

*TIME ALLOCATION AND NEGATIVE REINFORCEMENT*¹

WILLIAM M. BAUM

HARVARD UNIVERSITY

Pigeons' standing on one or the other side of a chamber was reinforced with timeout from electric shock on two concurrent variable-interval schedules. For two pigeons, the ratio of time spent on the left to time spent on the right approximately matched the ratio of timeouts obtained on the left to timeouts obtained on the right. The data of two other birds deviated from this relation, although in opposite directions. Overall, the results suggest that reduction in rate of electric shock plays a role in behavioral allocation analogous to that played by rate of positive reinforcement. It appears possible to describe aversive control and positive control within the same conceptual framework—that provided by the matching relation.

The positive law of effect, which attributes increases in responding to favorable consequences, has long been accepted. The negative law of effect, which attributes decreases in responding to unfavorable consequences, has fared less well. It was rejected both by Thorndike (1932) and by Skinner (1938). Recent research, however, has pointed to the insufficiency of the grounds for the rejection, and has stimulated the law's revival (Azrin and Holz, 1966; Rachlin and Herrnstein, 1969). Although one may puzzle over the reasons behind the prejudice against it, there is little doubt that its long unpopularity retarded the growth of understanding of aversive control, particularly punishment and avoidance. Whereas many of the phenomena of positive reinforcement can be understood within the framework of the matching equation (Herrnstein, 1970), the phenomena of aversive control have yet to be described coherently.

Some initial steps may point in this direction. Herrnstein (1969) and Herrnstein and Heline (1966) suggested that the independent variable controlling avoidance is shock-

rate reduction. Such a variable might permit a quantitative analysis of negative reinforcement (avoidance and escape) comparable to the analysis that rate of reinforcement has permitted for positive reinforcement (Herrnstein, 1970).

A study of multiple avoidance schedules by de Villiers (1972) supported this notion. He found behavioral contrast comparable to that in multiple schedules of positive reinforcement. When shock-rate reduction was decreased in one component, response rate in the other component increased, even though shock-rate reduction in that component remained the same. Conversely, when shock-rate reduction was increased in one component, response rate in the other component decreased. De Villiers was able to account for all the data with Herrnstein's (1970) equation for behavioral contrast, substituting shock-rate reduction for rate of positive reinforcement.

Perhaps the simplest instance of instrumental shock-rate reduction is response-produced timeout from shock, which is a form of escape. If an organism faces two alternatives differing in the frequency with which they produce such timeouts, then the two alternatives can be said to differ in the shock-rate reduction they produce in the same ratio as the ratio of the frequencies of timeout. For example, if one alternative provides the timeout twice as often as the other, then that alternative produces twice the shock-rate reduction of the other.

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The matching equation, now well established, specifies:

$$\frac{B_1}{B_2} = \frac{r_1}{r_2} \quad (1)$$

where r_1 and r_2 are the rates of reinforcement provided by Alternatives 1 and 2, and B_1 and B_2 are the response frequencies for Alternatives 1 and 2. The response frequencies B_1 and B_2 have generally been measured as response rates, for example, pecks per minute (Herrnstein, 1961; 1970). Baum and Rachlin (1969) suggested, however, that response frequency be measured as time spent responding. They studied responses that can be sensibly measured only in terms of time spent: standing in a location. They found that the ratio of times spent on two sides of a chamber was directly proportional to the ratio of the rates of food presentation provided on the two sides:

$$\frac{T_1}{T_2} = k \frac{r_1}{r_2} \quad (2)$$

The constant k represented a position bias, due to such asymmetries as differences in the food hoppers and movement of the two floor panels. That the position bias could be corrected by multiplying by a constant supports the general rule that the ratio of the times spent at two alternatives matches the ratio of the reinforcing values of the alternatives (Baum and Rachlin, 1969):

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} \quad (3)$$

where value, V , is defined as the product of all reinforcement variables (see Baum and Rachlin, 1969, Equation 10).

The present experiment used a similar situation, in which pigeons' standing on one side or the other of a chamber was reinforced on two concurrent variable-interval schedules, to consider the extent to which Equation 1 holds when the reinforcer is timeout from electric shock, instead of food. It takes a step toward bringing positive and negative reinforcement together into a single coherent framework in which reduction in rate of aversive stimulation plays a role corresponding to rate of positive reinforcement.

