

## CHOICE AS TIME ALLOCATION<sup>1</sup>

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When pigeons' standing on one or the other side of a chamber was reinforced on two concurrent variable-interval schedules, the ratio of time spent on the left to time spent on the right was directly proportional to the ratio of reinforcements produced by standing on the left to reinforcements produced by standing on the right. The constant of proportionality was less than unity for all pigeons, indicating a bias toward the right side of the chamber. The biased matching relation obtained here is comparable to the matching relation obtained with concurrent reinforcement of key pecks. The present results, together with related research, suggest that the ratio of time spent in two activities equals the ratio of the "values" of the activities. The value of an activity is the product of several parameters, such as rate and amount of reinforcement, contingent on that activity.

Psychology has inherited from reflexology the notion that behavior can be viewed as a mosaic of responses. Skinner (1938) thought of the rat's lever press as a type of reflex. Accordingly, his basic measure of behavior was a count of the number of lever presses made during an experimental session. He computed the frequency of lever presses by dividing the number of presses by the duration of the session. In order to make this computation, he had to treat each lever press as an instantaneous event, as a point in time, having no duration. This assumption implies that two responses could immediately follow one another, with no time intervening. Since each response requires a certain amount of time, however, the minimum interresponse time is greater than zero. When the actual interresponse times approach the minimum interresponse time, the computation of response rate should include a correction for response duration.

Since Skinner's work, experiments on operant behavior have usually treated responses as

instantaneous. Indeed, response keys and levers, in conjunction with pulse-formers (that produce short pulses of constant duration) are so commonly used today that available apparatus tends to enforce response counting as the means of measuring behavior.

If we admit that behavior has duration, an alternative scheme of measurement becomes available. Behavior that can be counted can also be timed. Response duration, or time spent responding, can be just as basic a measure of behavior as response frequency.

In some situations the two measures are equivalent. If a pigeon's pecks at a key, for example, were approximately constant in duration, then the key-peck time would equal that constant duration multiplied by the number of key pecks. If a rat's holding of a lever is reinforced, on the other hand, then lever-holding time might often vary independent of the number of depressions of the lever.

It is usual to select the measure of behavior on the basis of the conditions of reinforcement. If we reinforce at a certain point of time, say, at the moment when the lever has been depressed 5 mm, then it seems natural to count the number of such momentary occurrences as could have produced reinforcement. We might, on the other hand, reinforce while the animal is engaged in some activity, at no particular moment, as when we reinforce being in a certain location and continue reinforcement as long as the animal stays in that location. When such continuous action is rein-

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forced, we tend to use continuous measures of behavior, that is, to measure response time, rather than response number.

Although experimental procedures often carry clear implications for choosing measures of behavior, many experimental situations defy such ready decisions. Bullock (1960), for example, trained pigeons to peck a response key that was not connected to a pulse former, but instead produced reinforcement whenever the key was operated at the same time that reinforcement (on a variable-interval schedule) was due. The pigeons eventually came to hold the key, rather than peck it. Key holding led to a decrease in response rate. Bullock resolved the incompatibility between his measure of behavior and his method of recording behavior by changing his recording, rather than his measure. He found that a pulse former eliminated key holding and restored the response rate to a high level. He might, however, have substituted a timer for his response counter.

Ambiguities of measurement have commonly arisen in the study of responding on fixed-ratio schedules of reinforcement. The assumption that a brief response is instantaneous applies only when the interresponse times are substantially longer in duration than the responses themselves. The "internal coherence" of the bursts of responding typical of performance on fixed-ratio schedules (Mechner, 1958*a* and *b*) has led to the suggestion that these bursts themselves be considered as individual units, or "higher-order" operants (Millenson, 1967, pp. 170-172).

A reasonable alternative to this conception of fixed-ratio performance remains to be explored. Fixed-ratio runs are emitted at an almost constant rate (Ferster and Skinner, 1957). The number of responses in a fixed-ratio run determines the duration of the run. As with Bullock's solution to the problem of key holding, an alternative to re-defining the unit of behavior is to change to a different measure of behavior: the time spent responding. When we consider variable-ratio schedules, measuring response time has a decided advantage over counting bursts of responding as units. Performance on variable-ratio schedules includes as high and as constant a response rate as performance on fixed-ratio schedules. The bursts of responding, however, contain a variable number of responses. While it would be difficult to accept response runs of

widely different lengths as equivalent units of behavior, it would be easy to think of these variable runs as variable times spent responding.

The notion that a rate of responding defines a continuous activity can be applied to behavior other than performance on ratio schedules. Gilbert (1958) has suggested that local response rate on any type of schedule can be separated from periods of pausing or non-responding. Some experimental evidence supports his contention that long-term response rates are built up from combinations of pauses and periods of responding at a constant rate. Catania (1961) characterized performance on a variable-interval schedule as divided into response "runs" and pauses in responding. He found that time per run, responses per run, and response rate within a run all remained constant in performance on a 3-min VI schedule paired with a variety of other schedules in both multiple and concurrent comparisons. The constancy of the response runs remained even when behavioral contrast resulted in changes in the long-term response rate on the schedule. Catania (1962) found that responding on fixed-interval schedules retains the characteristic pattern of accelerating response rate (the FI "scallop") when paired with a concurrent variable-interval schedule. Since responding on the fixed-interval schedules occurred in bursts, the pattern of acceleration resulted from a gradual decrease in the periods between bursts, rather than a smooth increase in local rate of responding. Such results are not peculiar to concurrent schedules. Blough (1963) showed that in a variety of single-key situations, the majority of interresponse times fall in the range of 0.3 to 0.5 sec. This basic response rate (two to three responses per second) was insensitive to variations in schedule, rate of reinforcement, and extinction. Blough found that variation in long-term response rate, as exhibited in generalization gradients or extinction curves, results from changes in the long interresponse times, that is, the pauses between bursts of responses at the basic rate.

