answered by fitting Equation 1 using least-squares linear regression to the data obtained for each pair of component durations. The results are shown in Table 2, and those for one bird (154) chosen at random are graphed in Figure 1. Table 2 also shows the mean slope (value of a) for each pair of component durations, and the standard deviations of a and $\log c$ for each bird. It is evident from Table 2 that shortening the unequal component durations did not increase

Table 1

Experiment 1. Sequence of experimental conditions and number of sessions training under each condition. Schedule and component duration values are given in seconds.

Condition	VI Schedules		Component Durations		Sessions
	Red	Green	Red	Green	
1	480	120	600	120	29
2	120	120	600	120	18
3	120	480	600	120	19
4	240	120	600	120	20
5	120	240	600	120	20
6	480	120	150	30	28
7	120	120	150	30	18
8	120	480	150	30	29
9	240	120	150	30	35
10	120	240	150	30	16
11	480	120	50	10	24
12	120	120	50	10	16
13	120	480	50	10	19
14	240	120	50	10	20
15	120	240	50	10	19
16	120	480	10	10	18
17	30	120	10	10	17
18	120	480	5	5	17
19	120	480	25	5	16
20	120	120	25	5	15
21	480	120	25	5	17
22	120	240	25	5	16
23	240	120	25	5	20

Table 2

Experiment 1. Estimates of the values of a and $\log c$ in Equation 1 for each bird in each set of absolute component durations. Standard deviations of estimates are shown in parentheses.

	Bird						mean ¹
	151	152	153	154	155	156	
<i>Conditions 1 to 5</i>							
a	.45(.03)	.42(.06)	.60(.15)	.33(.05)	.31(.04)	.29(.04)	.40(.10)
$\log c$	0(.01)	-.14(.03)	-.28(.06)	-.02(.02)	-.02(.02)	-.08(.01)	-.09(.10)
<i>Conditions 6 to 10</i>							
a	.47(.01)	.41(.06)	.74(.20)	.36(.03)	.32(.07)	.61(.18)	.49(.13)
$\log c$	.01(0)	-.07(.04)	-.03(.08)	-.13(.02)	-.04(.03)	-.09(.08)	-.06(.04)
<i>Conditions 11 to 15</i>							
a	.47(.08)	.41(.09)	.31(.09)	.36(.05)	.33(.05)	.35(.05)	.37(.06)
$\log c$	-.08(.03)	-.10(.04)	-.26(.04)	-.15(.02)	-.08(.02)	-.07(.02)	-.12(.07)
<i>Conditions 19 to 23</i>							
a	.75(.09)	.45(.05)	.42(.09)	.72(.24)	.43(.06)	.36(.15)	.52(.16)
$\log c$	.13(.04)	.01(.02)	-.05(.05)	0(.10)	.07(.02)	-.08(.07)	.01(.07)
<i>Means for birds²</i>							
a	.54(.10)	.42(.03)	.52(.16)	.44(.16)	.35(.05)	.40(.12)	.45(.14) ³
$\log c$	.02(.07)	-.08(.06)	-.16(.11)	-.08(.06)	-.02(.05)	-.08(.01)	-.07(.09) ³

¹For these standard deviations, $N=6$

²For these standard deviations, $N=4$

³For these standard deviations, $N=24$

the estimated value of a in Equation 1, and this result was confirmed by nonparametric trend tests (Ferguson, 1965) applied to both sensitivity to reinforcement (a) and bias ($\log c$). Neither test gave significant trends at $p = .05$ with $k = 4$ conditions and $N = 6$ subjects. High values of a did occasionally occur (e.g., Bird 154 in Conditions 19 to 23, Figure 1, and Bird 153 in Conditions 6 to 10). These, however, were often associated with large standard deviations (Table 2) and so were not accurate estimates of sensitivity to reinforcement. Thus, decreasing unequal component durations in multiple VI VI schedules does not increase sensitivity to reinforcement.

If the closest approximation to matching ($a = 1$ in Equation 1) occurred when the ratio of component durations equaled the ratio of reinforcement rates, the straight lines fitted to the data (Table 2) should intersect the strict matching line ($\log P_1/P_2 = \log R_1/R_2$) when the log reinforcement ratio was .7 (the logarithm of 5, the component duration ratio). The obtained average log reinforcement ratios at the intersection points were: Conditions 1 to 5, $-.15$; Conditions 6 to 10, $-.12$; Conditions 11 to 15, $-.19$; and Conditions 19 to 23, $+.02$. None of these data, save those for the longest component durations (Conditions 1 to 5), were reliably different from 0 on a sign test. Since there was also no trend in the intersec-

tion points across absolute component durations, we must conclude that neither relative nor absolute component durations affected the degree of matching in the multiple schedules.

The present results constitute a systematic replication of those reported by Lobb and Davison (1977, Part 3). The procedure used by Lobb and Davison produced component durations that were inversely related to component reinforcement rates. The present experiment found the same value of a (.45, SD .14) for multiple VI VI performance as did Lobb and Davison (.45, SD .17), strong evidence that relative component duration does not affect the way in which responses are distributed between components in these schedules. Our finding that neither absolute nor relative component durations affects the degree of matching seems contrary to the results reported by Shimp and Wheatley (1971) and Todorov (1972).

This disagreement led us, in Conditions 16 to 18, to try briefly to replicate the results of Shimp and Wheatley and of Todorov. In these conditions, the log reinforcement ratio was arranged to be .6. Condition 16 used multiple VI 120-sec VI 480-sec with 10 sec component durations, and Condition 17 used multiple VI 30-sec VI 120-sec with the same component durations. In Condition 18, multiple VI 120-sec VI 480-sec with component durations of 5 sec were

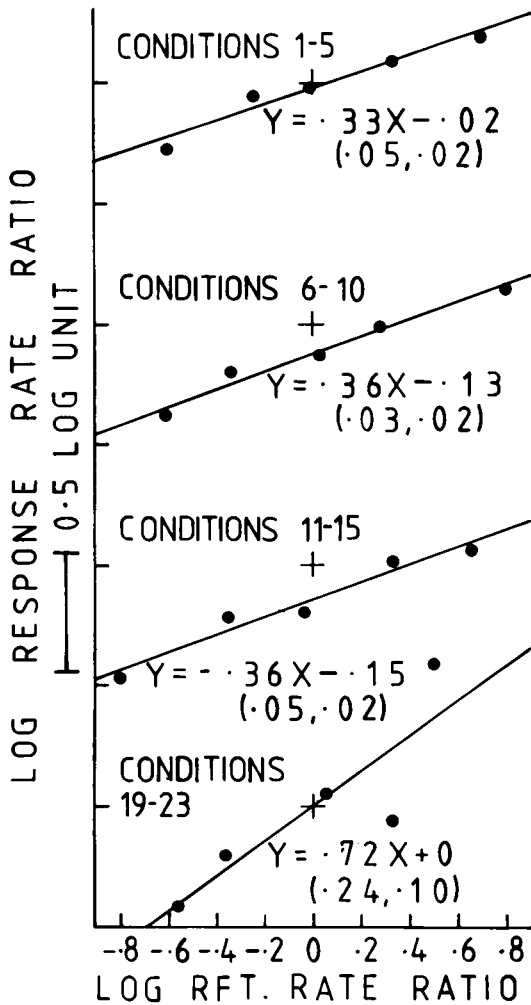


Fig. 1. Experiment 1. The logarithm of the ratio of response rates in the red and green components as a function of the logarithm of the ratio of the obtained reinforcement rates. Bird 154 was selected at random and its performance in each part of Experiment 1 is shown. Successive sets of conditions were displaced downwards by one log unit, and the origin for each set of data is shown by a cross. For each set of data, the least-squares line, its equation, and the standard deviation of the slope and intercept are shown.

arranged. The obtained mean log response rate ratios over the three conditions were, respectively, .20, .31, and .37. An estimate of the appropriate value of *a* in Equation 1 can be made if it is assumed that the value of log *c* is zero (a reasonable assumption for all birds except 153; see Table 2). Thus

$$a = \frac{\log(P_1/P_2)}{\log(R_1/R_2)} \quad (2).$$

Using Equation 2, the estimates of *a* for Conditions 16, 17, and 18 were respectively .33 (SD .17), .49 (SD .16), and .61 (SD .32). In none of these conditions did the value of *a* for each bird differ from the mean values for the bird (Table 2) in a consistent direction. This finding, with the large standard deviations of the estimates of *a*, thus gives no evidence of an increase in reinforcement sensitivity in Conditions 16 to 18. Because of our failure to replicate the results reported by Shimp and Wheatley (1971) and by Todorov (1972), a much more complete replication was carried out in Experiment 2.

EXPERIMENT 2

In this experiment, component durations in the multiple schedule were kept at 5 sec each, while the component reinforcement rates were varied over five experimental conditions so that a more reliable estimate of sensitivity to reinforcement could be obtained. In the second part of Experiment 2, we carried out the same manipulations of reinforcement rates but arranged the multiple schedule components on two separate keys rather than on one key. We did this because Merigan, Miller, & Gollub (1975) found a closer approximation to equality between response ratios and ratios of reinforcer durations when multiple VI VI schedules were arranged on two keys rather than on a single key.

