*SOME LIMITATIONS ON
BEHAVIORAL CONTRAST AND INDUCTION
DURING SUCCESSIVE DISCRIMINATION¹*

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A pigeon's rate of pecking on a red key, reinforced at a constant frequency, may be changed by increasing or decreasing the frequency of reinforcement of pecking on a successively presented green key. The changes in the rate of pecking on red, called interactions, are of two types: contrast, in which the changes in the rates of pecking on the two colors are in opposite directions; and, induction, in which the changes in the rates are in the same direction. In previous data, a change in the frequency of reinforcement associated with the green key produced a corresponding change in the rate of pecking the green key and an opposite change (contrast) in the rate of pecking on the red key. The present data suggest that the magnitude of contrast is very small if pecking on the red key is reinforced at a high enough frequency (about 40 reinforcements per hr in the present experiment). Also, given that interactions occur, induction rather than contrast may result from small changes in a low frequency of reinforcement associated with green.

The frequency of reinforced responding in the presence of one stimulus often depends in part on the consequences of responding in the presence of a different stimulus (Brethower and Reynolds, 1962; Pavlov, 1927, p. 188; Reynolds, 1961b; Reynolds and Catania, 1961; Smith and Hoy, 1954). Such an interaction is illustrated by the changes in the rate of key pecking that occur when a pigeon forms a discrimination between red and green response keys. In a common discrimination procedure, pecking on the green key is first intermittently reinforced and then extinguished, while pecking on the red key is intermittently reinforced, always according to the same schedule. The decrease to zero of the frequency of reinforcement associated with the green key produces the familiar effect of extinction, a decrease in the frequency of pecking the green key. It also produces an interaction: the frequency of pecking the red key increases, even though the consequences of pecking the red key have not changed (Reynolds, 1961 a, d, for example). Some experiments (Guttman, 1959; Reynolds, 1961c) suggest that the increase in the frequency of pecking the red key also occurs when the frequency of reinforcement associ-

ated with the green key is merely reduced, rather than eliminated as in extinction. Moreover, the opposite effect, a decrease in the frequency of pecking the red key, can usually be produced by increasing the frequency with which pecking the green key is reinforced (Reynolds, 1961b). It seems that whenever the frequency of pecking the green key changes, the frequency of pecking the red key changes in the opposite direction.

These types of changes in the frequency of pecking on the red key are called behavioral contrast (Skinner, 1938, p. 175), in order to distinguish them from induction. In the present usage, induction refers to cases in which the changes in each of two rates of responding are in the same direction. Contrast refers to cases in which the changes in each of two rates of responding are in opposite directions.

The present experiments study some of the conditions of occurrence of contrast and induction in a series of successive discriminations between stimuli associated with variable-interval schedules of various average intervals.

METHOD

Subjects

Three adult male, white Carneaux pigeons were maintained at 80% of their free-feeding weights.

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Apparatus

A standard experimental chamber (see Ferster and Skinner, 1957) contained a single response key, provision for transilluminating the key with red or green light, a magazine for delivering grain to the pigeon for 3 sec (the reinforcer), overhead illumination, and a white masking noise. Pecks of about 15 grams effective force operated the key. During reinforcement, only the grain was illuminated.

Procedure

The pigeons were reinforced on a series of multiple schedules, each composed of two variable-interval schedules of reinforcement. One schedule was in effect when the key was red, the other when the key was green. Each multiple schedule was in effect until the day-to-day changes in the rate of pecking each color were small and unsystematic. Occasionally, a schedule was in effect for a longer time in order to search for temporary steady states, which were not found.

Each daily session consisted of 15 (experiments 1 and 2) or 10 (experiment 3) cycles of a multiple schedule. Each cycle consisted of a 3-min presentation of a red key followed by a 3-min presentation of a green key. The VI schedules were programmed by a separate punched tape during each color. Reinforcements that became available during the presentation of one color and were not obtained were cancelled when the color of the key changed. Cancellations were very infrequent.

The various procedures are summarized in Table 1, which shows the actual number of reinforcements per hr obtained by pecks on the red key and by pecks on the green key, during successive phases of the experiment and the number of sessions for which each combination was in effect. In experiment 1, pecking the red key was reinforced 20 times per hr. The number of reinforced pecks on the green key varied. In experiment 2, the number of reinforced pecks on the red key and on the green key both varied. In experiment 3, pecking the red key was always reinforced 38 times per hr. The number of reinforced pecks on green varied.

