JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR VOLUME 6, NUMBER 1 JANUARY, 1963

ON SOME DETERMINANTS OF CHOICE IN PIGEONS

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A pigeon's pecking at each of two or three simultaneously available red keys was reinforced at different frequencies with a conditioned reinforcer, an orange key, on which 25 pecks resulted in a presentation of grain. Pecking was occasionally punished with a period of no reinforcement during which each key was dark. Both with two and with three keys, the relative frequency of pecking on a key was equal to the relative frequency of reinforcement obtained by pecks on that key. Also, the absolute frequency of pecking on each key was a linear function with zero intercept of the absolute frequency of reinforcement associated with that key. The slope of this function varied with the number of available keys; it was steeper with two than with three. The relative frequency of switching from any key (two successive pecks on different keys) approximated a linear function with zero intercept and slope slightly greater than 1.0 of the total relative frequency of reinforcement associated with the keys to which the bird could switch. However, the relative frequency of switching to a particular key often showed systematic irregularities. The invariance in these data is the equality between the relative frequency of pecks on one of two or three keys and the relative frequency of reinforcement associated with that key.

Under certain conditions, the relative frequency of pecking on one of two concurrently available keys is approximately equal to the relative frequency with which pecks on that key are reinforced. This powerful generalization, which breaks down under other conditions (Herrnstein, 1958), emerges from two recent experiments. Herrnstein (1961) reinforced pecks on either of two keys with a presentation of grain. Autor (1960) reinforced pecks on either of two keys with a presentation of a differently colored key, in whose presence pecks were reinforced with grain. The independent variable in each experiment was the frequency of primary reinforcement associated with each key. In each experiment, the percentage of the total number of pecks made on one of the keys was approximately equal to the percentage of the total number of reinforcers produced by pecks on that key.

The procedure[2] presented here differs slightly from those of Herrnstein and Autor. The independent variable is the frequency of occurrence of a conditioned reinforcer, and sometimes there are three rather than two concurrently available keys. Initially, each of the three keys is red. Pecks on a red key occasionally change the color to orange until reinforcement occurs, or produce 30-sec periods of total darkness. Grain is presented after 25 pecks on the orange key.

The first problem concerns the relation between the relative frequency of pecking on any one of the three or two keys and the relative frequency at which pecks on that key result in a presentation of the conditioned reinforcer, the orange key. This relation turns out to approximate equality, thus replicating the findings of Herrnstein and Autor.

Both previous studies also found that the absolute frequency of pecking on a key was a linear function with zero intercept of the absolute frequency of primary reinforcement produced by pecks on that key. The second problem arises from the fact that this linear function is different from the concave downward relation between these two variables when only one key is available to the pigeon (Herrnstein, 1961, Reynolds, 1961b). By what process does introducing a second key straighten out this function?

The third problem concerns the relation between the equality of the relative frequencies of responding and reinforcement and the bird's tendencies to continue pecking on

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[2] Research supported by grants 8621 from the National Science Foundation and M-5139 from the National Institutes of Health.

a key or to switch to pecking a different key. Measurements are made of these frequencies by recording the frequency of sequences of two pecks as a function of the first key pecked. These frequencies determine a matrix showing the relative frequencies with which the next peck was on the left, middle, or right key, given the key just pecked. In some cases, these probabilities are simply related to the relative frequencies of reinforcement associated with a key; in others, they are not.

METHOD

Subjects

Three adult male, white Carneaux pigeons were maintained at 80% of their free-feeding weights. The key pecking of each had previously been reinforced on concurrent schedules of reinforcement.

Apparatus

A standard experimental space for pigeons (Ferster and Skinner, 1957) contained three response keys in a line, 9 in. above the floor, 2.3 in. apart, center to center, with 3 in. between the outside edge of the left and right keys and the wall of the chamber. Each key could be transilluminated with red or orange light. Pecks of about 15 grams were sufficient to operate each key. Centered beneath the middle key was an opening through which the pigeon occasionally had access to grain for 3 sec (reinforcement). The chamber was illuminated by two six-watt lamps except during reinforcement, when only the grain was illuminated. A white noise masked most extraneous sounds.