METHOD

Subjects and Apparatus

These were the same as Experiment 1.

Procedure

The procedure used in the first part of Experiment 2 (Table 3 Conditions 1 to 5) was exactly the same as in Experiment 1 except that equal 5-sec component durations were arranged throughout. In Conditions 6 to 10, the center key of the chamber remained blacked out and inoperative, and the multiple schedule components were arranged on the two outer keys. The left key was illuminated red and the right key was illuminated green. Component durations were equal at 5 sec, and all other aspects of the procedure remained as in Experiment 1.

Table 3

Experiment 2. Sequence of experimental conditions and number of sessions training under each condition. Schedule values are in seconds. The component duration in red and green was 5 sec.

Condition	VI Schedules		Sessions
	Red	Green	
<i>One Key</i>			
1	480	120	18
2	120	120	17
3	120	480	33
4	240	120	20
5	120	240	20
<i>Two Keys</i>			
6	480	120	37
7	120	120	41
8	120	480	20
9	240	120	26
10	120	240	22

RESULTS AND DISCUSSION

The numbers of responses per minute emitted and the number of reinforcers obtained per hour on each component and for each bird are given in Appendix 2. Condition 3 was a replication of Condition 18 of Experiment 1, and these latter data were additionally used in the analysis of Experiment 2. Reinforcement rates obtained were close to those arranged and response rates were moderately high in all conditions for all birds except 152. There appeared to be no difference in absolute response rates when the multiple schedules were arranged on two, rather than on one, key.

Response distribution between components was analyzed in the same way as in Experiment 1. Figures 2 and 3 show log response rate ratios as a function of log reinforcement rate ratios for each bird in each of the two parts of Experiment 2. Straight lines were fitted to these data by the method of least squares, and the obtained parameter estimates for Equation 1 and their standard deviations are shown in the figures. For the single-key multiple schedules,

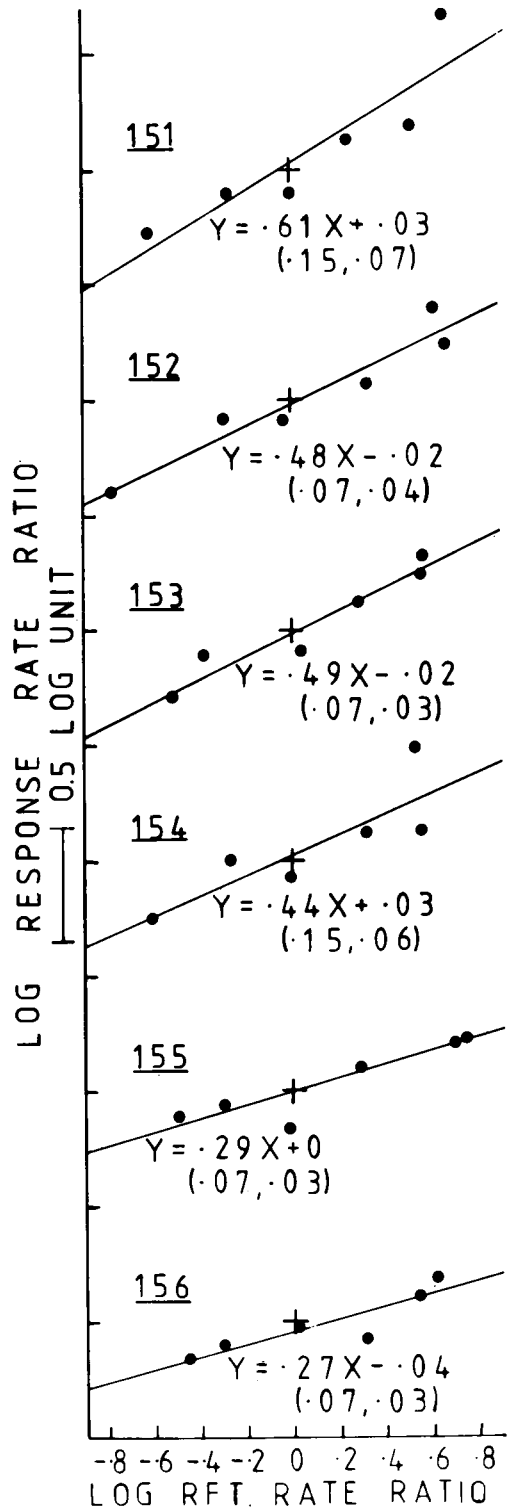
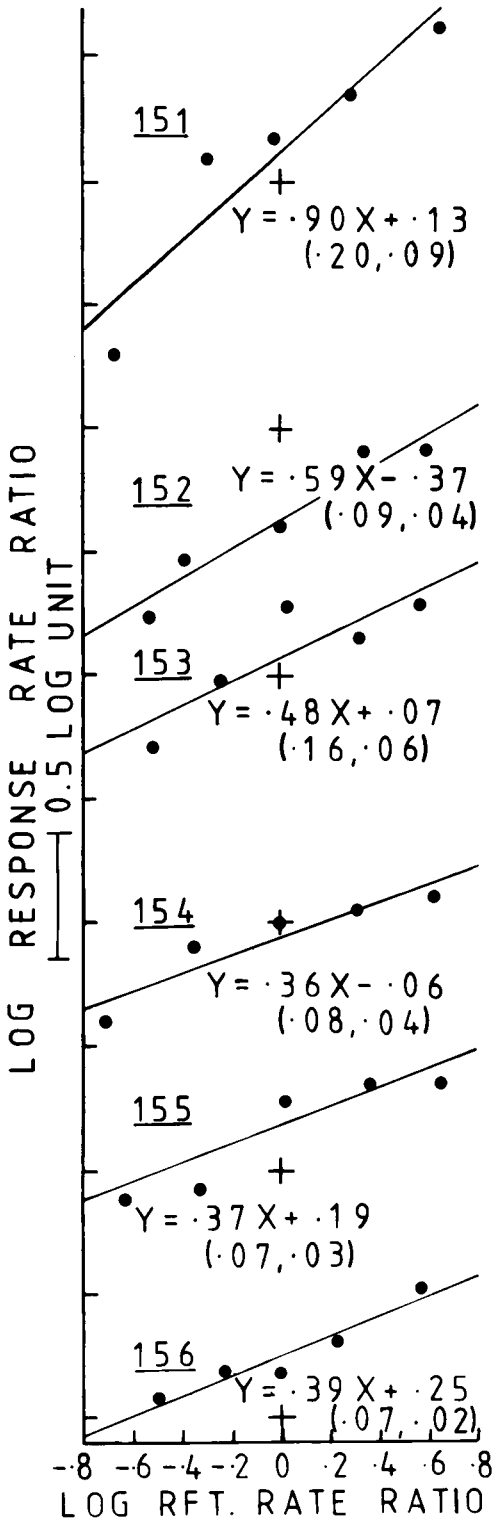


Fig. 2. Experiment 2, single-key multiple schedules. The logarithm of the ratio of response rates in the red and green components as a function of the logarithm of the ratio of the obtained reinforcement rates. The data for each bird are displaced down from those of the previous bird by one log unit, and crosses show the origin for each bird's data. For each bird, the least-squares line, its equation, and the standard deviation of slope and intercept are shown.



the mean sensitivity to reinforcement was .43 (SD .12), and there was no evidence of any change in sensitivity to reinforcement or bias from the mean data of Experiment 1 (Sign test, $p > .05$) or even from the data from the longest component durations in Experiment 1 (Conditions 1 to 5), again using a Sign test at $p = .05$. The change from single-key to two-key multiple scheduling increased the estimate of a to .52, but the standard deviation also increased to .21. Individually, the value of a increased for only four of the six birds, making the change not significant on a Sign test. The estimates of a from the second part of Experiment 2 were not significantly different on a Sign test from the mean data of Experiment 1.

The results from both Experiments 1 and 2 failed to replicate the findings of Shimp and Wheatley (1971) and of Todorov (1972). We found no increase in sensitivity to reinforcement when component durations were decreased, and they remained close to the values previously reported for performance when longer components were arranged (Lander & Irwin, 1968; Lobb & Davison, 1977). Although Merigan et al. (1975) found different sensitivities to reinforcement magnitude between one- and two-key multiple schedules, we failed to find a similar effect with sensitivity to reinforcement rate. The differences between the results of Merigan et al. and the present results may, perhaps, be understood in terms of the manipulation of different variables. But the failure to replicate the effect reported by Shimp and Wheatley and by Todorov poses problems. We therefore carried out further experimentation to determine whether some minor procedural detail was essential to produce short-component multiple schedule matching.