METHOD

Subjects

Four male White Carneaux pigeons—numbered 334, 488, 490, and 496—had free access to grain and water in their home cages throughout the experiment. Electrodes, at first stainless steel wire and later gold wire, were implanted around each bird's pubis bones. The electrodes were connected to a plug mounted on a harness that the bird wore throughout the experiment.

The pigeons served earlier in an experiment using food reinforcement in the same experimental chamber (Baum and Rachlin, 1969). Pigeon 488 died before the end of the experiment, from a broken neck due to a fall.

Apparatus

The experimental chamber was the same one used by Baum and Rachlin (1969), with a shock swivel (Ralph Gerbrands Co.) added. A slot cut in the roof of the chamber allowed the pigeons freedom of movement, in spite of the cable connecting the swivel to the plug on the harness. Electric shocks were delivered by connecting a pigeon's electrodes to 110 V ac through a resistor in series. The resistor was set to produce the desired current (7 mA, except during initial training) in a closed circuit with no bird (*i.e.*, as if the pigeon's resistance were zero).

The dimensions of the chamber were 23 (height) by 22 (depth) by 50 cm (9 by 8.5 by 20 in.). The floor of the chamber consisted of two adjacent platforms of equal area. When a bird stood on either platform, it dropped about 0.5 cm (0.125 in.), releasing a micro-switch. Three lights were mounted above the transparent Plexiglas roof: a red light (7 W) over the left-hand platform, a green light (7 W) over the right-hand platform, and a white light (two 6-W bulbs) over the boundary between the two platforms, at the center of the chamber.

Procedure

As long as one of the lights was on, the pigeon received brief (about 50 msec) 7-mA electric shocks at 1-sec intervals. Reinforcement consisted of a 2-min blackout (all lights off), during which the pigeon received no shock. These timeouts were scheduled by two separate variable-interval (VI) programmers,

one for each side of the chamber. The VI schedules, which were the same ones used by Baum and Rachlin (1969), conformed to the distribution suggested by Fleshler and Hoffman (1962). A bird's daily session ended when the sum of timeouts obtained on the two sides equalled 30. Sessions were conducted every day.

Whenever the pigeon moved from one side of the chamber to the other, a changeover delay (COD) prevented reinforcement for 1 sec. The bird had to dwell on a side for at least 1 sec to receive any reinforcement. During the COD, the white light alone was lit. After the COD, if the pigeon was on the left, the red light alone was lit. If the pigeon was on the right, the green light alone was lit. If the pigeon stood so as to depress both platforms at once, only the white light was lit. Reinforcements occurred only when the red or green light was lit. Time when the white light was on was excluded from the recorded time spent on either side.

While the red or green light was on, the VI programmer for that side presented timeouts according to its VI schedule. As long as the bird stood on a side, timeouts occurred at the prescribed rate. Both VI programmers advanced, regardless of which side the pigeon stood on. If a timeout was scheduled for one side while the bird was on the other, the programmer stopped until the bird changed over and obtained the scheduled timeout. During timeout, neither programmer advanced. The VI programmers stopped when the pigeon stood so as to depress both floor platforms at once (*cf.* Baum and Rachlin, 1969).

Two months of preliminary training preceded these final conditions. Since the pigeons tended to become immobile when shocked, they were initially required to receive timeouts on alternate sides. At first, timeout occurred after every changeover in this forced-alternation procedure. The shock intensity was gradually increased to 7 mA, and the timeout duration was gradually increased from 10 sec to 2 min. The COD, initially 5 sec, was decreased to 1 sec. Then, two VI 0.5-min schedules arranged the timeouts for one week. These were replaced with two VI 2-min schedules for another week, and finally, the requirement of alternation was removed.

With the beginning of the final conditions, the birds were all on a concurrent VI 2-min

VI 2-min schedule. Table 1 shows all the situations studied. The birds started with situation e. Two (334 and 490) were exposed to situations e through a, then a through i, and i through a, while two (488 and 496) were exposed to situations e through i, then i through a, and a through i, in order, with one week per situation. Before starting another cycle, situations a and i were presented alternately, two weeks per situation, each situation presented twice. A new cycle through the situations then began. Pigeons 334 and 490 were exposed to situations a through i, and then i through a, in order, for two weeks per situation. At the same time, Pigeons 488 and 496 were exposed to the same situations in opposite order: i through a, and then a through i. This cycle of situations was repeated, finally, with four-weeks' exposure to each situation.