Procedure

At the start of a session, each of the three keys was red. Associated with each key was a separate, but identical, variable-interval (VI) schedule with a minimum, average inter-reinforcement interval of 90 sec. Provided that the VI programmer associated with a given key had set up, a peck on that key had one of two effects (see Fig. 1, phase 2). Either the pecked key became orange and the other two dark, or all three keys became dark (a condition called time out). All three VI programmers stopped when either effect occurred. If the pecked key became orange, 25 pecks on the orange key produced grain. If all three keys became dark, they remained dark for 30 sec. After a presentation of grain, or at the end of time out, all three keys were red again, and the VI programmers restarted. If more than one programmer set up while the keys were red, only the one associated with the pecked key was restarted. Thus every conditioned reinforcer that became available was collected. The schedules associated with the three keys were entirely independent. A session ended after 40 presentations of grain.

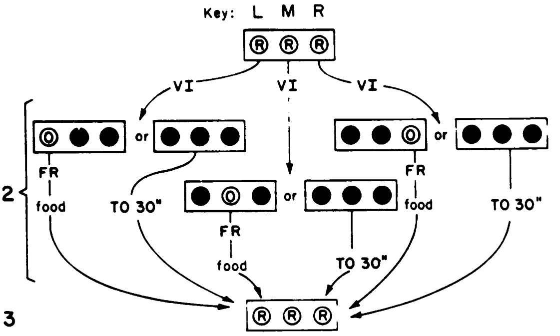

Fig. 1. A diagram of the procedure. Pecking at a red key in phase 1 had one of two consequences, shown in phase 2. In phase 3, which is the same as phase 1, each key was red again.

The independent variable was the average percentage of times, given that the VI programmer had set up, that the peck produced one orange key, the conditioned reinforcer, instead of three dark keys. The percentages of conditioned reinforcement, either 75, 50, or 25, were arranged by interposing an irregular on-off series between the equipment controlling the set-up and that controlling the consequence of the peck.

This procedure provided different frequencies of conditioned reinforcement on each key. From these frequencies, the relative frequency of conditioned reinforcement on a given key could be calculated by dividing the frequency on that key by the total frequency in the session (40).

The results from four successive daily sessions are reported here. The procedures on each day were as follows:

Days 1 and 3: The percentages of conditioned reinforcement associated with the left, middle, and right keys were, respectively, 75, 50, and 25.

Days 2 and 4: The left key was covered with opaque tape, so that two instead of three keys were available. The sessions ended after 40 presentations of grain, and therefore were 80 instead of 40 min long.

The birds had been exposed daily to this sort of procedure for about one year. A variety of specific procedures was studied, including each of the present ones several times, over a minimum of 15 sessions for each procedure. These data are mentioned in the discussion, but they are not presented here because they never departed significantly from the data from single sessions, reported below.

The frequency of pecking on each of the three keys was recorded. In addition, the frequencies of sequences of two pecks were recorded as a function of the key that was pecked first in the sequence of two. For example, of 2000 pecks on the left key, the bird might have next pecked the left (successive pecks) 1000 times, the middle 600, and the right 400.

RESULTS

The top row of Fig. 2 shows the number of responses per minute on each of the three red keys as a function of the number of times per minute that pecks on the key changed it to orange. Pecks on an orange or dark key are not included. For each day there are three points, one for each key.

The results for each bird fall onto two linear functions, both with zero intercepts but with different slopes. The first function, given by the filled and unfilled circles, comes from the three-key procedures. The second function, given by the filled and unfilled triangles, comes from the two-key procedures. With two keys, the rate of pecking on each increased over the rate when three keys were available,