These findings of Catania and Blough suggest that even such brief responses as key pecks tend to group into periods of action that alternate with periods of inaction. They imply that the quantitative relations we have found for numbers of responses can be reasonably reinterpreted in terms of times spent responding.

Herrnstein (1961) found that when a pigeon's pecks on two response keys are reinforced on two variable-interval schedules, the pigeon distributes its pecks between the keys as follows:

$$\frac{P_1}{P_1 + P_2} = \frac{r_1}{r_1 + r_2} \quad (1)$$

where  $P_1$  and  $P_2$  are the numbers of pecks on Key 1 and Key 2 during the course of a session, and  $r_1$  and  $r_2$  are the rates of reinforcement delivered by Key 1 and Key 2. Equation (1) states that the bird matches the relative number of emissions of a response to the relative rate of reinforcement for the response.

The relative number of pecks in Equation (1) can be rewritten as follows:

$$\frac{P_1}{P_1 + P_2} \equiv \frac{R_1 T_1}{R_1 T_1 + R_2 T_2} \quad (2)$$

where  $R_1$  and  $R_2$  are the rates of responding on Key 1 and Key 2, and  $T_1$  and  $T_2$  are the times spent responding on Key 1 and Key 2. Herrnstein (1961) reasoned that since both keys are always simultaneously available in the usual concurrent situation, the time base for calculating the two rates of responding should be the same for the two keys. He assumed, in other words, that in Equation (2)  $T_1$  equals  $T_2$ . He therefore expressed the matching law as:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \quad (3)$$

Equation (3) assumes that the matching law is generated by two simultaneously ongoing response rates. An alternative assumption is to suppose that the pigeon divides its time between the two keys, pecking on one and then the other for a while, but always pecking at the same rate at either key. One may assume, in other words, that in Equation (2)  $R_1$  equals  $R_2$ , but  $T_1$  may be different from  $T_2$ .

The results of Catania (1961, 1962) and Blough (1963) described above lend support to such an assumption, since they found that the response rate while pigeons are responding is invariant. With a constant response rate, time spent responding determines number of responses.

According to this line of reasoning, the matching law would predict relative time spent pecking at the two keys:

$$\frac{T_1}{T_1 + T_2} = \frac{r_1}{r_1 + r_2} \quad (4)$$

Although Equations (3) and (4) both predict the observation of Equation (1), they are independent of each other in the sense that either equation may apply in a given situation while the other does not. Distinguishing between the two experimentally is far from simple. In the standard two-key concurrent situation, there is no easy way to measure the time spent pecking at each key. There is no demarcation of time to indicate when the bird is pecking one key, when it is pecking the other, and when it is pecking neither, but engaged in some other activity altogether. One may argue that the time spent pecking a key is just the collective duration of the pecks, but a key peck undoubtedly requires more time than the time during which the bird's beak is actually in contact with the key. The lack of a clear beginning and end to each peck makes its duration difficult to measure. Assuming, however, that the time required for a key peck is approximately constant, as Catania's and Blough's results suggest, then the number of pecks would be an index of the time spent pecking.

A technique used by Findley (1958) allows a more direct approach to measuring the time spent pecking each key in a concurrent schedule. The two choice alternatives are represented by two different colors of a single key. The key color changes when the pigeon pecks a second key, called a changeover key. Instead of changing from one alternative to the other by moving from side to side, as in the standard two-key concurrent situation, the pigeon changes from one alternative to another in Findley's procedure by pecking the changeover key. Findley found that pigeons behaved, with respect to the two key colors, in the same way as they behaved with respect to two separate keys. Catania (1963a) demonstrated that pigeons in a concurrent situation like Findley's match the relative number of pecks on the two keys to the relative rate of reinforcement delivered by the two VI schedules, just as they do in a standard two-key concurrent situation. Equation (1) holds in both situations. Catania (1966) also showed that the pigeons match the relative time spent in the two components to the relative rate of reinforcement. The time spent in a component is not the

same as the time spent pecking in the component, but if the pigeons spent the same *proportion* of time responding in both components, then their performance would match relative time to relative rate of reinforcement. Catania's results, therefore, can be expressed either in terms of Equation (3) or in terms of Equation (4).

Brownstein and Pliskoff (1968) showed that in a concurrent situation like Findley's and Catania's, the matching of relative time spent in a component to relative rate of reinforcement occurs in the absence of pecking for reinforcement. In their experiment, the birds' pecks on the changeover key changed the color of a stimulus light, but the reinforcers in each component were delivered independent of the bird's behavior, at the rate determined by the VI schedule. This result presents some difficulty to the interpretation of the matching law as governing relative number of responses. It is difficult to find an appropriate measure of number of responses in Brownstein and Pliskoff's experiment. As noted earlier, it is possible to consider the number of pecks on a key as an index of the time spent pecking the key. In a like manner, it is possible to consider the time spent in a component in Brownstein and Pliskoff's experiment as an index of the number of emissions of some unspecified response. There would be little empirical basis for such an assumption, however.

The experiment described in this paper resembles that of Brownstein and Pliskoff in that it makes use of a non-specific response. It differs from their experiment in the same way that a standard two-key experiment differs from Findley's: the bird changes from one component to another not by pecking a key, but by moving from one position to another. Since the experiment demonstrates the matching relation in terms of time spent in two locations, it supports the interpretation of the matching law as a law of time allocation.

