ECONOMIC AND BIOLOGICAL INFLUENCES ON A PIGEON'S KEY PECK¹

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Pigeons were studied in a two-component multiple schedule. In the first phase of the experiment, key pecks were reinforced on a variable-interval 2-min schedule in both components and free food was delivered additionally during one component. When components alternated every 8 sec, all pigeons pecked at a much higher rate during the component with free food than during the other component. At a component duration of 16 min, the reverse was true: all pigeons pecked at a higher rate during the component without free food. In the second phase, the additional food during one component was made contingent on pecking. Responding during the component without the extra food remained essentially unchanged, as expected, since rate of reinforcement remained identical to that in the previous phase. However, rate of responding during the component with the extra food (now contingent on pecking) was elevated, compared to the rate in the first phase, and did not show the marked decline as component duration was increased.

The present experiment examined two ways in which the rate of a pigeon's key pecking may be influenced. Imagine a pigeon pecking a key at some rate, P , per minute. One way to change P is to vary the relative rate of reinforcement for pecking. This technique was described by Herrnstein (1970). Herrnstein's formula for P is:

$$P = \frac{Kr_p}{r_p + r_o} \quad (1)$$

where r_p is rate of reinforcement dependent on pecking, r_o is rate of reinforcement independent of pecking, and K is a constant. Note that P can be varied by means of r_p , r_o or both. What counts is *relative* rate of reinforcement. Herrnstein maintained that some reinforcement independent of pecking is always present (*e.g.*, preening, scratching, *etc.*) even when not arranged by the experimenter. But increments to r_o may be deliberately provided. Rachlin and Baum (1972) varied r_o in several ways.

One was to reinforce a different response by r_o ; another was to present r_o as free reinforcement (independent of the pigeon's behavior). The same function (Equation 1) described the relation between P and r_o , regardless of the source of r_o .

While manipulation of the consequences of an act is one way to change the frequency of that act, it is by no means the only one. A pigeon's rate of pecking is excited during a signal when the signal is associated with the delivery of free food (Brown and Jenkins, 1968) and inhibited when a signal is associated with presentation of a noncontingent aversive event such as electric shock (Leitenberg, 1966). These two opposite effects, given the unfortunate names "autoshaping" and "conditioned emotional response" seem to depend, like Herrnstein's law, on *relative* rather than absolute rate of reinforcement. For example, Gamzu and Williams (1971) showed that pairing of a signal with food was not sufficient to excite pecking unless an *increase* in the rate of food presentations was signalled. If the absence of the signal was associated with an equal amount of food, the signal excited little pecking. This second method of varying P —henceforth termed the "biological effect", as opposed to the "economic effect" which depends upon the consequences of an act—depends on the capacity of a signal when associated with free food to interact with the

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particular response being manipulated. In the case of the pigeon pecking the key, the tendencies of autoshaping to increase P and of the conditioned emotional response to decrease P depend on the biological interaction of P with the reinforcer. If the pigeon did not enter the experiment with the tendency to peck at a stimulus associated with food, autoshaping of the key peck would not occur.

Now, the economic and biological effects may be set in opposition. Consider a pigeon pecking a key where pecks are reinforced by food. Suppose we present a signal that has previously been, and is now, associated with a high rate of free food, delivered in addition to the food reinforcements the pigeon obtains by pecking the key. The economic effect would be to *decrease* P because of the increase of r_0 , rate of reinforcement independent of pecking. The biological effect of the stimulus associated with the increased rate of food presentation, however, should be to excite pecking and therefore *increase* P . With greater rates or amounts of free food, both effects become stronger, but in opposite directions. However, this does not preclude the design of meaningful experiments, since these two effects differ in their temporal characteristics. Whereas the economic effect is a steady state effect, the biological effect is presumed to be a transient one. The present experiment placed the economic and biological effects in opposition and varied the duration of the signal. The initial predominance and gradual dissipation of the biological effect is traced.

METHOD

Subjects

Two male White Carneaux pigeons (P 64 and P 67) had previous experience with various schedules of reinforcement. Two male homing pigeons (HP 100 and HP 154) had been studied in an experiment on the detection of magnetic fields. All four birds were maintained at 80% of their free-feeding weights. Grit and water were continuously available in their home cages.

Apparatus

A standard three-key pigeon chamber (Gerbrands Co.) was used in which only the center key, requiring a force of at least 10 g (0.10N),

was operative. General illumination was provided during the experiment by two 7-W white bulbs mounted on the ceiling. During reinforcement, which consisted of 2.5-sec access to Purina Pigeon Checkers, the food hopper was elevated and lighted by two 7-W feeder bulbs while the houselights and keylights were darkened. Pecks on the response key, transilluminated by either red or green light, produced an auditory feedback click by operating a 110-V ac relay. All scheduling and recording were performed automatically with standard relay equipment located in an adjacent room.

Procedure

All subjects had been trained to peck a key in previous experiments and were therefore exposed directly to the conditions of the present experiment. Experimental sessions of 32 min were conducted daily.