EXPERIMENT 3

Here, we investigated various procedural changes in the hope of delimiting the condi-

Fig. 3. Experiment 2, two-key multiple schedules. The logarithm of the ratio of response rates in the red and green components as a function of the logarithm of the ratio of the obtained reinforcement rates. The data for each bird are displaced down from those of the previous bird by one log unit, 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.

tions under which changes in sensitivity to reinforcement in multiple VI VI performance would occur. In most parts of Experiment 3, we exposed the birds to at least two experimental conditions, the second of which was a reversal in reinforcement ratio from the first. Two conditions are, of course, the minimum if the values of the two constants in Equation 1 are to be estimated. We also arranged a few conditions without reversals. For these, the value of a was estimated using Equation 2, that is, assuming $\log c$ was zero.

Whereas the procedures used in Experiment 3 were mostly arranged in the hope of increasing the sensitivity to reinforcement, some others were introduced to see whether reinforcement sensitivity could be decreased. The purpose of both types of manipulation was to demonstrate that variations in the value of a were at least possible with these birds.

METHOD

Subjects and Apparatus

These were the same as in Experiments 1 and 2.

Procedure

Except where otherwise stated explicitly, the procedure and the assessment of stability were the same as in Experiment 1.

The sequence of experimental conditions is shown in Table 4. Our first consideration was that the deprivation level used in Experiments 1 and 2 was too severe since deprivation and multiple-schedule matching are inversely related (Herrnstein & Loveland, 1974). We replicated two conditions from the second part of Experiment 2 with the birds deprived to only 90% of their free-feeding weights. The multiple schedules were arranged on two keys. Following these conditions, we reverted to a single-key multiple-schedule arrangement and, keeping the body weights at 90%, we changed the discriminative stimuli to two shades of red in order to decrease the discriminability of the stimuli and thus possibly to decrease reinforcement sensitivity. Then, in Conditions 5 to 7, the birds were trained in the same experimental chamber on concurrent VI VI schedules. The rationale for this was that the birds used by Shimp and Wheatley (1971) had previous experience on concurrent schedules, and those used by Todorov (1972) had been trained on several unspecified reinforcement sched-

ules. The right key was either red or green, each color being associated with one schedule, and the left key was pink. A response to the pink key changed the color and associated schedule on the right key. A changeover delay was started by each response to the pink key, removing the availability of reinforcement for 2 sec. The birds were maintained at 90% of their free-feeding weights. Following exposure to concurrent VI VI schedules, the birds were returned to multiple VI VI schedules arranged on a single key as in Experiment 2, Part 1, but with 10-sec component durations. Durations of 10 sec were chosen because our reanalysis of the data of both Shimp and Wheatley and Todorov showed that the closest approximation to matching occurred at these durations. In Conditions 10 and 11, we introduced 5-sec blackouts between the 10-sec multiple-schedule components in the expectation that this procedure would decrease interaction between the components (Herrnstein, 1970) and hence decrease the value of a . In Conditions 12 and 13, keeping the blackouts between the 10-sec components, we increased the reinforcer duration to 5 sec. Then, beginning with Condition 14, we physically enlarged the aperture through which the birds obtained grain in the food hopper. Following Herrnstein and Loveland (1974), we would expect increases in reinforcer magnitude to decrease sensitivity to reinforcement.

In Conditions 16 and 17, the blackouts between the components were removed and, keeping the reinforcer time at 5 sec and the component durations at 10 sec, we again varied the VI schedules. In Conditions 18 and 19, the component durations were increased to 180 sec, which we would expect to decrease reinforcement sensitivity, and in Conditions 20 to 22, using 10-sec components, the white hopper light was replaced with red and green lights, which illuminated the grain according to which component the reinforcer had been gained in. Following the results of Mariner and Thomas (1969), we hoped that this procedure would increase reinforcement sensitivity. In Condition 21, we increased the overall reinforcement rate by a factor of eight, which should decrease reinforcement sensitivity (Herrnstein & Loveland, 1974). In Conditions 23 and 24 we arranged an "error keys" procedure. In the green component, both left and right keys were green, but only the left

Table 4

Experiment 3. Sequence of experimental conditions and number of sessions training under each condition. All schedule, reinforcer duration, and component duration values are in seconds. Body weight is shown as a percentage of free-feeding weight.

Condition	VI Schedules		Component Durations	Reinforcer Duration	Body Weight	Other Conditions
	Red	Green				
1	120	240	5	3	90	} 2 Keys
2	240	120	5	3	90	
3	240	120	5	3	90	} 1 Key, 2 shades of red
4	120	240	5	3	90	
5	120	240	—	3	90	} Concurrent VI Schedules
6	240	120	—	3	90	
7	120	120	—	3	90	
8	120	480	10	3	80	} Multiple red/green
9	480	120	10	3	80	
10	480	120	10	3	80	} 5-sec blackouts between components
11	120	480	10	3	80	
12	120	480	10	5	80	} 5-sec blackouts between components
13	480	120	10	5	80	
14	480	120	10	5	80	} Magazine aperture enlarged* 5-sec blackouts
15	120	480	10	5	80	
16	120	480	10	5	80	} Blackouts removed
17	480	120	10	5	80	
18	480	120	180	5	80	
19	120	480	180	5	80	
20	120	480	10	5	80	} Hopper light color same as component
21	15	60	10	5	80	
22	60	15	10	5	80	} key color
23	60	15	10	5	80	
24	60	15	10	5	80	Error Keys and blackouts

*Magazine aperture remained enlarged from here.

key was associated with the VI reinforcement schedule. In the red component, both keys were red, but only the right key was associated with the VI schedule. Responses to all keys were counted. This procedure was used to assess the ability of the birds to differentiate the red and green multiple schedule stimuli. In Condition 24, 5-sec blackouts were arranged between the components.

RESULTS AND DISCUSSION

The numbers of responses emitted per minute and the numbers of reinforcers obtained per hour in each component are shown in Appendix 3. In Table 5 are shown estimates of *a* for each condition (when only one condition was arranged) or for each set of conditions, along with comparison data from Experiment 1. The values of *a* were estimated from Equation 2 for single conditions, by simultaneous equations when two conditions were arranged, or by least-squares linear re-

gression when three conditions were arranged. Standard deviations of parameter estimates are not possible from one or two contributing conditions and are virtually meaningless when calculated from three conditions. Hence none are shown for this Experiment. Since the values of *a* found in Experiment 3 are from few conditions, they are naturally more unreliable than those obtained in Experiment 1. The best way to assess these data is to compare them with the accurate, or more accurate, estimates obtained in Experiment 1. We use the criterion that a reliable difference is one in which the values of *a* for each bird differ in the same direction from the values found in Experiment 1 (equivalent to a Sign test).

First, the increases in body weight to 90% (Conditions 1 and 2) with 5-sec component durations had no consistent effect on the value of *a*, though the value for Bird 156 increased markedly. The attempt to decrease the discriminability of the discriminative stimuli in Conditions 3 and 4 had no effect on *a*, and it

Table 5

Experiment 3. Estimates of the value of a (from Equation 2, by simultaneous equations or by linear regression) in the various experimental conditions (see Table 4). For comparison purposes, the mean data from Experiment 1 are also shown.

Conditions	Bird						Mean
	151	152	153	154	155	156	
EXPT 1	.54(.10)	.42(.03)	.52(.16)	.44(.16)	.35(.05)	.40(.12)	.45(.14)
1,2	.59	.13	.50	.32	.43	.97	.49
3,4	.32	.52	.47	.37	.29	-.09	.31
5,6,7	1.44	1.29	1.17	.94	2.30	.87	1.34
8,9	.47	.43	.38	.41	.28	.26	.37
10,11	.44	.41	.43	.26	.26	.26	.34
12,13	.67	.53	.38	.25	.30	.29	.40
14,15	.88	.67	.19	.37	.34	.47	.49
16,17	.68	.73	.29	.44	.32	.20	.44
18,19	.27	.40	.34	.18	.08	.29	.26
20	.80	.97	.24	.49	.32	.20	.50
21,22	.49	.49	.17	.35	.34	.43	.38
23	1.12	.30	.56	-.03	.84	.73	.59
24	.82	.27	.05	-.14	.42	.34	.29

remains doubtful whether the attempt succeeded. Exposure to concurrent VI VI schedules in Conditions 5 to 7 showed that the subjects could show high sensitivities to reinforcement, and all values of a were higher than in Experiment 1. The analysis shown in Table 5 is a standard concurrent schedule analysis in which responses and reinforcement rates were measured according to the time available for each response to be emitted (the total session time). The estimates of a cannot be derived from Appendix 3 where the response and reinforcement rates are, for consistency, measured according to the time the bird was responding on the particular schedule, that is, the local response and reinforcement rates. The birds, of course, allocated more time to responding on the higher reinforcement rate schedule and maintained approximate equality of local response and reinforcement rates. The values of a estimated in Conditions 5 to 7 were, on the average, higher than those usually found for concurrent VI VI schedules (Baum, 1979). This probably resulted from estimating a from a small number of conditions, though we cannot rule out some kind of contrast effect from the preceding extended exposure to multiple schedules. However, exposure to the concurrent VI VI schedules had no consistent effect on the values of a in the subsequent multiple VI VI schedule performance (Conditions 8 and 9).