## METHOD

### Subjects

Six male White Carneaux pigeons were maintained at 80 to 85% of their free-feeding body weights. All had been trained previously with grain reinforcement to peck a key. Four birds, 488, 489, 490, and 496, had a brief period of such training. The other two, 334

and 360, had been exposed to a variety of procedures.

### Apparatus

The experimental chamber was 9 in. high, 8.75 in. deep, and 19.75 in. long (229 mm by 222 mm by 502 mm). Each end wall had a 2-in. by 2-in. (51-mm by 51-mm) opening near the floor, behind which a standard solenoid-operated food magazine was mounted. The floor of the chamber consisted of two separate grids, each pivoted on one side and suspended on the other side by a spring. The tension of each spring was sufficient to operate a microswitch when no weight was on that side. When a bird stood on either side, the floor dropped about 5 mm to release the microswitch on that side. Figure 1 is a diagram of the chamber.

Three lights were mounted above the transparent Plexiglas ceiling of the chamber. A red light was mounted above the left side, a green light above the right side, and a white light above the center.

The chamber was enclosed within a sound-attenuating box and white noise was constantly present. Events in the chamber were controlled and recorded by automatic scheduling equipment in the next room.

### Procedure

The birds were placed in the experimental chamber every day for a session that terminated when the sum of the reinforcements delivered by the two magazines equalled 40. A reinforcement on either side lasted 3 sec. During reinforcement, the three lights above the chamber were out; the only light on in the chamber was that illuminating the grain hopper. At other times one, and only one, of the three lights above the chamber was on.

While a bird stood on the left, the red light alone stayed on. While a bird stood on the

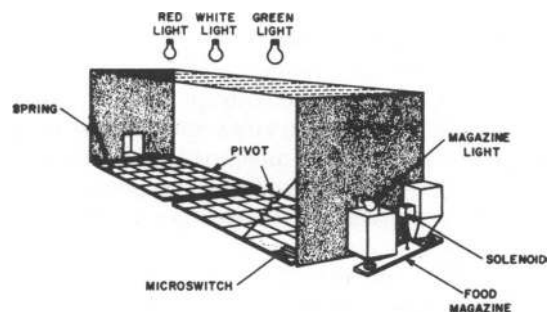


Fig. 1. The experimental chamber.

right, the green light alone stayed on. If a bird stood in the center, holding both floors down, the white light alone stayed on. No reinforcers were delivered while the white light was on. While the red or green lights were on, reinforcers were delivered only on the side that was lit, at variable intervals, according to the distribution developed by Fleshler and Hoffman (1962). Separate variable-interval timers controlled reinforcements on the two sides. A changeover delay (COD) of 4.25 sec operated whenever a bird changed sides. During the COD, only the white light was on.

These final conditions were gradually approximated over a period of two weeks. At first, the rates of reinforcement on the two sides were about 200 per hour and the COD was absent. The rates of reinforcement were gradually decreased to 30 per hour on each side while the COD was gradually lengthened to 4.25 sec.

The variable-interval timer for each side ran continuously, except from the moment a reinforcement set up for that side to the end

of that reinforcement. The timer for one side did not stop during reinforcement on the other side. Reinforcements were scheduled for both magazines no matter where the birds were standing. For a reinforcer to be actually delivered by either of the magazines, however, the bird had to be standing on the side corresponding to that magazine. Thus, in order to produce available reinforcements from both magazines, a bird would have to spend some time standing on each side of the chamber. The two principal data, time on the left and right, were cumulated on two running-time

eters. These timers did not run during the COD, during reinforcement, or while the bird held down both floors; that is, they ran only when the red or green light was on. The variable-interval (VI) schedules studied averaged 8, 4, 2, 1, and 0.5 min. Table 1 shows the situations studied. The first five situations in Table 1 were presented in a repeating cycle, conditions changing every seven days. The relative rate of reinforcement on the left went step by step from one extreme to the other and then back again. Eight weeks were needed to complete a cycle. Three of the birds were always at a position in the cycle opposite to the position of the other three. When one group was at one extreme, the other group was at the other extreme. The birds were on this cycle for nine months. Only the data for the last 13 weeks were analyzed. For half the birds, the last 13 situations occurred in the order: a, b, c, d, e, d, c, b, a, b, c, d, e; for the other birds, the situations occurred in the reverse order.

The last six pairs of schedules in Table 1 were studied after the first five pairs. The birds were exposed to each of these six conditions for two weeks, three birds in the order from f to k (in Table 1), and three in the order: i, j, k, f, g, h. In the transition from the first five conditions to the last six, three birds went from a to i, while the other three went from e to f.

The data were summarized as follows. The times and the number of changeovers were first computed as medians of the last three days of exposure to a set of VI schedules. Since each bird received conditions f through k in Table 1 only once, the three-day medians were the final form of the data for these conditions for each bird. The first five conditions (a through e in Table 1), however, appeared more than once: a and e were presented twice to each bird, and b, c, and d were presented three times to each bird. The three-day medians for each condition were averaged to produce a single data set for each condition for each bird. To obtain average data, the measures were averaged across birds at this stage in the analysis. All further computations, for the average and the individual birds, were made with the data sets so produced. The independent variables, number of reinforcements received on the left and number received on the right, were computed similarly, except that