Table 1
Summary of Experimental Situations

	Schedule on Left (in minutes)	Schedule on Right (in minutes)
a	VI 0.5	VI 8
b	VI 0.5	VI 4
c	VI 0.5	VI 2
d	VI 1	VI 2
e	VI 2	VI 2
f	VI 4	VI 2
g	VI 8	VI 2
h	VI 8	VI 1
i	VI 8	VI 0.5

RESULTS

Increasing the length of exposure improved the consistency in the data that summarized performance on the last five days of presentation of each situation. For example, when lines were fitted to the data showing time distribution as a function of reinforcement distribution, the variability around the fitted lines decreased as the length of presentation increased.

Since the performances with four weeks of presentation were generally the most orderly, they provide the best basis for relating the present results to previous research. These data, summarized by summing over the last five days of exposure to each situation, appear in the appendix.

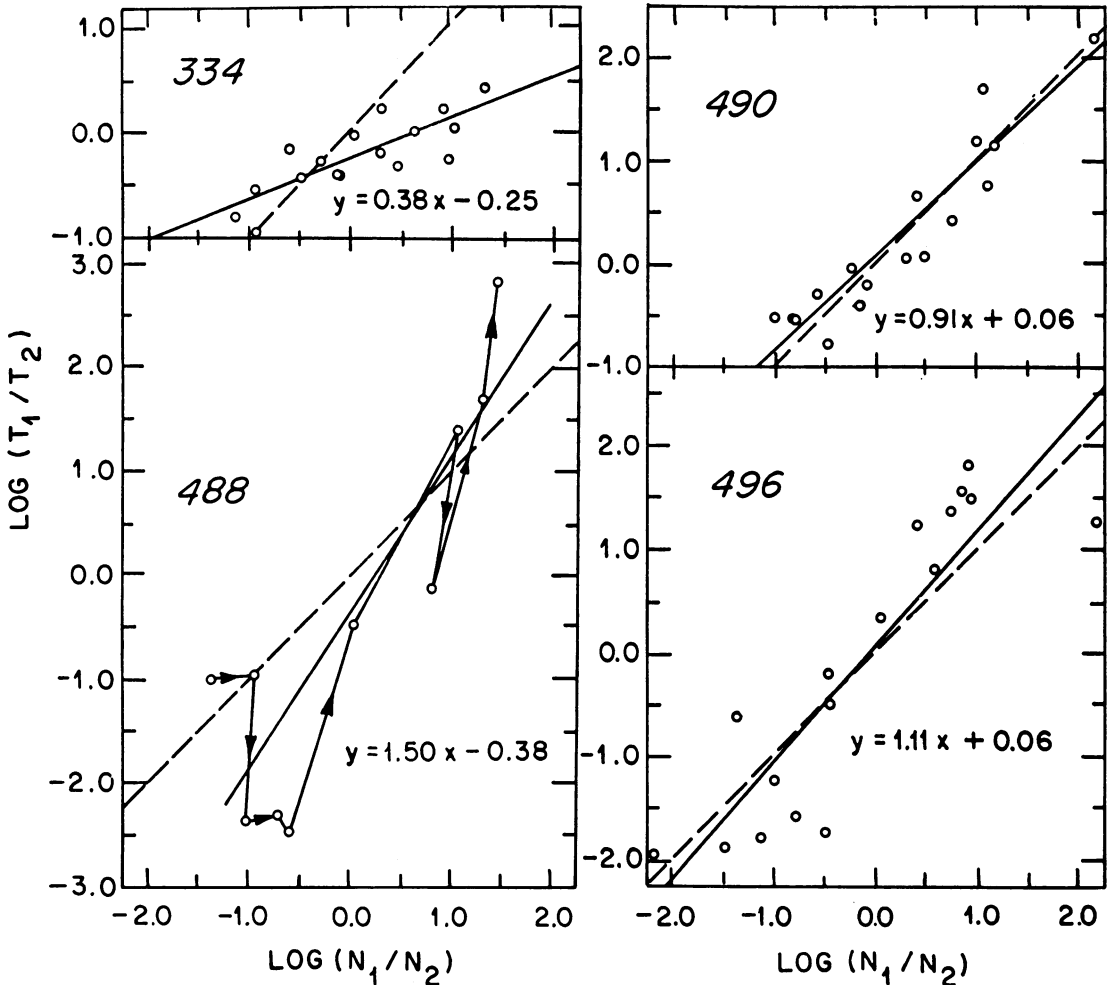


Fig. 1. The logarithm of the ratio of time spent on the left to time spent on the right as a function of the logarithm of the ratio of number of reinforcements obtained on the left to number of reinforcements obtained on the right. Each graph shows data from an individual bird. The solid lines were fitted by the method of least squares. The equation of the fitted line appears in each graph. The broken lines have a slope of one and pass through the origin; they represent the performance of perfect matching.