The addition of 5-sec blackouts between components in Conditions 10 and 11 produced

a consistent decrease in the values of a as would be expected if this procedure decreased interaction between the components. During the next two pairs of conditions (12 and 13, and 14 and 15), reinforcement magnitude was increased first by extending reinforcer duration to 5 sec and then by enlarging the magazine aperture. There was, on the average, an increase, rather than the expected decrease, in the value of a compared with Conditions 10 and 11, and the values of a obtained from Conditions 12 and 13, and 14 and 15 were no longer reliably different from those found in Experiment 1. Removing the blackout between components at this point (Conditions 16 and 17) produced no further change in the value of a .

In Conditions 18 and 19, when component durations were increased to 180 sec, there was, as expected, a consistent decrease in the value of a compared with Experiment 1, though the change was inconsistent with the previous pair of experimental conditions. Although this result supported the trends reported by Shimp and Wheatley (1971) and by Todorov (1972), the absolute values of a were still very different. Our calculations show that for 180-sec component durations, Shimp and Wheatley obtained an average a value of .41, entirely consistent with the results of Lander and Irwin (1968) and of Lobb and Davison (1977). The average a value found here in Conditions 18 and 19 was .26, and all individual bird values were below the value we calculated from

Shimp and Wheatley's data. Parenthetically, by least-squares estimation, we calculated an a value of .95 for the 10-sec component duration data reported by Shimp and Wheatley, a value equaled here by only the concurrent schedule data.

In Conditions 20 to 22 the color of the food hopper light was the same as the keylight on which the reinforced response had been emitted. Whereas the average value of a increased over the previous 180-sec component conditions, the value decreased for two birds (Table 5). Compared with the data from Experiment 1, and against our expectation, these conditions showed no differences in a value neither when 37.5 reinforcers per hour were arranged (Condition 20) nor when 300 reinforcers per hour were arranged (Conditions 21 and 22). Finally, in Conditions 23 and 24, we arranged the red and green components on two keys and added concurrently available extinction schedules signaled by the same key colors. In Condition 23, an average of 2.4 and 1.0 responses per minute were emitted on the Extinction keys in the red and green components respectively. A comparison of these rates with those on the VI schedules (Appendix 3) shows that the birds were discriminating the signaling stimuli very well. It was clear, however, that many of the responses emitted on the Extinction keys were due to overrunning component changes, so in Condition 24 a blackout of 5 sec was added between the components. In this condition, virtually no responses (red, .03; green, .14 responses per minute) were emitted on the Extinction keys, showing the red and green stimuli to be very highly discriminable. The values of a estimated in Conditions 23 and 24 were not reliably different from those obtained in Experiment 1.

To summarize, only the arrangement of blackouts between components and increasing component durations to 180 sec reliably decreased sensitivity to reinforcement in Experiment 3. Although the latter result is consistent with the results of Shimp and Wheatley (1971) and Todorov (1972), there are various reasons why little confidence can be placed on these results. First, the effects were not reliable across birds when compared either with the immediately preceding or with immediately following conditions. Second, the mean sensitivity to reinforcement (Table 5) was never more than one standard deviation greater than the mean

slope found in Experiment 1 (Table 2), except for the concurrent schedules. In only two parts of Experiment 3 was reinforcement sensitivity smaller than one standard deviation less than the mean slope in Experiment 1 (Conditions 18 and 19, and Condition 24). The smallest sensitivity (Conditions 18 and 19) was only 1.36 standard deviations from the mean slope. Third, the absolute values of the reinforcement sensitivities found in Experiment 3 were, apart from the concurrent schedule, close to those usually reported for long-component multiple schedules (Lander & Irwin, 1968; Lobb & Davison, 1977).

The difference between our results and those of Shimp and Wheatley (1971) and of Todorov (1972) might be explained if, in our experiments, control by component duration was overshadowed by reinforcement effects. Our usual practice in Experiments 1 to 3 was reversing the reinforcement schedules between conditions. Shimp and Wheatley infrequently reversed schedules, and Todorov made no reversals in his experiment. We therefore decided to investigate the possibility that changes in the value of a in Equation 1 could be produced reliably only when reinforcement frequencies remained constant when component durations were changed.

EXPERIMENT 4

METHOD

Subjects and Apparatus

These were the same as in Experiment 1 except that the birds were maintained at 85% of their free-feeding body weights.

Procedure

The procedure was the same as in Experiment 1, and the same stability criterion was used. In the first part of Experiment 4, the reinforcement schedules were VI 30-sec in the red component and VI 90-sec in the green component. Over five experimental conditions (Table 6), we reduced the equal component durations from 180 sec to 6 sec. Then, in Condition 6, retaining 6-sec component durations, we reversed the reinforcement schedules. In the second part of Experiment 4, we repeated the first part but with the reinforcement schedules reversed (red VI 90-sec, green VI 30-sec)

Table 6

Experiment 4. Sequence of experimental conditions and number of sessions training under each condition. Body weight was 85% of free-feeding weight. Reinforcer duration was 3 sec. Schedule and component values are in seconds.

Condition	VI Schedules		Component Duration	Sessions
	Red	Green		
1	30	90	180	16
2	30	90	60	18
3	30	90	30	16
4	30	90	9	24
5	30	90	6	16
6	90	30	6	16
7	90	30	180	15
8	90	30	60	15
9	90	30	30	14
10	90	30	9	15
11	90	30	6	18
12	30	90	6	15

and reversed the schedules again in Condition 12.

RESULTS

Figure 4 shows the relative rates of responding in the two components of the multiple schedule calculated from the data given in Appendix 4. Over Conditions 1 to 5, when the schedules were VI 30-sec and VI 90-sec and the component durations were decreased from 180 sec to 6 sec, the mean relative response rate to the red key increased from .56 to .63. This corresponds to a change in estimated a value (Equation 2) from .22 to .54. The greatest relative rates, on the average, occurred at the 9-sec component duration, with a relative response rate of .64 and an estimated a value of .56. The individual birds' performances generally showed the same trend as the group, this being particularly clear for Birds 151, 153, and 154. Bird 152 showed peak relative rate at a component duration of 60 sec, Bird 155 at 30 sec, and Bird 156 at 6 sec. A nonparametric trend test (Ferguson, 1965) showed a significant trend for relative rate to increase as component duration was decreased ($N = 6$ birds, $k = 5$ conditions, $z = 2.3$, $p < .05$).

The schedules were reversed in Condition 6, and large changes in relative response rates were seen for all birds except Bird 155. For every bird, the relative response rate was less extreme (closer to indifference) in Condition 6 than it had been in Condition 5. The mean relative response rate in Condition 6 was .49, an estimated a value of .03.

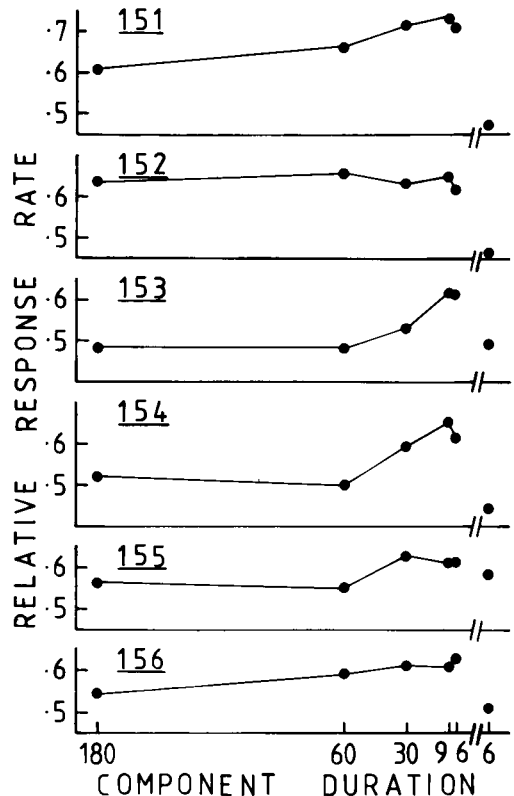


Fig. 4. Experiment 4. The relative rates of responding in the red component (red response rate divided by the sum of the response rates in the two components) as a function of component duration in seconds. The schedules were multiple VI 30-sec VI 90-sec until the data break on the x-axis. These schedules were reversed between components after the data break.