The number of reinforcements associated with a color was changed by increasing or decreasing the number of holes in punched tapes of fixed length that programmed reinforce-

Table 1
Obtained Number of Reinforcements per Hour

	Red Key	Green Key	Number of Sessions
Experiment 1		38	16
		7	20
		13	17
		53	15
always 20		1	31
		0	17
		19	13
Experiment 2	20	38	21
	7	1	16
	20	1	15
	19	9	17
	35	1	13
	36	9	21
Experiment 3		39	13
		9	18
		54	9
always 38		10	25
		20	19
		0	22
		37	19

ment. The entries in Table 1 are the actual frequencies of reinforcement obtained by pecks on the red key and on the green key.

RESULTS

The results consist of three functions. The first shows the rate of pecking on a key of one color as a function of the frequency with which pecks on a key of that color were reinforced. The second shows interactions: the rate of pecking maintained by a constant frequency of reinforcement during presentations of a key of one color as a function of the frequency with which pecks on a key of a different color were reinforced. The third shows the relative frequency of pecking on a key of one color as a function of the relative frequency with which pecks on a key of that color were reinforced.

Experiments 1 and 2

Figure 1 shows that the rate of pecking on a key of a given color is an increasing, negatively accelerated function of the frequency with which pecks on a key of that color were reinforced. The data from experiment 1 appear in Fig. 1a, those from experiment 2 in Fig. 1b. The data from each bird are shown in separate columns of the figure; the numbers identify the birds. Each point in this and other

Fig. 1. Rate of responding as a function of rate of reinforcement. The data of each pigeon occupy a separate column of panels, labeled with the pigeon's number. The data in Fig. 1a (top row of panels) come from presentations of a stimulus that was alternated with a different stimulus associated with 20 reinforcements per hr. The data in Fig. 1b (bottom row of panels) were obtained in alternation with a stimulus associated with various frequencies of reinforcement, which are indicated by different symbols identified in the middle panel. Each point is the average of data from the last three sessions of a procedure.

figures is derived from averages over the last three sessions on a given procedure.

The data from experiment 2 have been divided into four groups corresponding to the four different frequencies of reinforcement prevailing during the presentations of the other color. Each group is plotted with a different symbol, identified on the figure. Interactions are represented in this figure by the vertical separation between the different symbols. At a given frequency of reinforcement (a single value on the abscissa) the rate of responding varies with the frequency of reinforcement associated with the alternated color. The interactions are shown directly for experiment 1 in Fig. 2a and for experiment 2 in Fig. 2b. Each panel of Fig. 2 shows the rate of responding maintained by a constant fre-

quency of reinforcement during the presentation of one color as a function of the frequency of reinforcement of pecking on the alternated color. The data from each bird occupy a separate column of panels. If there were no interactions, each of the lines in Fig. 2 would be flat. A negative slope indicates that the rate of pecking maintained by a given frequency of reinforcement decreases as the frequency of reinforcement associated with the alternated color becomes greater.

In experiment 1 (Fig. 2a), the ratio between the maximum and minimum rates of pecking maintained by 20 reinforcements per hr is about 1.1 for pigeon 37 and about 2.1 for pigeons 52 and 53. The arrows in Fig. 2a point to the rate of pecking that prevailed when the same frequency of reinforcement (20 per hr)

was associated with each color. When the frequency of reinforcement associated with the other color (abscissa) was less than this value, the rate of responding maintained by 20 reinforcements per hr increased (positive contrast). When the frequency of reinforcement associated with the other color was greater than this value, the rate of responding maintained by 20 reinforcements per hr, decreased (negative contrast). Note that for pigeons 37 and 53 the highest rate of pecking occurs when seven, rather than zero, reinforcements per hr were received during presentations of the other color.

The same kind of interactions usually occurred in experiment 2 (Fig. 2b). The different symbols in Fig. 2b represent the frequencies of reinforcement associated with the color

from which the data are plotted. The vertical separation of the curves means that higher frequencies of reinforcement generally support higher rates of responding (as shown in Fig. 1b). There are no arrows indicating equality because the same frequency of reinforcement was never associated with each color in the same phase of the experiment.