Figure 1 shows the logarithm of the ratio of time on the left (T_1) to time on the right (T_2) as a function of the logarithm of the ratio of number of timeouts on the left (N_1) to number of timeouts on the right (N_2). In these coordinates, the matching relation appears as a line of slope one, passing through the point (0,0). A position bias will produce a value of k in Equation 2 less than or greater than one. If Equation 2 describes the data, they should conform to a line of slope one, possibly with an intercept ($\log k$) less than or greater than zero. In other words, if the data can be fitted with a line parallel to the matching line, they support Equation 2. The matching line ap-

pears in each graph in Figure 1 as a broken line. The solid lines were fitted to the data by the method of least squares. The equation of the fitted line appears in each graph. Since Pigeon 488 showed a tendency toward hysteresis (Stevens, 1957), the order of presentation of the situations is indicated with arrows in its graph. Once having preferred one side, this pigeon showed great resistance to shifting its preference to the other side.

For two birds (490 and 496), the slopes of the fitted lines are close to one. For Bird 334, the slope is substantially less than one. For Bird 488, the slope is substantially greater than one.

Figure 2 shows all the data of Figure 1 plotted in a single graph. The broken line represents the matching relation. The solid line was fitted to the data by the method of least squares. Its equation is given. Since the slope (1.01) is close to one, the central tendency in the data is described by Equation 2.

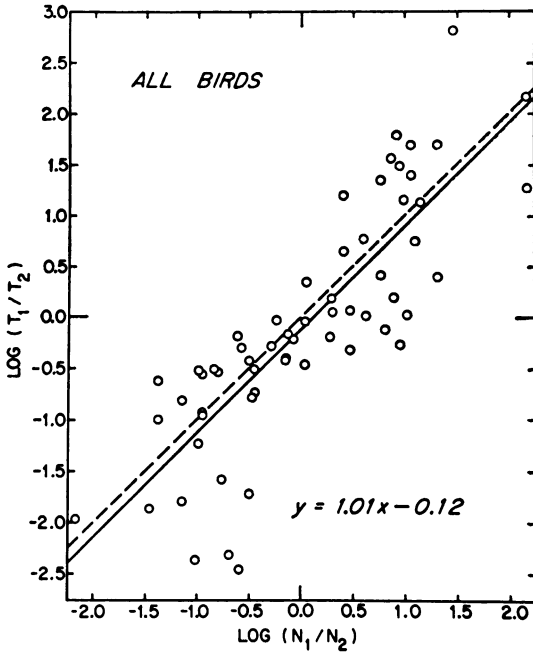


Fig. 2. The data of Figure 1 in a single graph. The solid line was fitted by the method of least squares. The broken line represents the matching relation.

Figure 3 shows rate of changeover as a function of preference. Both the results for negative reinforcement (triangles) and positive reinforcement (circles; Baum and Rachlin, 1969) appear for each bird. The data for positive reinforcement are more consistent than those for negative reinforcement. Still, the two experiments show a similar pattern of systematic variation in rate of changeover with preference. In the graphs for Pigeons 488, 490, and 496, an inverted U-shaped pattern can be seen in the distribution of points. For both positive and negative reinforcement, the maximum rate of changeover occurred in the region of indifference; as preference for either side increased, the rate of changeover decreased.

The graphs for 488, 490, and 496 in Figure 3 reveal also a systematic difference between the

results for positive and negative reinforcement. The ranges of preference and rate of changeover were greater for negative reinforcement. The greatest preferences were more extreme, and produced rates of changeover lower than the lowest rates with positive reinforcement. Around indifference, on the other hand, the rates of changeover were higher for negative reinforcement than for positive reinforcement.

The graph for Pigeon 334 shows a different pattern from the other three. Neither for positive nor for negative reinforcement was there any substantial systematic variation in rate of changeover with preference. In contrast to the other birds' data, the range of preferences was smaller for negative reinforcement than for positive reinforcement.