In Conditions 7 to 11, the schedules were VI 90-sec and VI 30-sec, and again the component durations were decreased from 180 sec to 6 sec. The average relative response rate fell from .45 to .39 (equivalent a values of .17 to .36, respectively), and the minimum average relative response rate occurred at a component duration of 30 sec (relative rate .38, equivalent a value, .44). Individually (Figure 5), three birds (151, 154, and 155) showed most extreme relative rates in 6-sec components, 153 and 156 in 30-sec components, and 152 in 60-sec components. The performance of two birds (153 and 156) showed trends that were opposite to those of the other four birds. At component durations of 9 and 6 sec, the relative rates of these birds moved strongly toward indifference and, for Bird 156, relative rate was higher for the lower reinforcement rate schedule in the 6-sec component durations. Despite these oppos-

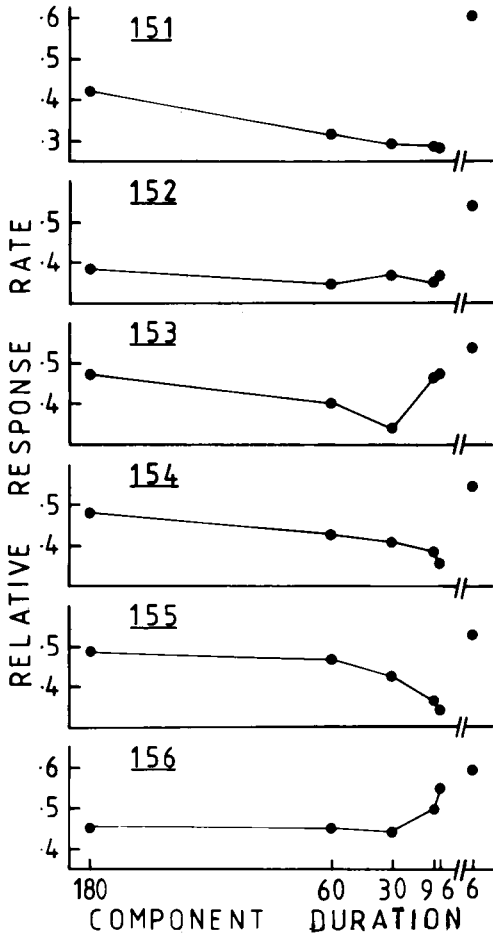


Fig. 5. Experiment 4. The relative rates of responding in the red component (red response rate divided by the sum of the response rates in the two components) as a function of component duration in seconds. The schedules were multiple VI 90-sec VI 30-sec until the data break on the x-axis. The schedules were reversed between the components after the data break.

ing trends, a nonparametric trend test showed a significant trend for relative rate to become more extreme with shortened components ($N = 6$ birds, $k = 5$ conditions, $z = 2.5$, $p < .05$). The reversals shown by Birds 153 and 156 were overcome by the strictly monotone trends shown by Birds 151, 154, and 155.

When the schedules were again reversed in Condition 12, the relative response rates were again closer to indifference than in Condition 11 for four of the six birds. The exceptions (Birds 153 and 156) were the two birds that showed increasing relative response rates to the lower reinforcement rate schedule in Conditions 7 to 11. The mean relative response

rate in Condition 12 was .56, an estimated a value of .24.

The last analysis in Experiment 4 consisted of estimating the value of a in Equation 1 from pairs of reversed schedule conditions (e.g., Conditions 1 and 7, 2 and 8, etc.). The mean value of a increased from .2 for the 180-sec component durations to .45 for the 6-sec component durations and peaked at a value of .47 when the components were 9 sec in duration. Three birds (151, 154, and 155) showed strictly monotone trends, and a trend test across the six birds and five conditions (excluding the reversal Conditions 6 and 12) showed a significant trend ($z = 3.1$, $p < .05$). The a values estimated from Conditions 6 and 12 averaged .16.

The numbers of responses emitted per minute in each component in Experiment 4 are shown in Figures 6 and 7. The trends in absolute response rates are not easy to discern, but trend tests showed that the response rate to the higher reinforcement rate component in each set of conditions (1 to 5 and 7 to 11) increased significantly ($z = 3.7$ and 2.2 , $p < .05$), whereas there were no significant trends in either set of conditions in the lower reinforcement rate component ($z = -.9$ and -1.5 , $p > .05$).

GENERAL DISCUSSION

The results of Experiment 4 are consistent with previous reports (Shimp & Wheatley, 1971; Todorov, 1972) that relative rates become more extreme when equal multiple schedule component durations are shortened. The size of the effect found here is, however, smaller than that reported previously. For example, our reanalyses of Shimp and Wheatley's data showed that they found values of a (estimated from two or more conditions) that increased from .41 (180-sec components) to .86 (2-sec components), and that peaked at .95 (10-sec components). Although the trends in the present data were similar, the reason for the generally smaller effect in the present data can only be guessed at. The behavior of Birds 153 and 156 in Conditions 11 and 12 of Experiment 4 suggests that they may have been affected by previous exposure to Conditions 1 to 5. Similarly, the magnitude of the relative rate changes in Experiment 4 may have been affected by the extensive exposure the sub-

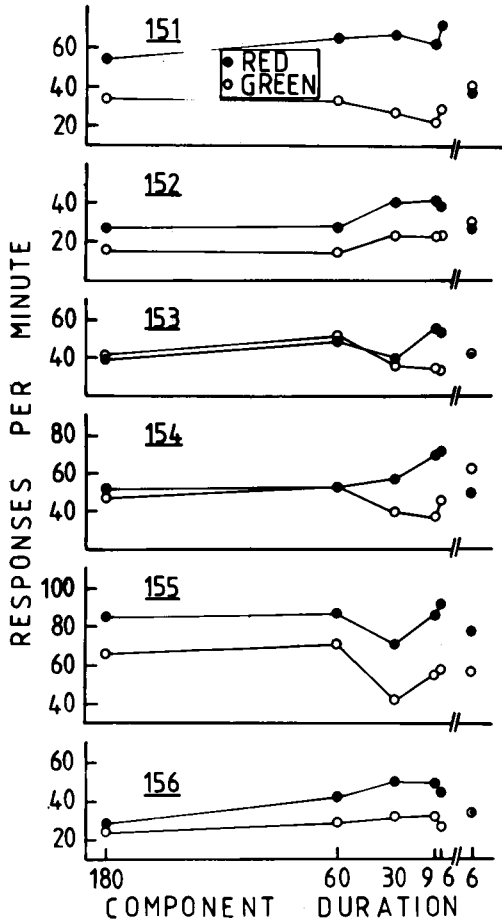


Fig. 6. Experiment 4. The number of responses per minute in the red and green components as a function of component duration in seconds. The multiple VI 30-sec VI 90-sec schedules were reversed after the data break.

jects had to various experimental conditions prior to Experiment 4, particularly to frequent changes in reinforcement rates in the two components.

The consistency of the present data with those reported by Shimp and Wheatley and by Todorov is also shown by the changes in absolute response rates in Experiment 4. Edmon (1978) analyzed the data from these two reports and showed that absolute response rates in the higher reinforcement rate components increased with shorter component durations, whereas the rates in the lower reinforcement frequency components remained constant. The same effect was found here (Figures 6 and 7). Edmon showed that the response rate increase

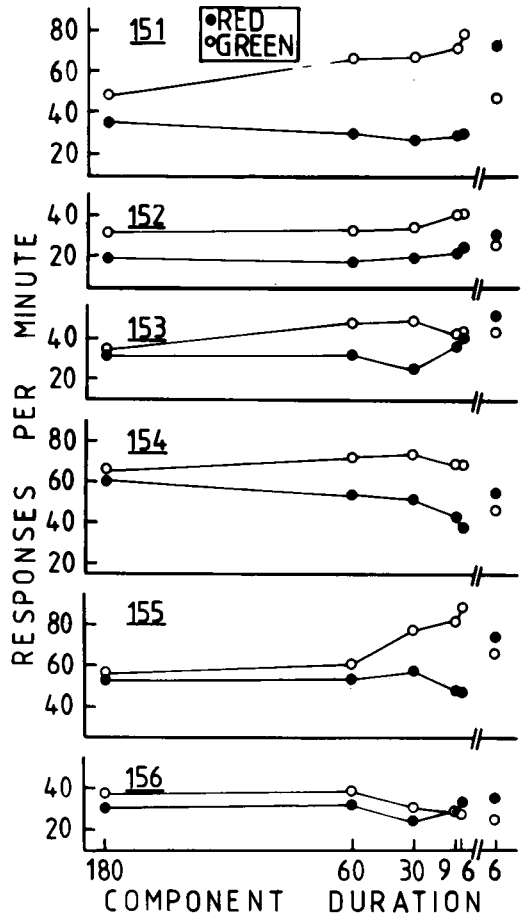


Fig. 7. Experiment 4. The number of responses per minute in the red and green components as a function of component duration in seconds. The multiple VI 90-sec VI 30-sec schedules were reversed after the data break.

was incompatible with the interpretation that more extreme multiple schedule relative response rates are caused by increasing component interaction (Herrnstein, 1970), and the present data add further support to Edmon's argument. Not only were the absolute response rate changes incompatible with this interpretation, but the present experiments failed to demonstrate any increase in sensitivity to reinforcement rate ratio (when it was varied) as component durations were shortened. If the effect cannot be interpreted as increasing reinforcement sensitivity in Equation 1, perhaps it may be seen as an increasing value of bias or $\log c$? But the definition of bias (Baum, 1974) is a constant proportional preference when

the value of some choice-affecting variable is changed. Experiment 4 showed that the increase was progressive, rather than constant, and that it could be eliminated by reversing the schedules. So the short-component multiple-schedule "matching" effect can be related neither to reinforcement sensitivity nor to bias. It is not related to matching versus undermatching nor to the generalized matching law. The only sense in which "matching" occurs in short-component multiple schedules is in the sense of a local equality, rather than a process. The short-component multiple-schedule effect is an effect of component duration changes on response rates only when relative reinforcement rates are constant. This conclusion implies that we must use extreme care in interpreting the results of multiple-schedule research, which involves changes in component duration without reinforcement variation. As we have shown, results in this area can be quite deceptive when they are related to matching or to response rates per se.