Interactions are shown by functions that are not flat. As in experiment 1, each curve suggests interactions. The data for 38 reinforcements per hr (unfilled squares) are, however, obtained over a restricted range. To anticipate, experiment 3 finds almost no systematic interactions with 38 reinforcements per hr when the frequency of reinforcement associated with the other color is varied over a range three times as great as the present one.

Fig. 2. Rate of responding during the presentation of a stimulus of one color as a function of the rate of reinforcement associated with an alternated stimulus of a different color. The data from each pigeon occupy a separate column of panels labeled with the pigeon's number. The responding summarized in Fig. 2a (top row of panels) was maintained by 20 reinforcements per hr. The responding in Fig. 2b (bottom row of panels) was maintained by various frequencies of reinforcement, which are indicated by different symbols identified in the middle panel.

The results of a previous experiment (Reynolds, 1961c), which involved contrast, appeared orderly when the relative frequency of pecking on a key of one color (pecks at that color divided by total pecks on both colors) was plotted as a function of the relative frequency of reinforcement obtained by pecks on that color (number of reinforcements obtained by pecks on that color divided by the total number in the session). The data from both the present experiments are plotted in this way in Fig. 3a, filled points from experiment 1, unfilled points from experiment 2. The graph provides a unitary description of the behavior of all the birds, despite the differences among the absolute values of their rates of pecking. For relative frequencies of reinforcement from about .2 to about .9, these data can be described by a linear function with a slope less than 1.0 and an intercept considerably greater than zero. Above a value of .9 on the abscissa, the curve bends upward sharply.

The function in Fig. 3a deviates from the function that would have been obtained if there were no interactions. In order to compute the magnitude of these deviations, which are one way of expressing the magnitude of the interactions, we computed from the data in experiment 1 the values that the points in Fig. 3a would have if the rate of pecking on the red key, maintained by 20 reinforcements per hr, had remained constant at the actual value it assumed when 20 reinforcements per hr were obtained during presentations of each color. The difference between these values, computed on the basis of a constancy prediction, and the obtained values is shown in Fig. 3b as a function of the relative frequency of reinforcement represented by the constant 20 reinforcements per hr. Data from experiment 2 are not included. The constancy prediction could not be made for experiment 2 because the same frequency of reinforcement was never associated with each color in the same phase of the experiment, and thus no data completely free from interactions were available.

The data in Fig. 3b show that for relative frequencies of reinforcement below .5 (x in Fig. 3b), the actual relative frequencies of pecking are lower than those predicted on the basis of constancy. For relative frequencies of reinforcement above .5, the actual relative frequencies of pecking are greater than the

Fig. 3a (top). Relative frequency of responding in the presence of a stimulus of one color as a function of the relative frequency of reinforcement associated with that color. The relative frequencies were calculated by dividing the number of pecks or reinforcements during the presentation of a key of one color by the total number of pecks or reinforcements in the session.

Fig. 3b (bottom). The deviations of the relative frequencies in the top graph from those expected on the basis of a constant rate of responding during presentations of the stimulus associated with a constant frequency of reinforcement. The deviations are shown as a function of the relative frequency of reinforcement associated with that stimulus. The x at a deviation of zero and a relative frequency of .5 indicates that the expected and obtained relative frequencies of responding were approximately the same during each stimulus when each stimulus was associated with 20 reinforcements per hr.

constancy prediction. Since the curve in Fig. 3a is sharply concave upward beyond abscissa values of about .8 or .9, there is no appreciable difference between the actual relative frequencies of pecking and the constancy prediction when the relative frequency of reinforcement assumes a value close to 1.0. (At that point, all of the reinforcements were obtained by pecks on one color, and nearly

all of the pecks in the session occurred during the presentations of that color.)

Experiment 3

The rate of pecking maintained by 38 reinforcements per hr during presentations of a red key was studied as the number of reinforcements per hr during presentations of the green key varied from 0 to 58. In experiment 2, the rate maintained by approximately this frequency of reinforcement was studied over a range of from one to 20 reinforcements per hr during presentations of the other color. The present range is nearly three times as great.