Table 1  
Summary of Experimental Conditions

	<i>Schedule on Left (in minutes)</i>	<i>Schedule on Right</i>	<i>Scheduled Relative Rate of Reinforcement on Left</i>
a	VI 8	VI 2	0.20
b	VI 4	VI 2	0.33
c	VI 2	VI 2	0.50
d	VI 1	VI 2	0.67
e	VI 0.5	VI 2	0.80
f	VI 8	VI 0.5	0.06
g	VI 1	VI 8	0.89
h	VI 4	VI 0.5	0.11
i	VI 0.5	VI 8	0.94
j	VI 8	VI 1	0.11
k	VI 0.5	VI 4	0.89

of that reinforcement. The timer for one side did not stop during reinforcement on the other side. Reinforcements were scheduled for both magazines no matter where the birds were standing. For a reinforcer to be actually delivered by either of the magazines, however, the bird had to be standing on the side corresponding to that magazine. Thus, in order to produce available reinforcements from both magazines, a bird would have to spend some time standing on each side of the chamber. The two principal data, time on the left and right, were cumulated on two running-time

the original summaries were seven-day averages, instead of three-day medians. It was possible to use seven-day samples because the distribution of reinforcements between the two sides was unaffected by changes in the distribution of time between the two sides. The only interactions occurred during the first few days of the two-week exposures to the last six conditions in Table 1, when the birds were changing from an extreme preference for one side to an extreme preference for the opposite side.

Some symbols appearing commonly in the rest of the paper are defined as follows:

- $T_1$  is time spent on the left side
- $T_2$  is time spent on the right side
- $T_s$  is session duration (not including time during which either food magazine was operated)
- $n_1$  is number of reinforcements delivered on the left side during a session
- $n_2$  is number of reinforcements delivered on the right side during a session

## RESULTS

The data for individual birds, for all conditions, in the order of presentation, appear in the appendix.

Figures 2 and 3 show the principal result of the experiment. For each bird (Fig. 2) and the average (Fig. 3), the logarithm of the ratio of time spent on the left to time spent on the right is plotted against the logarithm of the ratio of the number of reinforcements received on the left to the number of reinforcements received on the right. In such coordinates, direct proportionality between the two ratios will appear as a straight line with a slope of one. If the ratios match, as they would according to the matching law, then the line of slope one would pass through the point (0,0). This line, the locus of perfect matching, appears in each graph in Fig. 2 and 3 as a light line. The heavier lines were fitted to the data points by the method of least squares. The equation of the fitted line is given in each graph.

The slopes of the fitted lines in Fig. 2 vary both above and below one. Their average is 1.00. The slope of the line fitted to the average data (Fig. 3) is close to one. Within the limits of individual variation, therefore, we can conclude that the ratio of times is directly proportional to the ratio of reinforcements.

For all the birds and the average, the line fitted to the data has a negative intercept. Though the line in Fig. 3 may be parallel to the matching line, it falls below it. The negative intercept means that the birds spent relatively less time on the left than the matching law would predict. Since a constant displacement like that in the logarithmic coordinates of Fig. 3 signifies a constant proportion in linear coordinates, the birds showed a constant proportional preference for the right side over the left. The result can be expressed in the following equation:

$$\frac{T_1}{T_2} = k \frac{n_1}{n_2} \quad (5)$$

where  $k$  is a constant less than one. If  $k$  were unity, Equation (5) would be identical to the matching law. Since  $k$  is not unity, we may say that a biased matching has been found, with the bias expressed by the departure of  $k$  from unity. For the average data,  $k$  equals 0.60.

Since the birds generally waited for the end of the COD before changing over again, it is reasonable to suppose that the collective time spent during CODs was equal on the two sides. Adding a constant to two variables will necessarily decrease the variance of their ratio. If the measures  $T_1$  and  $T_2$  in Fig. 2 and 3 had included the collective COD time, the slopes of the lines fitted to the data points would have been less than the slopes of the lines fitted to the data points in Fig. 2 and 3. The slope of the line fitted to the average data with the COD time included was 0.42. Equation (5) applies, therefore, only when the time spent in the COD is excluded from  $T_1$  and  $T_2$ .

Catania (1963a) and Rachlin and Baum (1969) demonstrated that in a two-key concurrent situation, the rate of pecking on either key depends only on the relative rate or amount of reinforcement delivered by the key, and is independent of the rate of pecking on the other key. Although Equation (5) specifies the *relative* time spent on either side of our apparatus, it provides no information about the analog to the *absolute* rate of key pecking, the time spent on a side as a proportion of the total session time.

The session time in this experiment is defined as the sum of the times during which the red, green, or white lights were on, that is, the sum of  $T_1$ ,  $T_2$ , the COD time, and the time spent straddling the two floors. Since the latter