It may be suggested that Killeen's (1972) results argue against our conclusion. Killeen arranged unequal-component multiple schedules by yoking the multiple schedule birds to birds working on similar concurrent schedules. He reported consistent multiple-schedule matching of relative response frequencies to relative reinforcement frequencies even following a reversal (his Experiment 1). Killeen's measurement of response frequency was, however, responses per total session time. But, as Herrnstein (1970, p. 259) pointed out, the appropriate measure of response rate in a schedule is the number of responses divided by the time for which the schedule is available (local response rate). In the assessment of matching, Killeen's measure would have been entirely satisfactory if the component durations were equal. But, because of the yoking procedure, relative component durations approximately equaled relative reinforcement frequencies. As a result, "matching" of relative response to relative reinforcement frequencies simply implies that local response rates were about equal. Indeed, our reanalysis of Killeen's data showed that in the two yoked procedures (Experiment 1), the average values of a in Equation 1 were $-.16$ and $.12$, values very distant from matching. In Experiment 1, the component durations were 2.4 and 6.4 sec on the average. Fixed component durations of the

same lengths were arranged in Experiment 2, Procedure 1, and gave an estimated a value of $-.1$. Thus, in none of the three procedures in which Killeen used unequal component durations did matching occur. In Experiment 2, Procedure 2, he changed to equal 4.5-sec component durations, and the value of a increased to $.31$ on average. In all procedures mentioned so far, both multiple schedules ran throughout the session. When, as is typical with multiple schedules, he arranged that each schedule stopped when the bird was in the alternate component (Procedure 3), the value of a increased to $.88$. Finally, in Procedure 4, both components were increased to 45 sec and the value of a fell to $.63$. Only Procedures 3 and 4 of Experiment 2, in which equal component durations were arranged, support the results of Shimp and Wheatley (1971) and of Todorov (1972). Since no reversals of schedules were carried out in Killeen's Experiment 2, the data are also consistent with our conclusion. The results from Experiment 1 and from Experiment 2, Procedure 1 could indicate that component duration does not affect relative response rates when component durations are unequal; but as reversals were arranged within that set of procedures, they could simply support our conclusion that schedule reversals eliminate the short-component effect.

Like so many others (de Villiers, 1977; Merigan, Miller, & Gollub, 1975; Schwartz & Gamzu, 1977; Silberberg & Schrot, 1974), we were guilty of misreading Killeen's (1972) results, which give only equivocal support for the findings of Shimp and Wheatley (1971) and of Todorov (1972). Stronger support for Shimp and Wheatley and for Todorov apparently came from an experiment by Silberberg and Schrot. Using a yoked procedure like Killeen's (thus with unequal component durations), they showed that relative local response rates (responses per time available) for the multiple schedule birds fell as component duration increased. But the support given by these data for a movement towards matching with shorter components is also equivocal simply because, for many birds in many conditions, local reinforcement rates were equal. Such an equality precludes any assessment of matching.

The most comprehensive data on matching in multiple schedules are from Merigan, Miller, and Gollub's (1975) experiment on reinforcer duration. Pigeons matched relative local

response rates to relative reinforcer durations when equal 5-sec component durations were arranged using equal schedules on two keys. The matching effect was robust against reversals of reinforcer durations between the components, but there was no assessment of the effects of relative reinforcer frequency variation. Two-min component durations and 5-sec component durations, arranged on a single-key multiple schedule, both produced substantial undermatching.

In summary, the available data on the relation between component duration and response rate in multiple VI VI schedules are confused. The present data, taken with those already available, suggest that performance in multiple VI VI is characterized by a sensitivity to reinforcement of about .45. This sensitivity appears to be independent of absolute or relative component duration. But variation of component duration alone produces a lawful, consistent, but fragile increase in response rate in the higher reinforcement rate component. This effect is termed fragile because it is eliminated by a schedule reversal. What mechanism might produce the short-component effect? It is tempting to invoke a local contrast theory, as did McLean and White (1981). Response rates are particularly high just after a transition into a high reinforcement rate component and are particularly low just after a transition into a low reinforcement rate component. If decreasing component durations left this local contrast intact while subsequent response rates, which are more equal between components, are removed, a relative response rate change is predicted. But to account fully for our results, we must suppose that schedule reversals eliminate local contrast. We can find no data to support this suggestion. This theory must also predict response rate changes in both components as component durations are shortened. But the present results (Experiment 4) and the analyses reported by Edmon (1978) showed changes only in the higher reinforcement rate component. Although we may therefore reject McLean and White's explanation, we have no viable alternative to offer. Rather than speculation, this area now needs research to delimit the conditions under which the short-component effect occurs, to determine whether other variables may have similar effects, and to en-

sure that the analysis of multiple-schedule response allocation is not needlessly complicated by fragile short-component effects.

REFERENCES

- Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 231-242.
- Baum, W. M. Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 1979, **32**, 269-281.
- de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Edmon, E. L. Multiple schedule component duration: A re-analysis of Shimp and Wheatley (1971) and Todorov (1972). *Journal of the Experimental Analysis of Behavior*, 1978, **30**, 239-241.
- Fergusson, G. A. *Nonparametric trend analysis*. Montreal: McGill University, 1965.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Herrnstein, R. J., & Loveland, D. H. Hunger and contrast in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 511-517.
- Killeen, P. A yoked-chamber comparison of concurrent and multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 13-22.
- Lander, D. G., & Irwin, R. J. Multiple schedules: Effects of the distribution of reinforcements between components on the distribution of responses between components. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 517-524.
- Lobb, B., & Davison, M. C. Performance in concurrent interval schedules: A systematic replication. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 191-197.
- Lobb, B., & Davison, M. C. Multiple and concurrent schedule performance: Independence from concurrent and successive schedule contexts. *Journal of the Experimental Analysis of Behavior*, 1977, **28**, 27-39.
- Mariner, R. W., & Thomas, D. R. Reinforcement duration and the peak shift in post-discrimination gradients. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 759-766.
- McLean, A. P., & White, K. G. Undermatching and contrast within components of multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1981, **35**, 283-291.
- Merigan, W. H., Miller, J. S., & Gollub, L. R. Short-component multiple schedules: Effects of relative reinforcement duration. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 183-189.
- Schwartz, B., & Gamzu, E. Pavlovian control of operant behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Shimp, C. P., & Wheatley, K. L. Matching to relative reinforcement frequency in multiple schedules with

- a short component duration. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 205-210.
- Silberberg, A., & Schrot, J. A yoked-chamber comparison of concurrent and multiple schedules: The relationship between component duration and responding. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 21-30.
- Todorov, J. C. Component duration and relative response rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 45-49.

Received March 23, 1981

Final acceptance January 19, 1982

Appendix 1

Experiment 1. Responses per minute and reinforcements per hour in each component and experimental condition.