In all conditions, the keylight alternated between red and green colors signalling the two components of a multiple schedule. The green component always signalled a variable-interval 2-min (VI 2-min) schedule of food reinforcement for pecking the green key. In the first phase, the red component signalled an identical VI 2-min schedule for pecking the red key but during the red component, free food was also delivered at variable intervals averaging 15 sec (VI 15-sec free). The actual intervals used for both the peck-dependent and free-food schedules were determined as specified by Fleshler and Hoffman (1962). On the average, during 2 min of green-key illumination the pigeon could obtain one food reinforcer by pecking the key, whereas during 2 min of red-key illumination the pigeon could obtain one reinforcement by pecking plus eight food presentations delivered free.

The second phase differed from the first in that the VI 15-sec schedule that formerly arranged free-food presentation now arranged reinforcements for pecking. In the second phase, therefore, *all* food presentations depended on pecking. On the average, during 2 min of the green-key illumination, the pigeon could still obtain one food reinforcement by pecking the key, whereas during 2 min of red-key illumination, the pigeon could obtain nine reinforcements by pecking, one from the VI 2-min schedule and eight from the VI 15-sec schedule.

Table 1 summarizes the conditions of both phases. Components were alternated every 8 sec, 8 min, or 16 min. Thus, when the red and green colors alternated every 8 sec there were 120 8-sec red components and 120 8-sec green components in each 32-min session. With the colors alternating every 8 min, there were two 8-min red components and two 8-min green components in each session. In the 16-min condition, only one 16-min red and one 16-min green component were presented daily. The component starting a session (red or green) was alternated daily. The timer controlling duration of the components was stopped during reinforcements. Food presentations dependent on pecks were occasionally not collected during the component in which they were scheduled. In such cases, they remained "set" until finally collected when that component was again in effect. Food presentations not dependent on pecks (Phase I, red component) were, of course, always collected during the component in which they were scheduled.

RESULTS AND DISCUSSION

Reinforcement rates and response rates were calculated for each pigeon for each session, separately for each component. The actual reinforcement rates varied within $\pm 15\%$ of the scheduled rates from session to session. The median response rates of each pigeon for the last 11 sessions at each condition are shown in Figure 1. (One condition, the 8-sec component duration in Phase II, was studied for

10 sessions only, and the median of all 10 sessions is shown.)

Consider first the Phase I results as represented by the left-hand column of graphs in Figure 1. When component duration was 8 sec, all pigeons pecked much more rapidly during the red component (with the free food) than during the green (without free food), showing dominance of the biological over the economic effect. As component duration increased, rate of responding in the red component (with the free food) decreased and rate of responding in the green component (without free food) increased. The curves cross for all pigeons. At a component duration of 16 min in Phase I, all the pigeons pecked faster in the green (without free food) than in the red (with free food), showing dominance of the economic over the biological effect.

Turning now to the results of Phase II (in which all food presentations depended on key pecks), shown in the right-hand column of graphs in Figure 1, note that the upward sloping curves for the green component are similar to the corresponding curves in Phase I. This result was expected, because the schedule of reinforcement during the green component and the decrease in rate of reinforcement represented by the change of keylight from red to green were identical in both phases. It made little difference, with respect to responding during the green component, whether most of the reinforcements during the red component were independent of responding, as in Phase I, or dependent on responding, as in Phase II.

Table 1

Pigeon and Order of Conditions				Schedule during Green Keylight	Schedule during Red Keylight	Duration of Components	Number of Sessions
P64	P67	HP100	HP154				
PHASE I							
1	2	1	2	VI 2-min	VI 2-min + VI 15-sec free	8-sec	25
2	1	2	1	VI 2-min	VI 2-min + VI 15-sec free	8-min	25
3	3	3	3	VI 2-min	VI 2-min + VI 15-sec free	16-min	35
PHASE II							
4	4	4	4	VI 2-min	VI 2-min + VI 15-sec	8-sec	10
5	5	5	5	VI 2-min	VI 2-min + VI 15-sec	8-min	25
6	6	6	6	VI 2-min	VI 2-min + VI 15-sec	16-min	40

Fig. 1. Response rates for individual pigeons at 8-sec, 8-min, and 16-min component durations. The left-hand column of graphs represents response rate during Phase I (VI 2-min schedule of food reinforcement during green component, VI 2-min plus VI 15-sec free schedule during the red component), while Phase II response rates are presented in the right-hand column (VI 2-min during green, VI 2-min plus VI 15-sec during red).

The difference between phases is mainly due to the elevation of response rates during the red component from Phase I to Phase II. In Phase II, the biological effect (responsible for the slope of the curves) remains the same as it was during Phase I, but the economic effect in the red component is reversed. The VI 15-sec schedule which, in Phase I, was independent of responding (a factor in the denominator of Equation 1) and decreased P was, in Phase II, dependent on responding (a factor in the numerator of Equation 1) and increased P .