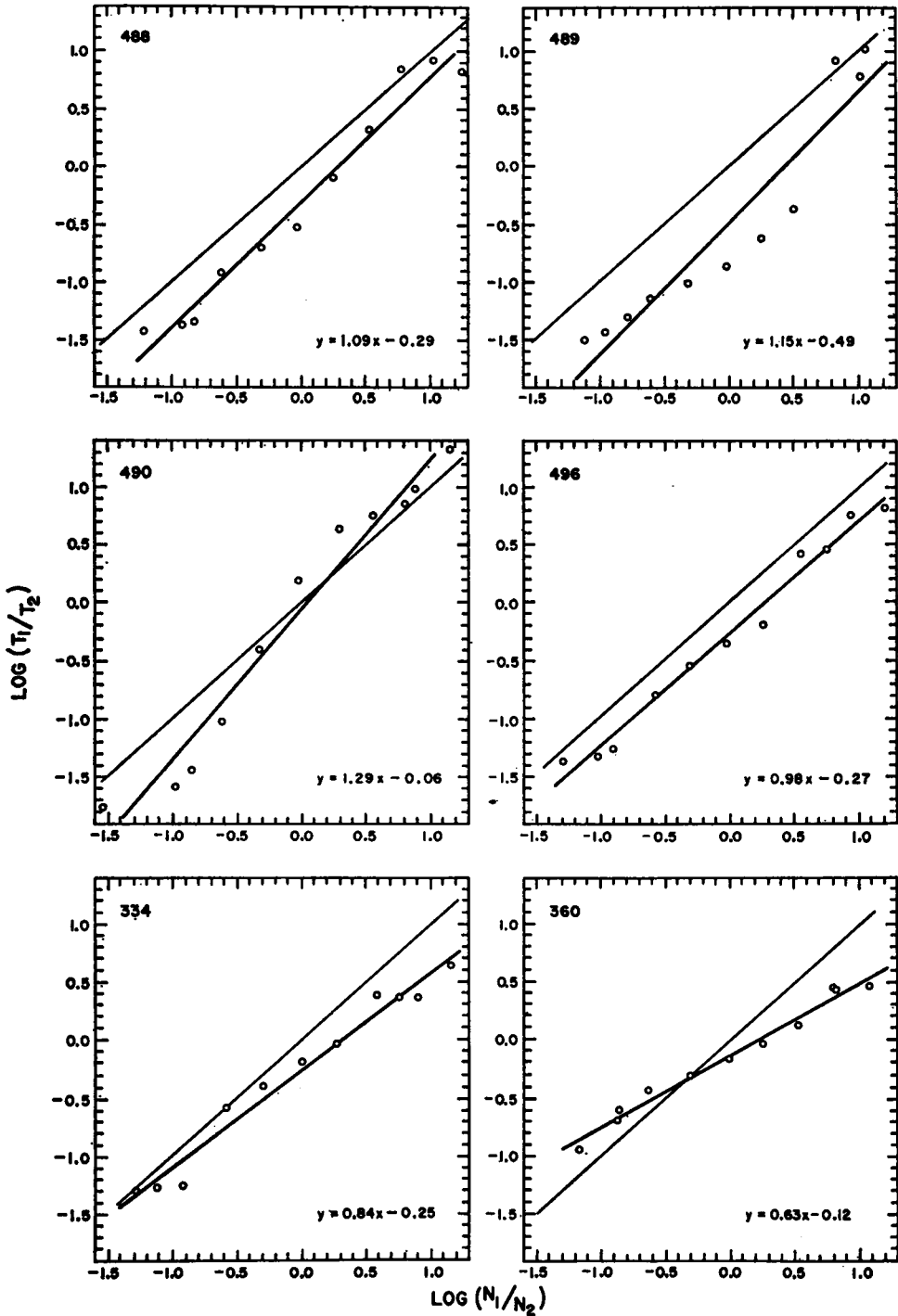


Fig. 2. Individual data: the logarithm of the ratio of time spent on the left to time spent on the right plotted as a function of the logarithm of the ratio of number of reinforcements received on the left to number of reinforcements received on the right during an experimental session. Each of the six plots shows data for one of the six birds. The heavy lines were fitted to the data points by the method of least squares. The equation of each regression line appears beside it. The light lines have a slope of one and pass through the origin; they represent the performance of perfect matching.

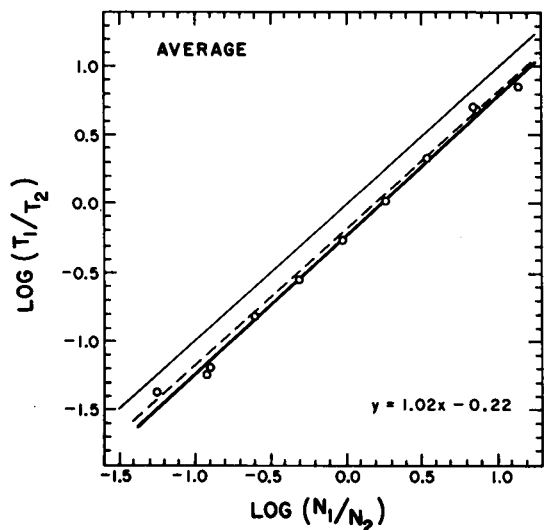


Fig. 3. Averaged data: the logarithm of the ratio of time spent on the left to time spent on the right plotted as a function of the logarithm of the ratio of number of reinforcements received on the left to number of reinforcements received on the right during an experimental session. The heavy solid line was fitted to the data points by the method of least squares. Its equation appears alongside it. The light solid line has a slope of one and passes through the origin; it represents the performance of perfect matching. The light broken line is the performance predicted on the basis of the data in Fig. 5; a full explanation appears in the text.

was minimal after initial training, the session time closely approximated the sum of  $T_1$ ,  $T_2$ , and the COD time.

Because the COD was fairly long in duration and because the pigeons crossed frequently from one side to the other, the COD time was a significant fraction of the session time (from 16% to 70%, depending on the subject and the conditions of the experiment). It would be possible, then, for the fraction  $T_1/T_2$  to vary as in Fig. 2 and 3, while  $T_1$ , for instance, remained constant, all the variation being accounted for by variations in  $T_2$  and the COD time. Despite the relative lawfulness of  $T_1/T_2$  as a function of the reinforcements produced on the two sides of the chamber, there is no *a priori* necessity that  $T_1$  or  $T_2$  individually vary lawfully with reinforcements.