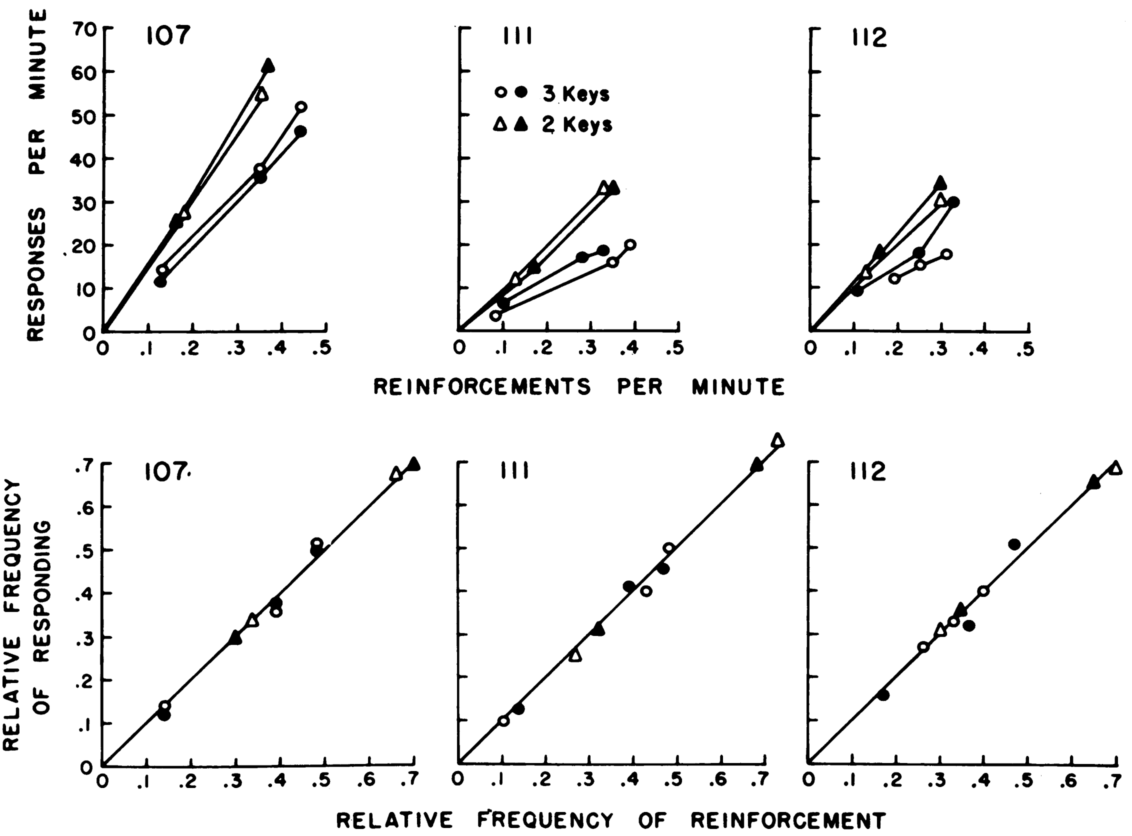

Fig. 2. Top. The number of responses per minute on each of two or three keys as a function of the number of reinforcements per minute obtained by pecks on that key.

Bottom. The relative frequency of pecking on each of two or three keys as a function of the relative frequency of reinforcement associated with that key.

despite the near constancy of the rate of reinforcement associated with each of the two keys and the halving of the overall rate of reinforcement in the session, which had doubled in length.

The bottom row of Fig. 2 shows, using the same symbols, the relative frequency of pecking on a key (pecks on that key divided by the total number of pecks on all three keys) as a function of the relative frequency of reinforcement associated with that key (reinforcers obtained by pecks on that key divided by the total number of reinforcers). The data for the three- and two-key procedures are plotted together. The line shows the locus of the points if it were precisely true that the relative frequency of pecking on one of two or three keys equals the relative frequency of reinforcement. The magnitude of the largest deviation from the line is 0.05, the average deviation is 0.014.

The frequencies of sequences of two successive pecks determine a matrix of relative frequencies, showing the relative frequency with which a peck on any one of the keys was followed by a peck on any other key. The matrix for pigeon 107 for the first day with three keys is shown in Table 1. As an example of the construction of the matrix, consider the left key, on which there were 2022 pecks. Of these, 745 or .37 of them were followed by another peck on the left key, 1184 or .59 of them by pecks on the middle key, and 93 or .05 of them by pecks on the right key.

Table 1.