Figure 4 shows the proportion of the session time (excluding reinforcement) spent in the middle of the experimental chamber, depressing both floor platforms at once, as a function of preference. Comparison of Figures 3 and 4 reveals a strong correspondence between rate of changeover and time spent in the middle. When preference was strong, little time was spent in the middle; when preference was weak (near zero), the portion of time spent in the middle increased. For Pigeon 488, which spent little time in the middle, this correspondence appears to reflect nothing more than the necessity of standing in the middle momentarily during changeover. This bird's highest rate of changeover (42 per minute) and highest proportion of time in the middle (0.1) produce an estimate of about 0.14 sec in the middle per changeover, about the time that it might have taken the pigeon to lift its foot off the platform it was leaving. The other three birds (334, 490, and 496) present a different pattern. When near indifference, these birds spent substantial portions of time in the middle. Whereas Pigeon 488 spent 0.14 sec in the middle per changeover, the other birds spent about 1 sec, far more than the time required to step from one side to the other. Apparently, when near indifference, these birds stayed near the middle, hopping back and forth from side to side, sometimes depressing both platforms, because the light signalling the COD was the same as the light signalling that both platforms were depressed. Informal observation during experimental sessions supported this interpretation.

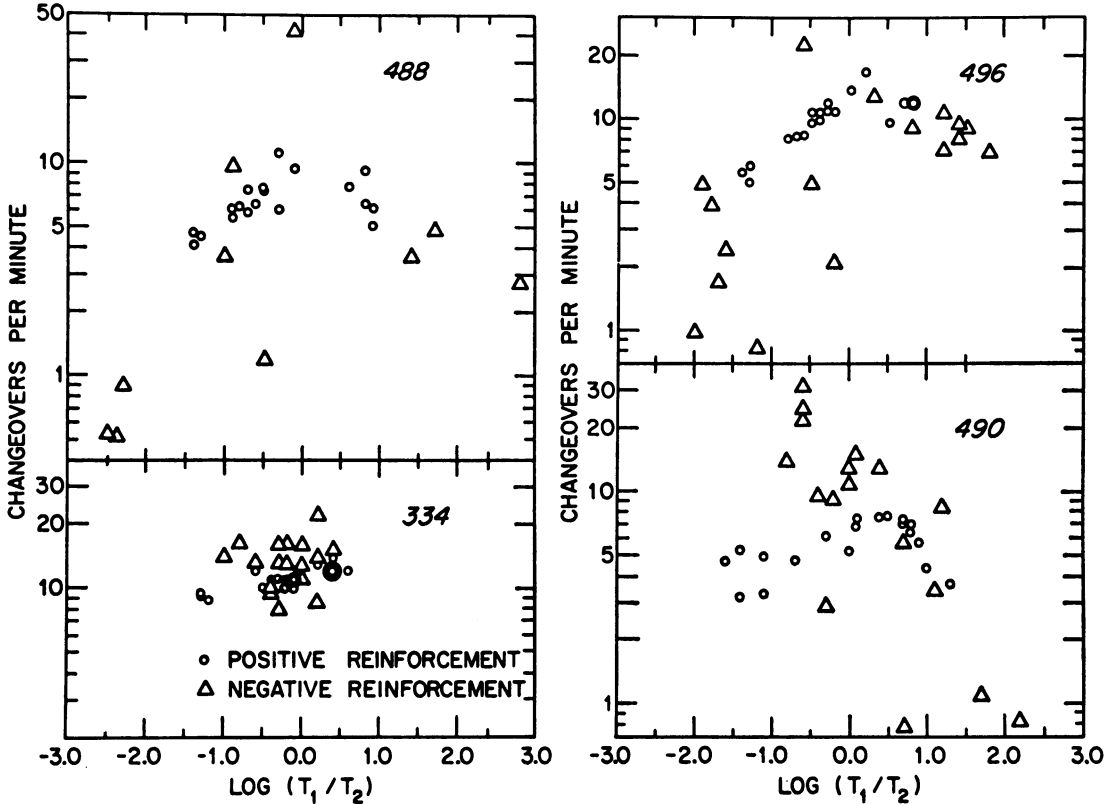


Fig. 3. Rate of changeover as a function of preference (ordinate of Figure 1). The triangles show the data from this experiment. The circles show the data from the similar experiment with positive reinforcement (Baum and Rachlin, 1969). Each graph shows data from an individual pigeon.