Figures 4 and 5 show plots for individual birds (Fig. 4) and the averaged data (Fig. 5), of the proportion of the total session duration spent on each side as a function of the relative number of reinforcements for that

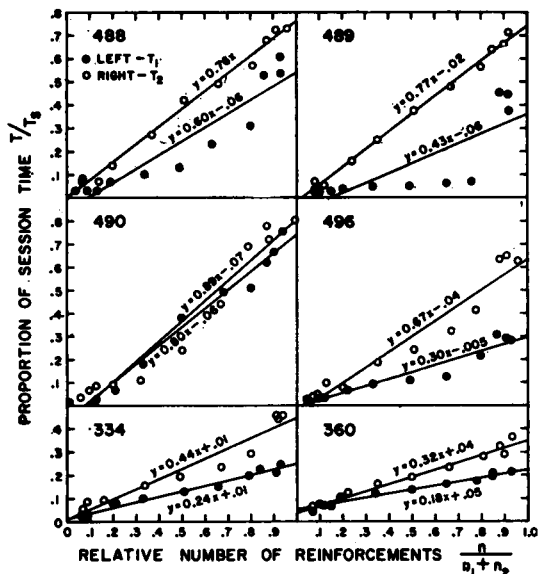


Fig. 4. Individual data: the proportion of the session time spent on the left (filled circles) and on the right (open circles) plotted as functions of the proportion of reinforcements received on the left (filled circles) and on the right (open circles). The lines were fitted to the data points (open or filled circles separately) by the method of least squares. The equation of each regression line appears alongside it.

side. The filled circles represent the proportion of time on the left,  $T_1/T_s$ , as a function of the relative number of reinforcements on the left,  $n_1/(n_1 + n_2)$ . The open circles represent the proportion of time on the right,  $T_2/T_s$ , as a function of the relative number of reinforcements on the right,  $n_2/(n_1 + n_2)$ . The two lines

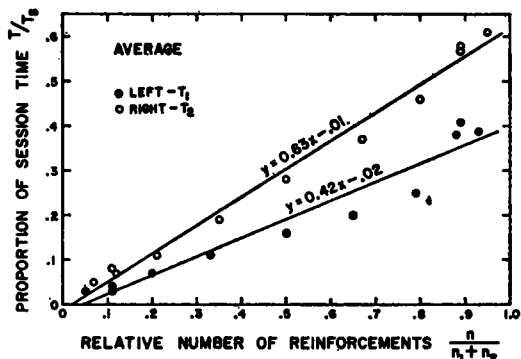


Fig. 5. Averaged data: the proportion of the session time spent on the left (filled circles) and on the right (open circles) plotted as functions of the proportion of reinforcements received on the left (filled circles) and on the right (open circles). The lines were fitted to the data points (open or filled circles separately) by the method of least squares. The equation of each regression line appears beside it.



in each graph of Fig. 4 and 5, one for time spent on the left (filled circles) and one for time spent on the right (open circles), were fitted by the method of least squares. The equation of each regression line appears alongside its graphical representation.

The relationships depicted in Fig. 4 and 5 appear approximately linear but slightly concave upward. The data from Bird 489, for time spent on the left, constitute an exception to the general rule. The intercepts of the regression lines for all subjects were small in absolute value. Some were negative, others were positive. The proportion of the session spent on either side appears, therefore, to be approximately proportional to the relative number of reinforcements delivered on that side. The relationships approximated in Fig. 4 and 5 are:

$$\frac{T_1}{T_s} = c_1 \frac{n_1}{n_1 + n_2} \quad (6)$$

for the left side, and

$$\frac{T_2}{T_s} = c_2 \frac{n_2}{n_1 + n_2} \quad (7)$$

for the right side, where  $c_1$  and  $c_2$  are constants of proportionality.

For every bird, the data for time spent on the right produced a steeper regression line than the data for the time spent on the left. In terms of Equations (6) and (7), for every bird,  $c_2$  was greater than  $c_1$ . This tendency to spend a greater proportion of time on the right than on the left for the same relative rate of reinforcement illustrates again the position preference that appeared in Fig. 2 and 3.

Equations (6) and (7) may be thought of as more basic than Equation (5), since Equation 5 can be derived from Equations (6) and (7). The ratio of Equation (6) to Equation (7) reduces to:

$$\frac{T_1}{T_2} = \frac{c_1}{c_2} \cdot \frac{n_1}{n_2} \quad (8)$$

Comparison of Equation (8) with Equation (5) indicates that  $c_1/c_2$  should equal  $k$ . Because the slopes in Fig. 3 were not all equal to unity, but varied around it, and because of the non-linearity of some of the individual functions in Fig. 4, only a very rough correspondence exists between the individual constants,  $k$  and  $c_1/c_2$ . For the average curves, however, where

the slope was equal to unity (Fig. 3) the values of  $k$  and  $c_1/c_2$  were 0.60 and 0.66. The closeness of these two values is illustrated by the broken line in Fig. 3, which shows the predicted biased matching based on Equation (8) with  $c_1/c_2$  taken from Fig. 5.

Herrnstein (1961) and Brownstein and Pliskoff (1968) found that as the difference in frequency of reinforcement between the two concurrent components increased, the frequency of changeover between components decreased. In the present experiment, four birds, 488, 489, 490, and 496, showed a similar relationship. Bird 334, however, showed no systematic variation in rate of changeover, and Bird 360 changed over most frequently when the rates of reinforcement were most different. All birds showed a tendency to change over more often when they preferred the left side than when they preferred the right side. It may be that the persistent bias toward the right (Fig. 2, 3, 4, and 5), which generally weakened preferences for the left when they occurred, also made these preferences relatively unstable.