Relative frequencies of sequences of two pecks for pigeon 107

		Given a peck on the			
		Left	*Middle*	*Right*	*KEY*
Cells show the relative frequency of next peck on	Left	.37	.52	.95	
	Middle	.59	.23	.04	
	Right	.05	.25	.02	
Relative frequency of reinforcement	KEY	.48	.39	.14	

First consider only the relative frequency with which pecks on one key were followed by pecks on the same or on any different key. The behavior involved in emitting successive pecks on different keys is called switching. By this definition, a reinforced switch necessarily involves a reinforced peck on the key to which the bird switches. In the example, successive pecks on the left key occurred with a relative frequency of .37, and switching from the left key to any other key occurred with a total relative frequency of 0.64. (The lack of complementarity is due to rounding.)

The relative frequency of successive pecks on a key approximates a linear function of the relative frequency of reinforcement associated with that key. These data are shown in the top row of Fig. 3, for the three pigeons. Circles represent three-key procedures, triangles two-key procedures. The lines drawn by eye through the points each have slopes greater than 1.0, and they intercept the abscissa at a value greater than zero. If this line were a strictly correct description of the behavior, there would be no successive pecks on a key unless the relative frequency of reinforcement associated with it were greater than this intercept—a sort of threshold for two successive pecks. This is not an unreasonable notion, but it is not entirely correct. What, in fact, happened is seen in the middle graph (from pigeon 111). When the relative frequency of reinforcement was below the intercept, a few successive pecks continued to occur. Above the intercept, the relative frequency of successive pecks increased linearly with the relative frequency of reinforcement.

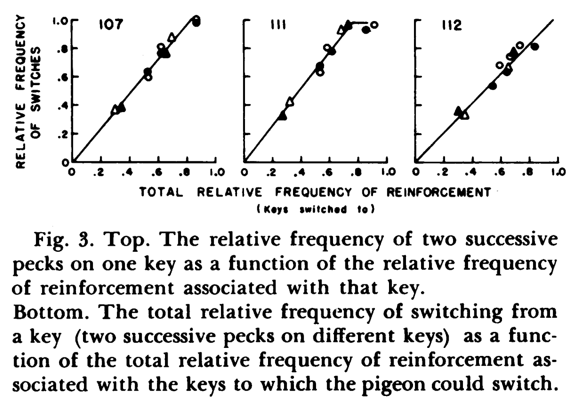

Fig. 3. Top. The relative frequency of two successive pecks on one key as a function of the relative frequency of reinforcement associated with that key.
Bottom. The total relative frequency of switching from a key (two successive pecks on different keys) as a function of the total relative frequency of reinforcement associated with the keys to which the pigeon could switch.

Of course, the complementary relation between the total relative frequencies of switches from one key to another and the total relative frequency of reinforcement associated with all the keys to which the bird switches is also linear with the same slope. This function, describing switching, is shown in the bottom row of Fig. 3. The lines extrapolate through the origin; switching would not occur were it never reinforced (See, *e.g.*, Findley, 1958).

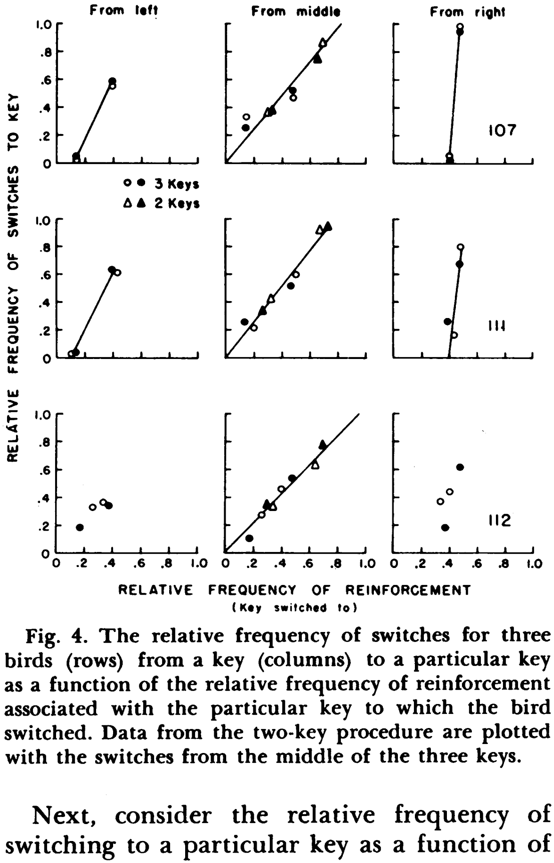

Fig. 4. The relative frequency of switches for three birds (rows) from a key (columns) to a particular key as a function of the relative frequency of reinforcement associated with the particular key to which the bird switched. Data from the two-key procedure are plotted with the switches from the middle of the three keys.