Condition	Responses/min		Reinforcements/hr		Condition	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
<i>Bird 151</i>					<i>Bird 153</i>				
1	28.7	49.5	7.3	27.3	1	9.6	51.3	8.2	25.7
2	36.8	39.4	32.0	32.2	2	47.3	66.9	32.3	25.7
3	45.2	28.2	31.6	11.1	3	58.2	56.4	31.0	9.5
4	32.2	40.6	16.3	25.7	4	37.7	75.6	15.3	30.6
5	35.8	21.5	31.6	11.1	5	43.2	51.9	30.9	11.1
6	26.9	54.5	7.0	32.1	6	28.3	69.4	7.6	31.9
7	41.3	40.5	31.3	32.0	7	44.8	50.4	30.9	30.2
8	43.9	17.7	29.9	4.9	8	35.8	12.2	28.8	11.6
9	31.5	42.8	15.7	35.4	9	34.2	78.4	15.2	28.4
10	41.1	27.9	29.9	13.3	10	36.9	30.6	29.8	13.2
11	25.3	69.3	7.9	39.8	11	38.7	103.0	7.1	28.0
12	39.8	56.8	31.4	33.4	12	61.6	87.7	31.6	31.6
13	49.0	33.8	30.8	13.2	13	53.7	59.1	30.7	8.2
14	43.4	67.0	14.6	33.1	14	40.3	105.9	14.5	29.8
15	42.8	42.3	30.8	14.8	15	54.1	92.8	30.3	13.2
16	60.2	30.7	31.4	8.8	16	67.5	64.9	30.8	7.1
17	104.1	33.8	134.4	29.2	17	126.9	74.1	131.4	31.1
18	78.9	17.3	33.4	7.3	18	75.8	36.5	33.3	9.0
19	54.5	13.4	31.0	8.3	19	42.8	25.2	30.9	4.9
20	46.0	25.9	29.7	26.3	20	56.0	48.6	30.0	35.2
21	32.1	54.0	8.2	26.1	21	40.7	91.4	7.9	36.4
22	41.4	22.3	30.7	14.8	22	55.7	42.0	30.9	13.1
23	30.8	38.8	16.2	29.9	23	44.6	84.2	15.2	29.6
<i>Bird 152</i>					<i>Bird 154</i>				
1	7.2	19.5	7.0	35.6	1	25.3	47.3	7.3	29.0
2	15.5	22.0	29.9	34.0	2	41.3	43.0	30.0	30.5
3	13.3	9.1	31.9	4.7	3	35.3	23.0	31.9	6.3
4	9.8	20.9	16.6	34.0	4	45.6	50.6	16.6	28.9
5	10.2	9.7	29.3	20.8	5	42.0	34.4	29.6	14.3
6	5.2	12.0	6.9	26.8	6	21.7	51.7	7.9	31.9
7	14.8	14.1	29.9	33.7	7	39.5	53.9	30.2	28.2
8	16.9	8.1	31.6	3.3	8	28.1	19.8	31.2	4.9
9	15.3	24.1	14.9	30.2	9	38.8	61.6	15.2	33.4
10	16.4	16.4	30.2	14.9	10	30.9	31.8	31.6	16.5
11	12.7	27.9	7.8	26.5	11	19.2	56.3	6.8	43.1
12	15.0	21.7	30.4	28.4	12	39.7	63.4	29.5	31.6
13	12.6	9.2	30.4	6.6	13	27.3	24.0	30.3	6.6
14	15.4	23.2	14.8	29.8	14	50.0	82.9	14.8	33.2
15	19.6	15.7	30.4	18.2	15	46.0	45.1	32.0	14.9
16	23.1	12.3	30.4	7.1	16	55.8	33.5	31.3	7.6
17	44.1	23.5	127.0	31.0	17	76.4	29.9	134.5	28.7
18	27.9	11.1	30.4	7.3	18	77.0	25.0	30.4	9.0
19	27.0	13.6	29.9	8.2	19	51.1	13.2	31.3	9.9
20	25.1	21.6	31.3	28.2	20	51.8	46.7	32.3	28.1
21	13.1	22.7	7.2	29.6	21	33.4	86.1	7.2	26.3
22	25.4	18.4	31.3	13.1	22	47.4	54.4	31.6	14.9
23	18.0	26.6	14.8	27.9	23	45.3	72.3	15.1	34.8

Condition	Responses/min		Reinforcements/hr		Condition	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
<i>Bird 155</i>					<i>Bird 156</i>				
1	60.6	96.5	7.9	37.2	1	33.6	54.0	7.6	24.1
2	71.7	75.5	31.0	32.3	2	31.5	38.9	31.9	27.4
3	89.4	50.4	33.9	6.3	3	37.4	35.4	33.2	16.0
4	45.8	67.5	15.3	38.8	4	22.2	34.0	16.3	32.2
5	82.0	67.0	30.9	9.5	5	26.7	25.4	31.3	16.0
6	53.8	89.4	7.6	31.9	6	23.3	40.4	8.2	26.9
7	72.5	80.1	30.8	31.7	7	19.4	32.4	29.8	28.4
8	58.3	39.2	29.8	11.6	8	43.0	14.4	31.3	6.5
9	59.8	86.3	14.9	33.7	9	25.2	51.3	15.6	28.3
10	68.2	67.5	30.5	13.2	10	37.3	39.6	30.8	16.6
11	55.7	101.9	8.5	21.2	11	20.7	42.0	7.5	31.2
12	59.7	77.7	30.2	31.5	12	21.2	25.3	31.0	33.1
13	35.8	23.7	31.0	4.9	13	18.8	14.1	30.6	6.5
14	44.5	56.4	14.8	28.1	14	21.1	32.0	14.8	29.7
15	46.9	41.7	31.3	13.1	15	29.0	24.0	29.3	16.5
16	57.2	37.5	31.4	8.7	16	37.4	23.1	30.8	6.5
17	54.1	34.0	131.4	31.0	17	37.5	20.3	131.5	33.2
18	60.7	35.9	31.4	5.6	18	48.4	37.2	31.1	8.9
19	52.2	20.9	30.8	6.7	19	27.6	24.0	30.6	6.5
20	56.1	44.4	29.9	29.9	20	35.2	28.6	31.6	36.6
21	62.4	94.8	6.5	31.2	21	26.7	60.0	8.8	34.4
22	70.9	58.2	30.8	20.0	22	25.0	20.3	31.6	16.5
23	75.2	90.5	15.8	30.1	23	23.2	45.3	15.2	30.4

Appendix 2

Experiment 2. Responses per minute and reinforcements per hour in each component and experimental condition.

Condition	Responses/min		Reinforcements/hr		Condition	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
<i>Bird 151</i>					<i>Bird 154</i>				
1	24.4	46.7	7.9	32.6	1	29.9	53.6	7.8	31.5
2	31.5	39.3	31.3	31.1	2	43.0	49.9	29.5	29.8
3	52.7	34.0	31.6	9.5	3	46.0	34.3	32.6	8.9
4	49.0	61.1	16.3	30.5	4	53.8	53.4	16.9	31.5
5	62.2	45.9	31.0	17.4	5	59.7	45.7	29.5	14.1
6	12.6	62.8	5.6	27.0	6	30.4	77.0	6.2	32.0
7	48.7	32.0	31.3	33.7	7	54.4	54.3	31.3	32.0
8	74.6	17.9	30.3	6.9	8	50.2	38.8	33.6	8.0
9	54.5	43.1	15.3	30.8	9	42.2	53.3	14.2	31.7
10	68.6	30.4	29.0	15.3	10	46.8	41.9	31.1	15.3
<i>Bird 152</i>					<i>Bird 155</i>				
1	11.0	27.8	5.0	30.2	1	63.2	81.0	9.5	29.8
2	18.7	23.0	28.7	31.1	2	56.6	81.7	31.0	32.8
3	25.4	14.7	31.4	6.7	3	78.3	48.3	30.8	6.1
4	19.9	23.8	15.1	29.2	4	60.8	69.2	15.6	31.0
5	22.5	19.0	31.5	14.6	5	84.0	67.2	30.8	15.7
6	5.3	30.7	8.9	30.5	6	37.7	48.3	7.3	31.5
7	10.2	25.3	30.2	29.9	7	47.5	24.7	32.4	31.0
8	11.6	14.1	29.0	7.4	8	47.5	21.0	30.2	6.8
9	8.4	28.6	13.0	31.8	9	37.3	32.0	14.2	30.7
10	15.3	18.9	31.8	14.6	10	47.3	21.1	32.3	14.2
<i>Bird 153</i>					<i>Bird 156</i>				
1	40.2	78.8	10.1	33.2	1	20.8	30.3	10.1	29.2
2	49.6	60.9	32.7	29.5	2	43.0	45.7	31.5	30.0
3	65.9	37.6	30.3	8.4	3	42.4	27.3	30.3	7.3
4	38.6	50.3	14.0	33.2	4	34.9	43.7	15.2	31.3
5	61.1	46.3	30.9	15.7	5	28.1	32.8	29.6	14.6
6	14.6	28.2	9.0	29.8	6	28.7	24.0	9.0	28.7
7	62.2	32.6	31.4	29.2	7	26.3	17.3	30.1	30.4
8	43.2	22.4	30.1	8.0	8	30.5	9.2	31.9	8.5
9	28.3	29.8	17.5	30.1	9	20.5	13.3	17.6	29.6
10	37.4	26.7	30.5	14.7	10	18.4	9.0	30.0	17.5

Appendix 3

Experiment 3. Responses per minute and reinforcements per hour in each component and experimental condition.