DISCUSSION

The results suggest that reduction in rate of electric shock enters into the matching relation in the same way as rate of food presentation (Baum and Rachlin, 1969; Herrnstein, 1970). Table 2 gives the slopes and intercepts of the fitted lines for this experiment and for the similar experiment (Baum and Rachlin, 1969) with food reinforcement. In neither ex-

periment did the slopes deviate systematically from one. In each experiment, two of the birds' data (488 and 496 for positive reinforcement; 490 and 496 for negative reinforcement) had fitted lines with slopes close to one. In each experiment, one of the other two birds' data produced a slope less than one, whereas the other produced a slope greater than one. In each experiment, the average slope is close to one (1.05 and 0.98).

Table 2

Comparison of time allocation with positive reinforcement (Baum and Rachlin, 1969) and negative reinforcement.

Pigeon	Positive Reinforcement		Negative Reinforcement	
	Slope	Intercept	Slope	Intercept
334	0.84	-0.25	0.38	-0.25
488	1.09	-0.29	1.50	-0.38
490	1.29	-0.06	0.91	0.06
496	0.98	-0.27	1.11	0.06
Average	1.05	-0.22	0.98	-0.13

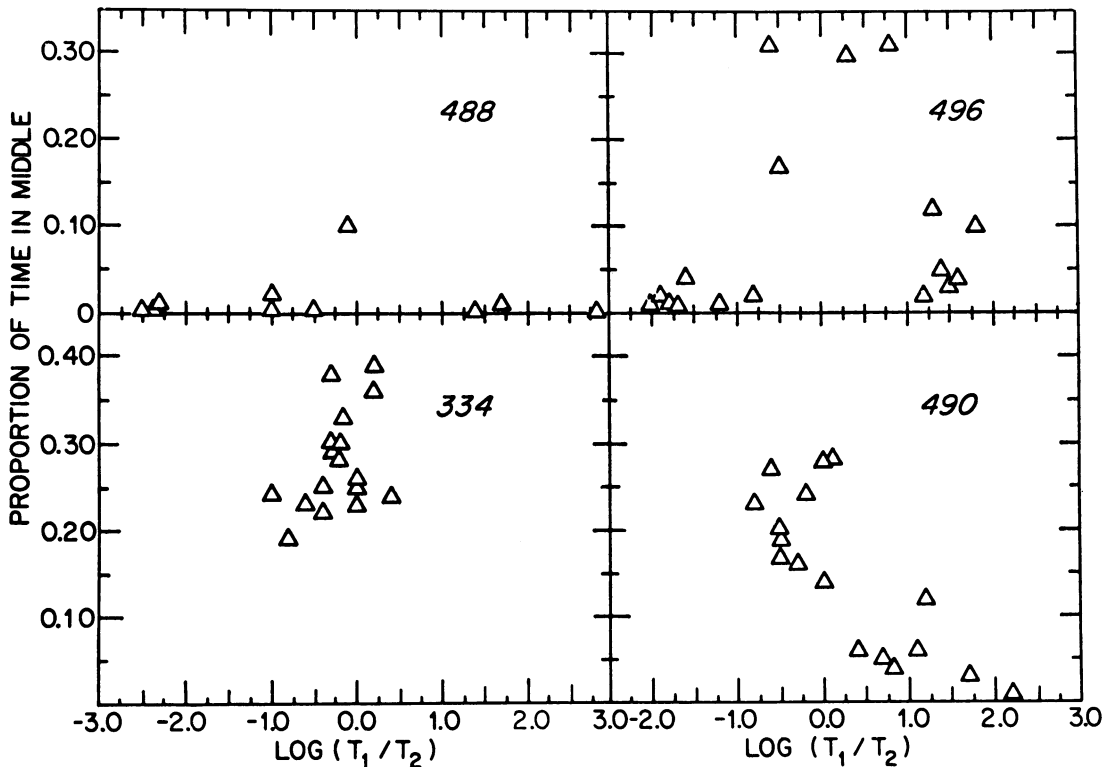


Fig. 4. Proportion of the session time spent in the middle of the chamber, depressing both floor platforms at once, as a function of preference (ordinate of Figure 1). Each graph shows data from an individual pigeon.