Next, consider the relative frequency of switching to a particular key as a function of the relative frequency of reinforcement associated with the particular key to which the bird switches. In the previous example (Table 1), a switch from the left to the middle key occurred with a relative frequency of .59; from the left to the right with a relative frequency of .05. These data appear in Fig. 4. The left column of graphs shows the relative frequencies of switches from the left key (to the right or the middle), the middle column switches from the middle key, and the right column switches from the right key. The data from the two-key procedure is plotted in the middle column of graphs. The straight lines in the middle column of graphs are copied from those describing the total relative frequency of switching in the bottom row of Fig. 3. The agreement between the points and these lines means that the individual relative frequencies of switching to the left and right keys from the middle key are related to the relative frequency of reinforcement associated with the left and right keys in the same way as the total relative frequency of switching is related to the total relative frequency of reinforcement for switching. However, no such simple correspondence holds for switches from the left or from the right keys. Moreover, for pigeon 112, the switching from the left and right keys changes between the two exposures to the three-key procedure (filled *vs.* unfilled circles, bottom row, left and right columns in Fig. 4). Nevertheless, as is illustrated in the bottom row of Fig. 2, the relative frequency of pecks on one of two or three keys is quite nearly equal to the relative frequency of reinforcement obtained by pecking on that key.

DISCUSSION

Behavior in the presence of more than one key consists of more reinforced operants than there are keys. Switches from one key to another are separate operants (Skinner, 1950; Herrnstein, 1961). With two keys, there are therefore at least four operants: two pecks and two switches. At any moment, two of the four operants are available to the pigeon: peck this key or switch to the other key. With three keys, there are three possible pecks and six possible switches; a total of nine operants, three of which are available at one time: peck this key or switch to either of the other two keys.

The frequencies of three of these operants, pecking at the three keys, approximate a linear function with zero intercept of the absolute frequencies at which they were reinforced (Fig. 2, top). And, the relative frequency of pecking at a given key is not measurably different from the relative frequency of reinforcement associated with that key (Fig. 2, bottom).

First, let us consider the relation between these two simple functions. Herrnstein (1961) points out that the linear relation with zero intercept between the absolute frequencies of pecking and reinforcement implies the equality of the relative frequencies of pecking and reinforcement. If the frequency of pecking p is related to the frequency of reinforcement r by the function

$$p = kr,$$

then

$$\frac{p_1}{p_1 + p_2} = \frac{r_1}{r_1 + r_2} \tag{1}$$

the constant k dropping out. He suggests (p. 272) that the linear relation between the relative frequencies arises from the linear relation between the absolute frequencies. However, it is important to note that the implication between the two functions is symmetrical because the same equation should describe the pecking at each of the keys. One can, then, as easily choose to say that the linear relation between the absolute frequencies is a consequence of the equality between the relative frequencies of pecking and reinforcement. Moreover, unless both functions can be derived from some known rules of behavior, such a formulation may have some advantages.

1. The equality between the relative frequencies remains invariant, while the relation between the absolute frequencies of pecking and reinforcement can assume several different slopes, depending both upon the bird and the number of available keys (Fig. 2, top). The function for two keys has a steeper slope than the function for three keys. Given this variability in the relation between the absolute frequencies in this experiment, the invariant equality between the relative frequencies appears to be the primary process characteristic of responding to more than just one operandum.