Condition	Responses/min		Reinforcements/hr		Condition	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
Bird 151					Bird 153				
1	68.4	22.2	30.9	12.7	1	35.6	18.7	30.0	15.9
2	42.6	32.6	17.1	29.6	2	30.0	30.8	14.0	28.9
3	29.2	44.8	14.9	29.7	3	11.4	23.1	13.0	30.4
4	27.6	27.4	26.8	13.6	4	16.5	17.1	27.2	15.2
5	32.6	24.1	42.4	49.1	5	6.5	5.2	23.5	16.0
6	12.4	15.1	41.9	39.8	6	14.1	22.5	36.0	47.0
7	25.5	21.1	49.3	62.0	7	17.9	19.5	53.8	50.5
8	87.2	30.9	32.3	6.0	8	40.1	26.2	31.6	6.0
9	33.6	50.8	8.2	32.9	9	10.7	23.1	7.1	30.1
10	41.1	70.4	9.5	31.7	10	14.9	30.8	6.8	26.1
11	98.7	50.1	28.9	6.0	11	37.7	23.4	29.7	6.8
12	135.3	40.7	36.9	8.7	12	42.0	20.3	36.7	6.0
13	62.8	99.3	11.3	32.2	13	19.6	34.0	6.9	32.0
14	43.3	143.0	9.5	31.3	14	42.9	77.6	9.5	33.0
15	131.6	50.0	36.9	10.4	15	38.6	40.7	34.0	6.9
16	117.7	29.3	29.5	8.7	16	59.3	42.2	34.0	9.5
17	52.4	78.5	7.8	32.2	17	34.6	54.3	6.9	29.2
18	40.4	63.7	7.3	32.0	18	39.1	65.3	7.9	30.6
19	54.3	42.0	29.3	9.1	19	56.5	36.9	31.3	7.9
20	84.8	29.0	34.2	9.0	20	62.4	44.6	36.0	9.0
21	74.6	29.1	328.4	73.1	21	56.9	43.9	301.5	72.1
22	32.8	56.9	67.2	298.2	22	48.4	63.6	76.9	310.5
23	15.2	82.4	65.4	294.0	23	20.3	47.0	64.8	289.2
24	39.0	107.7	74.4	257.4	24	42.0	44.5	78.6	261.6
Bird 152					Bird 154				
1	19.7	21.1	30.8	16.4	1	27.5	28.3	30.8	13.6
2	7.1	11.8	13.6	29.3	2	27.6	46.2	16.3	33.4
3	13.4	24.3	17.0	30.5	3	22.8	27.2	14.1	29.3
4	17.7	16.7	31.1	15.8	4	38.2	28.0	27.7	15.7
5	11.6	8.3	32.6	38.4	5	33.9	28.3	46.9	46.3
6	5.5	5.1	34.6	33.8	6	42.6	34.5	44.9	47.2
7	10.0	14.1	67.9	42.2	7	40.8	27.1	67.1	58.7
8	26.2	13.2	34.6	7.6	8	44.6	22.6	30.5	8.7
9	11.4	19.8	8.2	34.9	9	28.5	42.0	7.6	30.0
10	14.0	26.5	6.0	30.6	10	34.3	49.1	6.0	32.3
11	26.1	13.3	36.8	7.7	11	38.7	25.6	29.6	8.6
12	31.3	9.7	32.1	6.9	12	55.4	33.1	34.0	6.0
13	21.0	27.0	10.4	32.0	13	42.4	59.8	6.0	32.0
14	7.5	23.6	9.5	33.8	14	39.8	70.4	7.7	32.0
15	26.4	12.0	34.9	6.9	15	82.8	47.9	33.7	6.9
16	22.2	5.3	34.9	6.1	16	75.8	32.1	36.7	6.9
17	10.2	21.2	8.6	29.2	17	45.0	71.5	8.6	32.8
18	8.3	13.8	7.3	26.7	18	46.6	53.5	8.5	33.9
19	14.8	7.7	29.3	6.1	19	58.0	41.1	31.9	9.1
20	24.9	6.6	30.8	7.8	20	64.1	31.7	32.7	7.7
21	27.3	10.4	285.3	49.1	21	52.0	28.2	297.4	65.3
22	20.7	36.2	70.2	277.8	22	55.2	92.3	65.4	301.2
23	17.5	26.1	69.0	264.0	23	48.1	45.9	70.2	292.2
24	33.0	44.9	79.2	248.4	24	94.0	79.0	75.0	253.8

Condition	Responses/min		Reinforcements/hr		Condition	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
<i>Bird 155</i>					<i>Bird 156</i>				
1	58.4	26.5	31.1	15.8	1	13.2	4.1	28.9	15.8
2	44.4	35.0	16.3	29.4	2	12.5	16.2	13.5	32.3
3	46.9	59.2	17.4	30.5	3	8.9	6.6	12.9	28.7
4	65.5	58.8	29.7	16.4	4	11.1	9.5	29.9	14.6
5	47.1	28.7	36.5	59.2	5	7.1	8.2	35.2	40.0
6	38.2	46.5	67.1	35.5	6	8.6	9.6	34.0	45.5
7	37.4	39.9	64.6	85.1	7	22.7	19.6	66.0	57.3
8	68.7	39.7	36.8	6.5	8	17.0	12.5	31.7	8.2
9	37.9	48.4	9.8	31.7	9	7.0	10.0	7.6	27.7
10	50.7	74.3	10.3	32.4	10	10.6	24.1	9.5	29.6
11	75.3	51.4	37.7	6.0	11	16.8	18.7	35.0	6.8
12	71.6	46.9	33.1	8.6	12	24.9	19.3	31.1	8.6
13	50.2	69.6	10.4	32.0	13	14.5	24.5	7.7	31.0
14	30.8	54.5	9.5	29.3	14	24.4	62.9	11.2	33.0
15	49.3	35.7	33.8	7.7	15	50.3	38.0	32.0	6.8
16	44.8	22.4	34.9	7.7	16	29.7	22.3	32.0	6.0
17	29.2	35.7	8.6	32.0	17	29.1	37.5	12.1	32.0
18	50.6	53.1	7.9	32.6	18	14.3	22.2	7.3	33.2
19	47.7	39.0	33.9	5.5	19	20.5	13.7	33.2	8.5
20	64.9	41.7	36.0	9.0	20	22.3	17.2	32.8	8.9
21	77.5	35.9	317.5	64.4	21	43.7	18.8	283.8	65.9
22	31.8	44.7	58.9	276.2	22	29.5	44.1	77.8	282.4
23	13.6	49.6	61.8	289.8	23	9.9	25.5	64.2	234.6
24	32.8	53.7	74.4	241.2	24	36.9	58.4	67.2	254.4

Appendix 4

Experiment 4. Responses per minute and reinforcements per hour in each component and experimental condition.

Component Duration (sec)	Responses/min		Reinforcements/hr		Component Duration (sec)	Responses/min		Reinforcements/hr	
	Red	Green	Red	Green		Red	Green	Red	Green
<i>Bird 151</i>					<i>Bird 154</i>				
180	54.3	34.8	130.8	41.4	180	51.2	46.5	127.2	42.6
60	65.3	33.2	130.8	41.4	60	52.5	52.6	129.6	42.6
30	67.4	27.4	132.0	43.8	30	56.8	39.2	133.8	42.0
9	62.5	22.9	144.0	49.2	9	68.8	37.0	144.6	49.8
6	73.0	29.9	143.4	52.8	6	71.6	45.1	141.6	52.2
6	37.3	41.9	43.8	154.8	6	49.1	62.0	49.8	154.2
180	35.7	48.4	40.2	127.8	180	60.5	65.1	42.0	127.2
60	30.8	66.6	41.8	130.0	60	53.4	71.7	41.7	132.3
30	27.5	66.7	42.4	127.9	30	51.0	73.8	42.1	129.5
9	29.0	71.1	42.5	149.0	9	42.4	68.0	44.4	150.6
6	30.7	78.6	45.8	150.9	6	37.0	68.0	49.0	154.2
6	73.6	47.6	138.6	49.5	6	54.7	45.5	139.1	49.4
<i>Bird 152</i>					<i>Bird 155</i>				
180	27.4	15.5	127.8	42.6	180	84.5	65.8	131.4	42.6
60	27.5	14.4	130.8	40.8	60	86.7	70.7	132.0	40.2
30	40.3	23.7	130.2	43.2	30	70.3	41.5	131.4	46.8
9	41.2	22.3	135.0	43.8	9	85.8	54.8	138.0	46.8
6	38.8	23.9	138.6	50.4	6	91.6	57.5	140.4	51.6
6	26.7	30.8	49.2	147.0	6	77.8	56.2	45.0	156.6
180	19.9	31.8	40.2	126.0	180	52.9	56.0	42.0	127.8
60	17.2	32.3	41.8	129.4	60	53.0	60.2	43.3	128.5
30	19.7	34.0	41.2	131.0	30	57.0	77.2	41.5	137.5
9	21.6	40.1	46.4	139.3	9	47.1	81.9	48.6	148.9
6	24.3	41.7	41.5	150.0	6	46.2	88.9	46.1	162.7
6	30.1	25.6	133.4	49.5	6	74.4	65.9	134.7	51.4
<i>Bird 153</i>					<i>Bird 156</i>				
180	38.9	41.4	128.4	40.2	180	28.2	23.5	115.2	38.4
60	48.5	51.7	129.6	42.0	60	41.7	28.6	128.4	41.4
30	39.5	35.1	132.6	43.2	30	49.2	31.0	135.0	40.8
9	55.0	34.3	139.8	49.8	9	48.1	31.2	138.6	47.4
6	52.9	33.6	147.6	46.8	6	43.4	25.8	138.0	49.8
6	41.3	42.4	46.8	157.2	6	33.0	32.2	48.0	150.6
180	31.2	34.6	42.0	127.8	180	30.9	37.2	40.8	129.0
60	31.8	47.2	41.0	126.6	60	31.4	38.3	42.3	129.0
30	24.8	48.2	42.0	136.6	30	23.9	30.3	42.7	135.5
9	35.8	41.5	42.2	144.6	9	28.0	29.0	41.0	134.0
6	39.6	43.9	46.4	145.7	6	33.0	27.0	46.4	149.0
6	50.3	42.9	140.0	49.6	6	35.3	24.2	139.2	53.6