## DISCUSSION

The present experiment, together with that of Brownstein and Pliskoff (1968), showed that in the absence of reinforcement for any specific response, the same type of law governs the division of an organism's time among the activities in which it engages as governs the distribution of responses among choice alternatives (Herrnstein, 1961; Reynolds, 1963; Catania, 1963a). Catania (1966) found that even when behavior is defined and measured in terms of discrete responses (key pecks), the time allocation matching law still applies. As noted in the introduction, the results of several experiments (Blough, 1963; Catania, 1961, 1962; Mechner, 1958a and b) suggest that series of repetitions of a discrete act (a key peck or a lever press) can be thought of as periods of engaging in a continuous activity (key pecking or lever pressing). Thus, even though behavior in a given situation may be defined and measured as if it consisted of discrete acts, it is still possible to derive continuous measures of behavior in that situation. Laws of time allocation, therefore, are likely to be more widely applicable to behavior than laws of response distribution.

If we accept the idea that the matching law governs time allocation among activities, what can we say about experiments that have demonstrated matching of relative number of pecks to variables other than relative rate of reinforcement? Catania (1963*b*) found that pigeons match relative pecks to relative amount of reinforcement. Chung and Herrnstein (1967) obtained matching of relative pecks to relative immediacy of reinforcement (reciprocal of delay of reinforcement). We can express the three matching laws in terms of time spent pecking at two keys ( $T_1$  and  $T_2$ ) as follows:

$$\frac{T_1}{T_2} = \frac{r_1}{r_2}$$

$$\frac{T_1}{T_2} = \frac{a_1}{a_2}$$

$$\frac{T_1}{T_2} = \frac{i_1}{i_2}$$

where  $r_1$  and  $r_2$  are the rates of reinforcement,  $a_1$  and  $a_2$  are the amounts of reinforcement, and  $i_1$  and  $i_2$  are the immediacies of reinforcement, produced by pecking at Key 1 and Key 2, respectively.

We are now led to ask how these three independent variables might combine to determine choice when they are varied together, instead of one at a time, as Herrnstein, Catania, and Chung and Herrnstein varied them. The simplest possible relation might be multiplication of the ratios of independent variables to produce the ratio of times, as follows:

$$\frac{T_1}{T_2} = \frac{r_1 a_1 i_1}{r_2 a_2 i_2} \quad (9)$$

The most general form of such a matching law, which would include new variables besides the three already known, would be:

$$\frac{T_1}{T_2} = \prod_{j=1}^n \frac{x_{1j}}{x_{2j}} \quad (10)$$

where  $x_{1j}$  and  $x_{2j}$  are the values of variable  $x_j$  associated with Key 1 and Key 2, and there are  $n$  such variables, instead of just three, as above. If we define the *value*,  $V_i$ , of Activity  $i$  as:

$$V_i = \prod_{j=1}^n x_{ij}$$

then Equation (10) reduces to:

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} \quad (11)$$

Equation (11) states that pigeons allocate time to any given pair of activities in such a way that the ratio of the times allocated equals the ratio of the values of the activities.

Neuringer (1967) verified Equations (10) and (11) for two variables: amount and rate of reinforcement. He found that pigeons in a two-alternative choice situation matched relative frequency of choice to relative "total access to reinforcement," the product of amount times rate of reinforcement. He found, in other words, Equation (9) with  $i_1$  equal to  $i_2$ .

The form of the position preference shown in Fig. 2 lends further support to Equation (10). We do not know what variables determined the preference for the right side over the left. Perhaps the right magazine allowed the birds to eat more during the magazine cycle. Perhaps a greater movement of the left floor when stepped on contributed to the bias. Whatever the determinants, however, the position preference only necessitated multiplying the ratio of the rates of reinforcement by a constant to produce matching. In terms of Equation (10), this constant is either the ratio of two values of a single variable that differed from one side to the other, or, perhaps more likely, the product of several ratios of the values of several variables that differed from one side to the other. The form of the position preference, therefore, suggests that Equation (10) may predict preference with great generality.

We can only hope that other variables that fit into this formulation will be as simple to express as rate, amount, and immediacy of reinforcement. Staddon (1968) suggested that such simplicity may not completely prevail.

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*Appendix:* Table of data for individual birds in each condition.

The data appear in the order in which they were gathered. See Table 1 for the schedules corresponding to each lettered condition. The symbols  $T_1$  and  $T_2$  stand for time spent on the left and time spent on the right, respectively. All data are medians of the last

three days of exposure to the conditions, except the number of reinforcements on the left, which are sums over the last seven days. The total reinforcements delivered over the last seven days was 280 for each condition.

## Bird 488

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
a	4.61	38.05	20.19	65.77	359	54
b	4.51	29.18	20.96	56.33	349	89
c	3.62	18.38	17.15	40.12	299	134
d	4.63	9.78	13.55	28.28	301	178
e	8.00	1.13	6.78	17.06	158	217
d	11.73	3.04	13.78	28.30	220	185
c	8.28	16.89	14.41	40.64	249	136
b	6.85	24.97	21.87	56.44	359	96
a	4.78	36.58	23.87	65.93	403	57
b	5.40	27.88	20.05	55.35	329	95
c	4.58	16.59	19.68	42.58	317	137
d	3.54	10.56	13.85	28.90	220	177
e	3.04	3.89	11.53	18.45	172	216
f	0.58	14.83	4.64	20.38	96	16
g	23.20	2.65	10.51	38.31	196	256
h	0.58	13.60	3.85	18.74	77	30
i	10.81	1.56	6.97	20.19	129	265
j	1.13	24.57	8.60	35.90	162	37
k	9.90	1.35	6.79	18.76	115	240