Figure 4a shows that the rate of pecking the green key is the typical, increasing, negatively accelerated function of the fre-

quency with which pecking the green key was reinforced. Each pigeon's data appears in a separate graph, labeled with the bird's number. An inspection of cumulative records of performance suggests that the high rate of pecking by pigeon 53 at zero reinforcements was due to reinforcement of pecking by the onset of the stimulus associated with reinforcement.

Figure 4b shows the rate of responding maintained by 38 reinforcements per hr during presentations of the red key as a function of the frequency of reinforcement associated with the green key. This is the same type of graph that appears in Fig. 2a and Fig. 2b; if there were no interactions the rate of pecking would be constant. Over this range of frequencies of reinforcement, there are no systematic

Fig. 4a (top). Rate of responding as a function of rate of reinforcement during presentations of a stimulus alternated with a stimulus associated with 38 reinforcements per hr.

Fig. 4b (bottom). Rate of responding maintained by 38 reinforcements per hr as a function of the rate of reinforcement associated with the alternated stimulus.

interactions across birds. The relevant data from experiment 2 (unfilled squares from Fig. 2b) are reproduced here as crosses to show that similar rates of responding were obtained in both experiments.

The magnitude of the interactions appears to decrease with increases in the maintaining frequency of reinforcement. This is seen by comparing the magnitudes of the changes in the rate of responding maintained by 20 reinforcements per hr (Fig. 2a) with those maintained by 38 reinforcements per hr (Fig. 4b) as the frequency of reinforcement associated with the other color varies from zero to 60 reinforcements per hr.

Figure 5 shows that a graph of the relative frequencies of pecking and reinforcement is not a unitary description of the data for all birds, as it appears to be in experiments 1 and 2 where the maintaining frequency of reinforcement is lower, and there are systematic interactions.

Fig. 5. Relative frequency of responding maintained by 38 reinforcements per hr in the presence of one stimulus as a function of the relative frequency of reinforcement associated with presentations of that stimulus (relative to the total number of reinforcements obtained during a session).

DISCUSSION

The rate of responding maintained by a given frequency of reinforcement in the presence of one stimulus may in some cases be partly determined by the frequency of reinforcement associated with alternated pres-

entations of a different stimulus. Such an effect is shown in Fig. 2a. The rate of pecking on a red key, reinforced 20 times per hr, is generally higher, the lower the frequency with which pecking on an alternated green key is reinforced. These interactions with 20 reinforcements per hr are about as large in magnitude as those obtained previously by varying the value of a fixed-ratio schedule programmed during the presentations of the green key (Reynolds, 1961c).

The present data show that the magnitude of the interaction depends upon the frequency of reinforcement that maintains pecking. There appears to be no systematic interaction when pecking is maintained by 38 rather than 20 reinforcements per hr. This is not clear over the restricted range of experiment 2 (Fig. 2b, unfilled squares), but in experiment 3 (Fig. 4b) there is relatively little change in the rate of pecking maintained by 38 reinforcements per hr during the presentations of the red key when the frequency of reinforcement during green varies over a range of from zero to 58 reinforcements per hr.

The data in Fig. 1 and 4a show that the rate of pecking is relatively insensitive to variations in the frequency of reinforcement above a value of about 30 or 40 reinforcements per hr. At about this same level, the rate of pecking also becomes relatively insensitive to changes in the frequency of reinforcement associated with an alternated, different stimulus (Fig. 4b). The failure of high values of both of these variables to influence greatly the rate of pecking is not due to a limit on the rate of pecking, because pigeons will peck considerably faster under appropriate contingencies of reinforcement. Rather, the frequency of variable-interval reinforcement appears to become less and less effective as a controlling variable as it becomes more and more frequent.

When interactions occur (experiment 1 and 2) the relation between the relative frequencies of responding and reinforcement (Fig. 3a) is approximately the same for all of the birds. The magnitudes of the differences between the obtained relative frequencies of responding and the relative frequencies expected if no interactions had occurred are shown in Fig. 3b (for experiment 1). This is simply another way of showing that the rate of pecking maintained by a given frequency of reinforcement tends to increase when pecking is reinforced

less and less frequently during the presentations of a different stimulus.