Two of the pigeons' data (490 and 496) produced slopes in both experiments close enough to one to be considered within the limits of typical individual variation. The incompleteness of the data for Pigeon 488 argues against weighing its results heavily. Pigeon 334, which produced a slope less than one in the experiment with positive reinforcement, produced a slope substantially less than one in this experiment. The most likely explanation of the deviation is that the changeover delay (COD) of 1 sec was too short for this bird (Herrnstein, 1961; Shull and Pliskoff, 1967). The slope closer to one with positive reinforcement may have been due to the longer COD (4.25 sec) in that experiment.

Research with positive reinforcement has shown an inverse relation between rate of changeover and COD (Shull and Pliskoff, 1967; Brownstein and Pliskoff, 1968; Pliskoff, 1971). There is, at present, no reason to suppose that a different relation holds for negative reinforcement. It is possible, therefore, that the higher rates of changeover with negative rein-

forcement (around indifference; see Figure 3) may have been due to the shorter COD in the present experiment.

Previous research (*e.g.*, Herrnstein, 1961, and Brownstein and Pliskoff, 1968) has shown that pairs of alternatives producing stronger preferences also produce lower rates of changeover. These studies related rate of changeover to the difference in the rates of reinforcement of the alternatives, rather than to preference, as in Figure 3. When preference conforms exactly to the matching relation (Equation 1), then rate of changeover can be considered equally an outcome of reinforcement or preference. When, as in the present experiment, preference often deviates from matching, it is possible to discriminate between the effects of reinforcement and preference on rate of changeover. Plotted as a function of the logarithm of the ratio of timeouts on the two sides (abscissa in Figure 1), the data of Figure 3 showed an unchanged pattern for Pigeon 334, but substantially reduced orderliness for Pigeons 488, 490, and 496. In this experiment,

therefore, rate of changeover covaried more closely with preference than with relative rate of reinforcement. This suggests that changeover and preference are not independently manipulable, but rather are interdependent aspects of performance.

The present results can be summarized as follows. Two pigeons' data suggest that relative time spent with an alternative matches the relative reduction in rate of electric shock that the alternative provides. The data from the other two pigeons deviate from this relation, but in opposite directions. Whether these aberrant data are included or not, the average performance (slope of 0.98 or 1.01; see Table 2) closely approximates matching (slope of 1.00). In addition, when the data of all four birds are considered together (Figure 2), overall performance approximates matching.

Since the matching relation can be taken as the definition of reinforcement (Herrnstein, 1969; Rachlin, 1971), the results support the view that reduction in rate of aversive stimulation constitutes negative reinforcement (Herrnstein and Hiline, 1966; Herrnstein, 1969).

In contrast to the experiment with food (Baum and Rachlin, 1969), the present experiment was technically more difficult. First, use of implanted electrodes for delivering the shock introduced new sources of variability not present in work with positive reinforcement. Electrodes became encrusted with the birds' bodily secretion. They had to be cleaned or reimplanted periodically. A broken wire between shock swivel and bird was not always detected immediately. Such variation in the delivery of the electric shock probably accounts for much of the greater unsystematic variation in the data for negative reinforcement. Second, the pigeons demonstrated greater hysteresis in changing from one choice situation to another. The observed tendency to become immobile in the presence of the electric shock could produce such an effect. Once a preference appeared, immobility would tend both to exaggerate it and to fix it, with the result that preference would resist change as the relative rate of reinforcement changed, but would reverse rapidly when it did finally change. The high rates of changeover in Figure 3, however, argue that this cannot be the whole explanation. Third, per-

formance took longer to stabilize after a change of situations. Whereas a week generally sufficed with positive reinforcement, more than two weeks—sometimes more than four weeks—seemed necessary to achieve stable performance with negative reinforcement.

Despite the technical difficulties of working with electric shock, this promises to be a fruitful line of work. De Villiers's (1972) study of multiple avoidance schedules and the present experiment suggest the possibility of integrating positive and negative reinforcement into the same conceptual framework. In the terms of Equation 3, the value of an alternative may be directly proportional to the reduction in rate of aversive stimulation it provides (see Baum and Rachlin, 1969). The generalized matching relation (Baum and Rachlin, 1969; Herrnstein, 1970) may prove the means to draw together our understanding of aversive control (punishment and avoidance) and positive control (reward and omission of reward).

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APPENDIX:

TABLE OF DATA FOR INDIVIDUAL BIRDS
IN EACH SITUATION

The data appear in the order in which they were gathered. See Table 1 for the schedules corresponding to the lettered conditions. The symbols T_1 and T_2 stand for time spent on the left and time spent on the right, respectively, including neither timeouts, COD time, nor time in the middle (depressing both floor platforms). All data are sums over the last five days of exposure. The total number of timeouts was 150 for each condition.