Note, however, that the invariance in the relation between the relative frequencies of pecking and reinforcement does not explain the change in the slope of the relation between the absolute frequencies. In order to maintain the equality of the relative frequencies, the bird need not peck more rapidly at the two keys alone than at the same two when a third is available. The equality would have been maintained if the absolute frequency of pecking had remained constant. This is because, assuming equation (1) above, both of the following equations hold:

$$\frac{p_1}{p_1 + p_2} = \frac{r_1}{r_1 + r_2}$$

and

$$\frac{p_1}{p_1 + p_2 + p_3} = \frac{r_1}{r_1 + r_2 + r_3},$$

as any constant drops out of the right side of each.

Thus, we are left with two separate effects: the invariance in the equality between the relative frequencies of pecking and reinforcement, and, the variation in the slope of the function relating the absolute frequencies of pecking and reinforcement. The latter, the increase in the rate of pecking the two keys, results from pecks that occur during the time the bird would be going to and pecking on the third key, were it available. These additional pecks are divided between the two keys in proportion to the frequency of reinforcement associated with each key. A given rate of reinforcement does not, therefore, control a given rate of pecking. But a given relative frequency of reinforcement appears precisely to control a given relative frequency of pecking (Fig. 2).

2. The second point has to do with the fact that the linear relation between the absolute frequencies is different from the relation between the same two variables with only one key, where it is sharply concave downward over the same range (Catania and Reynolds, in preparation; Herrnstein, 1961; Reynolds, 1961b). The present suggestion is that the function becomes straight with zero intercept with more than one key as a by-product of the bird's matching the relative frequency of pecking to the relative frequency of reinforcement.

It is perhaps not too surprising that pigeons respond to the distribution of relative frequencies of reinforcement in space across the keys because they respond quite precisely to the distribution of relative frequencies of reinforcement in time (Catania and Reynolds, in preparation).

3. It remains to discuss the fact that the equality between the relative frequencies of responding and reinforcement on two or three keys was produced by different sequences of behavior at the level of pecking successively and of switching from key to key.

Theoretically, the results could have been very simple. Each of the functions of the relative frequency of reinforcement in Figs. 3 and

4 could have been linear with slopes of 1.0 and passing through the origin. In that case, the matrix of Table 1 would be completely determined by the relative frequencies of reinforcement associated with each key. For example, given relative frequencies of .50, .30, and .20 on the left, middle, and right keys, respectively, the matrix would appear as in Table 2.

Table 2

Hypothetical relative frequencies of sequences of two pecks

		Given a peck on the			
		Left	*Middle*	*Right*	*KEY*
Cells show the relative frequency of next peck on	Left	.50	.50	.50	
	Middle	.30	.30	.30	
	Right	.20	.20	.20	
	KEY				
Relative frequency of reinforcement		.50	.30	.20	

This simple outcome is approximated only once, by pigeon 112 (unfilled circles, Figs. 3 and 4). Usually, the linear relation between the relative frequency of switching from the middle key or between only two keys, and the relative frequency of reinforcement for switching to the left and right keys, passes through the origin, but has a slope greater than 1.0 (Fig. 4, middle column). This function is close to the function describing the total relative frequency of switching (Fig. 3, bottom). From the middle key, or from one of two keys, then, the bird is led both to switch, and, to switch to a particular key by the same function of the relative frequency of reinforcement associated with the keys. However, the relative frequencies of switching from the left and right keys (Fig. 4) are generally described by much steeper functions of the relative frequency of reinforcement.

These deviations from the simple outcome of the sort displayed in Table 2 may reasonably be interpreted as behavioral contrast (See Reynolds, 1961a). In the present three-key procedure, left-key pecking, which is reinforced most frequently, leads the pigeon to switch very little to right-key pecking, which is reinforced least frequently. Pecking at the right key for few reinforcements, on the other hand, leads the pigeon to switch disproportionately frequently to left-key pecking, which is reinforced most frequently. While working at a low rate of reinforcement, the largest available appears even larger, and while working at a high rate of reinforcement, the lowest available appears even lower. Pigeon 112 shows this effect least, but it appears in his switches from the right key (filled circles, Fig. 4). Despite these distortions of the simple outcome and despite the differences between birds at this level of analysis of their behavior, the invariance in these experiments is the overall equality between the relative frequency of pecks on one of two or three keys and the relative frequency of reinforcement obtained by pecks on that key.

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Received January 16, 1962