## Bird 489

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
e	1.26	3.35	12.05	18.17	234	208
d	2.24	5.31	19.40	28.77	375	180
c	2.02	15.18	21.23	42.76	387	136
b	2.50	25.82	25.82	57.14	455	94
a	2.70	33.12	26.27	64.60	475	58
b	2.49	27.22	23.10	53.70	424	91
c	2.16	17.49	21.47	42.87	396	139
d	1.74	7.84	16.76	28.27	307	180
e	1.31	2.44	13.25	17.79	240	219
d	1.45	8.37	16.72	28.18	310	183
c	2.48	15.55	21.85	42.02	384	138
b	3.03	27.53	22.53	57.05	424	91
a	2.72	41.00	19.33	66.35	406	54
i	7.56	0.72	9.75	20.13	188	258
j	1.13	22.58	10.30	35.36	198	40
k	8.85	1.03	8.37	19.48	172	245
f	0.44	14.03	4.37	19.62	94	20
g	17.50	2.82	16.51	39.31	340	256
h	0.45	12.10	4.75	18.20	86	28

## Bird 490

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
a	6.51	40.34	14.69	63.27	304	59
b	10.24	19.75	17.14	54.40	337	91
c	16.75	6.17	16.03	40.92	314	138
d	14.97	2.51	9.60	28.54	204	187
e	9.61	1.59	5.87	18.18	118	222
d	15.38	2.93	9.45	29.02	205	191
c	16.79	12.44	13.96	43.70	303	143
b	16.75	18.71	16.92	56.11	299	94
a	1.97	46.61	14.23	63.19	338	52
b	2.69	34.90	13.49	56.29	281	87
c	13.70	11.35	14.34	40.13	300	134
d	12.25	4.19	10.63	29.13	228	182
e	9.10	1.67	6.57	18.60	138	219
f	0.28	16.05	3.19	19.98	66	8
g	25.44	2.61	8.82	38.06	166	248
h	0.34	13.11	3.96	18.22	86	27
i	14.27	0.66	3.47	18.94	70	262
j	1.01	27.60	6.04	35.53	112	35
k	11.52	1.58	5.22	18.60	107	243

## Bird 496

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
e	2.45	1.65	12.43	17.58	297	216
d	3.52	3.55	19.09	27.80	378	186
c	4.33	8.43	24.22	39.28	437	140
b	4.57	14.81	32.33	54.43	578	92
a	4.13	28.03	31.30	67.49	554	60
b	4.88	16.81	29.57	53.81	515	94
c	4.21	9.73	24.43	40.70	436	136
d	3.00	6.26	17.67	28.82	343	181
e	5.23	1.15	10.49	18.10	220	224
d	4.24	6.19	17.74	29.63	320	183
c	4.92	11.42	23.25	42.03	416	138
b	5.60	21.31	27.74	56.31	472	95
a	4.76	26.11	30.21	63.58	533	61
i	5.97	0.85	12.65	21.04	257	264
j	1.21	25.12	9.00	38.70	193	25
k	5.81	0.97	11.83	19.89	232	252
f	0.55	12.47	6.23	19.85	112	14
g	12.03	3.88	19.60	39.31	386	239
h	0.62	11.05	5.93	17.44	104	32

## Bird 334

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
a	5.13	20.21	37.35	66.41	765	58
b	5.62	15.14	32.05	55.97	592	93
c	6.15	8.58	24.27	44.50	478	143
d	3.81	4.81	16.28	28.63	321	183
e	3.47	1.36	11.17	18.34	253	222
d	5.06	3.40	16.94	28.66	382	187
c	4.66	7.80	25.73	42.47	483	139
b	5.60	11.94	33.91	56.90	613	96
a	5.44	19.02	35.39	67.30	674	59
b	5.37	13.15	32.61	56.96	646	96
c	5.61	8.63	24.47	40.95	429	140
d	4.04	5.18	17.37	29.11	305	180
e	3.87	1.52	10.41	18.26	210	223
f	0.47	9.20	9.13	19.99	188	14
g	8.39	3.44	21.56	36.87	454	239
h	0.50	8.74	8.23	19.11	167	30
i	5.36	1.17	12.84	21.72	252	262
j	0.94	17.08	17.53	38.22	356	20
k	4.53	1.86	12.47	21.51	251	249

## Bird 360

Condition	$T_1$ (min)	$T_2$ (min)	COD Time (min)	Session Time (min)	Change- overs	Left Rein- forcements
e	2.80	2.31	11.23	17.37	242	218
d	4.21	4.70	17.81	28.12	319	182
c	5.24	9.08	24.55	41.45	442	139
b	6.57	12.95	33.09	56.55	617	94
a	6.48	17.36	37.41	64.17	805	54
b	5.94	12.33	31.91	53.85	647	95
c	5.36	7.64	27.41	43.60	512	139
d	4.23	4.54	18.17	28.42	315	183
e	3.39	2.07	11.56	17.64	221	216
d	5.28	4.55	16.62	28.51	348	183
c	7.01	7.97	25.30	42.53	441	141
b	7.97	14.06	32.88	57.37	580	94
a	7.75	20.17	40.91	70.44	853	54
i	4.80	1.49	13.63	22.31	387	259
j	3.07	11.87	22.67	41.13	571	34
k	4.02	1.39	12.94	20.04	347	244
f	0.90	7.83	11.19	21.55	281	18
g	8.17	2.65	24.16	39.08	671	242
h	1.39	6.52	10.48	20.08	296	33