Bird 334

Situation	T_1 (min)	T_2 (min)	COD Time (min)	Time in Middle (min)	Change-overs	Timeouts Left
a	18.68	34.98	7.96	37.5	1576	135
b	22.85	14.26	6.50	25.5	1489	133
c	13.92	29.44	9.32	21.5	962	112
d	35.93	23.06	6.32	41.2	1492	99
e	49.85	72.61	5.87	57.2	1598	64
f	48.19	90.92	5.18	64.4	1642	51
g	62.81	94.27	11.73	65.0	3155	29
h	20.72	74.86	4.38	30.7	1655	15
i	6.87	45.35	4.56	13.3	1102	10
h	9.37	86.68	6.56	32.9	1858	15
g	61.32	163.55	13.70	67.6	2954	36
f	51.03	133.22	11.48	63.9	2697	62
e	51.15	55.74	5.93	37.5	1663	78
d	24.81	38.21	5.78	34.6	1616	98
c	22.39	21.95	4.38	16.7	1066	121
b	26.85	25.09	4.41	16.5	979	137
a	36.57	14.68	4.73	17.6	1121	143

Bird 488

Situation	T_1 (min)	T_2 (min)	COD Time (min)	Time in Middle (min)	Change-overs	Timeouts Left
i	0.95	9.55	58.54	0.3	260	6
h	5.50	48.94	71.27	2.9	1254	15
g	1.02	238.87	36.08	0.0	143	13
f	1.00	203.14	37.84	1.9	219	25
e	0.82	235.12	1.52	0.0	127	30
d	41.85	120.15	2.34	0.1	202	78
c	62.19	2.46	2.34	0.3	245	138
b	12.49	16.31	32.11	6.7	2839	130
a	64.68	1.30	3.45	0.4	334	143
b	66.41	0.10	2.06	0.1	188	145

Bird 490

<i>Situation</i>	T_1 (min)	T_2 (min)	<i>COD</i> <i>Time (min)</i>	<i>Time in</i> <i>Middle (min)</i>	<i>Change-</i> <i>overs</i>	<i>Timeouts</i> <i>Left</i>
a	71.38	0.48	0.87	0.8	62	149
b	52.78	3.60	4.36	8.4	593	136
c	59.87	4.42	1.76	4.0	245	140
d	124.60	2.54	0.29	3.5	138	138
e	242.31	54.00	0.68	14.3	242	108
f	77.54	82.54	13.45	41.3	2788	55
g	74.36	146.33	2.93	43.2	786	31
h	20.92	67.14	14.75	25.2	3180	19
i	9.85	32.81	12.56	12.6	2187	14
h	19.90	68.12	20.29	21.8	2867	20
g	29.70	177.53	23.70	70.6	4249	38
f	48.72	123.50	13.61	69.0	2434	62
e	45.56	73.86	6.46	40.0	1529	68
d	31.58	28.15	15.61	29.9	1169	100
c	24.19	20.61	7.62	20.5	1076	112
b	37.51	14.28	8.59	3.7	861	128
a	54.94	9.69	3.22	2.6	409	139

Bird 496

<i>Situation</i>	T_1 (min)	T_2 (min)	<i>COD</i> <i>Time (min)</i>	<i>Time in</i> <i>Middle (min)</i>	<i>Change-</i> <i>overs</i>	<i>Timeouts</i> <i>Left</i>
i	7.73	33.00	11.60	23.9	1727	6
h	1.24	116.77	24.73	1.5	142	1
g	12.66	219.70	32.69	2.6	223	14
f	73.55	128.62	46.82	14.9	558	39
e	3.96	209.17	2.34	3.1	379	36
d	86.96	5.41	7.55	1.9	742	108
c	51.79	2.31	5.72	2.9	605	128
b	55.57	1.81	4.77	1.8	525	135
a	56.98	3.08	6.00	9.4	864	149
b	58.06	0.94	4.37	7.3	494	134
c	55.19	1.49	6.12	2.6	609	132
d	70.44	11.76	3.23	38.3	1142	120
e	73.92	33.56	6.94	47.9	2078	79
f	46.33	149.89	3.37	42.0	1199	39
g	5.80	225.27	2.78	9.2	580	22
h	2.39	152.45	1.51	1.1	607	10
i	0.87	64.66	2.40	1.6	341	5