The advantages of the graph of relative frequencies are that it summarizes simply the behavior of all three pigeons and that it permits concise comparisons between the results of the present procedure and those of some different procedures. For example, if the various pairs of frequencies of reinforcement studied here are associated with two simultaneously available keys, instead of with two successive colors of one key, the relation between the relative frequencies of responding and reinforcement (on each of the two keys) is linear with an intercept of 0 and a slope of 1.0. That is to say, with a choice of two keys the bird maintains an equality between the relative frequencies of responding and reinforcement. (This is true provided that certain procedures are employed, for which see Herrnstein, 1961; also Reynolds, 1963.) With two successive stimuli (Fig. 3a) the bird maintains only a rough proportionality between the relative frequencies of responding and reinforcement, and that over only a limited range of relative frequencies of reinforcement (about .2 to .9). For another example, if pecking a red key is reinforced while pecking an alternated green key is both reinforced and punished, the rate of pecking the green key declines as a result of punishment and the rate of unpunished pecking on the red key may increase (Brethower and Reynolds, 1962). Compared to the present Fig. 3a, these two changes in rate jointly determine a much steeper rise in the relative frequency of pecking the red key as the relative frequency of reinforced pecks on red increases (due to the presentation of fewer reinforcements during green when the bird pecks green less frequently due to punishment). The graph of relative frequencies of pecking and reinforcement summarizes the results of these three procedures into three functions among which comparisons may be made.

The present data show that contrast may not occur under two conditions. First, the rate of responding maintained by about 40 reinforcements per hr may not systematically vary with the frequency of reinforcement associated with an alternated stimulus (Fig. 4b). For example, extinction (zero reinforcements per hr) during alternated presentations of a different stimulus seems neither to increase

nor to decrease systematically the rate of responding maintained by 38 reinforcements per hr. Second, induction rather than contrast, may occur when the rate of reinforcement associated with the alternated stimulus is slightly increased from a very low value. In Fig. 2a, for example, an increase in the frequency of reinforcement associated with the green key from one to 10 per hr brought about an increase (induction) rather than a decrease (contrast) in the rate of pecking on the red key. However, further increases in the frequency of reinforcement associated with green decreased the rate of pecking the red key, below the rate prevailing when one reinforcement per hr was associated with green. Thus one and 10 reinforcements per hr during green produce contrast, an increased rate in red, relative to the effect of 40 or 60 reinforcements per hr during green. But, relative to the effects of each other, 10 and one reinforcements per hr during green produce induction: the rate of responding maintained by 20 reinforcements per hr during red changes in the same direction as the change in the rate of responding during green.

The occurrence of contrast forbids an accurate derivation of discrimination from a combination of simple gradients of positive or negative response tendencies spreading out along a continuum around the two discriminated stimuli. This point is discussed elsewhere (Reynolds, 1961b, d) for the case in which a discrimination is formed by extinguishing responding in the presence of one of two or more stimuli after responding has been reinforced in the presence of each. A gradient of negative response tendencies spread around the stimulus associated with extinction would be expected to bring about a decrease in the tendency to respond in the presence of the stimulus still associated with reinforcement. The fact is that the tendency to respond increases in the presence of that stimulus; contrast rather than induction occurs.

A second example, which is more difficult to conceive, comes from the present data. It concerns the formation of a discrimination by reinforcing responding more frequently in the presence of one of two stimuli after responding has been reinforced at the same frequency in the presence of each stimulus. By the theory under discussion, the tendency to respond in

the presence of each stimulus should increase, as the height of the gradient around one of the stimuli increases. The fact is that the tendency to respond often decreases in the presence of the stimulus whose associated frequency of reinforcement remained the same (Fig. 2).

More generally, it is an error to conceive of the formation of a discrimination as composed of simple, independent changes in the tendency to respond to one stimulus when the consequences of responding to that stimulus change. Rather, a change in responding and its consequences during the presentation of one stimulus usually brings about changes in the responding to the other stimuli which the organism successively encounters. (This statement is limited by the present data; it is not true for the conditions displayed in Fig. 4b.) These changes, interactions, are of two sorts: contrast, in which a change in the rate of responding in the presence of one stimulus is accompanied by a change of opposite sign in the rate of responding in the presence of another stimulus; and, induction, in which the changes in the rate of responding in the presence of each stimulus are of the same sign.

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