Figure 2 shows responding at various intervals within the 8-min and 16-min components. The curves of Figure 2 were obtained as follows: during the last eight sessions of each condition with 8-min and 16-min component durations, a print-out counter recorded the number of pecks every 8 sec. Data from only the second half of each session were used so that the beginning of each curve represents a transition from another condition. For the 8-min components, one red and one green component comprised the second half of the session. For the 16-min components, only one component, red or green, comprised the second half of the session. For each pigeon, the number of pecks was cumulated over the eight sessions during each of the sixty 8-sec periods within an 8-min component and each of the one hundred twenty 8-sec periods within a 16-min component. Then, the pecks in the various 8-sec periods were combined into longer intervals, as shown on the abscissa of Figure 2. (The logarithmic arrangement of intervals allows the rapid changes during the early intervals in a component to be seen clearly against the relatively steady responding over most of the component.) Then, the number of pecks was divided by the width of the interval to get a rate of responding during each interval. That distribution is plotted for each pigeon separately in Figure 2. The left column shows responding during 8-min intervals; the right column shows responding during 16-min intervals. Figure 2 shows that there were several instances where the change in components failed to excite or inhibit pecking (as shown by the several instances of horizontal dotted and solid lines).

Figure 1 shows responding as component duration was changed. Figure 2 shows responding at various intervals *during* a component. These two measures may be better compared

by examining the average of the curves in Figure 1 (Figure 3A) and the average of the curves in Figure 2 (Figure 3B). Figure 3A was obtained from Figure 1 by averaging across pigeons. In Figure 1, there are four curves for each pigeon (two for Phase I and two for Phase II). The averages are the curves of Figure 3A.

In Figure 2, corresponding curves in the left column (8-min components; four curves for each pigeon) were averaged across pigeons and corresponding curves in the right column (16-min components; four curves for each pigeon) were averaged across pigeons. Then, the two column averages (four curves each) were combined in Figure 3B. Thus, the leftmost points of Figure 3B are averages of responding of all pigeons during the first 8 sec of the 8-min and 16-min components. The points in the next column are averages of responding during the eighth to twenty-fourth second of the 8-min and 16-min components, *etc.* The rightmost point represents responding during the last 8 min of the 16-min component. There was no corresponding point from the 8-min components to average. This point was obtained by matching the slope of the last segment of Figure 3B with the slope of the last segment of the average 16-min curve.

The leftmost points of Figure 3B are based on only a few 8-sec intervals (four for each of the corresponding curves of Figure 2) and so are less reliable than the corresponding points of Figure 3A, which are based on hundreds of observations. Nevertheless, there are a few consistent differences between Figures 3A and 3B. One is that rate of pecking during the first 8 sec of the 8- and 16-min free-food components is higher than the rate of pecking during the 8-sec free-food component. Another difference between Figures 3A and 3B is that rate of responding during the VI 2-min component (green) is higher in Phase II than Phase I in Figure 3B. This is shown by the dotted line connected by filled circles higher than the dotted line connected by open circles. (Corresponding elevations appear in all eight sets of functions of Figure 2.) The differences between Figures 3A and 3B appear to be mostly due to variations in the transient biological effect. The rightmost points (representing half of the component duration on the log scale) are in general correspondence. The differences may have been due to the erratic nature of the biological effect or to other

Fig. 2. Response rates for individual birds during successive intervals within the 8-min component durations (left-hand column of graphs) and 16-min component durations (right-hand column). Solid lines represent rates during the red component, dotted lines are rates during the green component. Phase I is represented by open symbols, Phase II by closed symbols.

Fig. 3. (A) Mean response rates for all four pigeons at 8-sec, 8-min, and 16-min component durations. (B) Mean response rate during successive intervals within the 8-min and 16-min component durations. (See text for explanation.)

effects we have not considered. In any case, to the extent that Figures 3A and 3B are different, pecking at any instant depends on overall rate of alternation of components as well as time since the last component change.

GENERAL DISCUSSION

Two effects influenced the pigeons' key peck. One was a transient excitatory or inhibitory effect caused by the sudden change to a stimulus correlated with a higher or lower rate of food delivery, respectively. The other was a steady state effect caused by the proportion of the total number of food presentations dependent on pecking; the greater this proportion the faster the rate of pecking. These two effects represent a long-recognized dichotomy of influences variously labelled emotional-rational, involuntary-voluntary, respondent-operant, and classical-instrumental. We have chosen to use the more general terms "biological" and "economic" because these terms seem to convey the properties of the effects with no specific assumptions about their underlying nature.

It was argued elsewhere (Rachlin, 1973) that these effects and their interaction were re-

sponsible for the observation of behavioral contrast in multiple schedules and matching in concurrent schedules of reinforcement.

Herrnstein has explained behavioral contrast by a modification of Equation 1, which includes a term in the denominator, m , representing the influence during one component of reinforcement obtained during the other component.

$$P_1 = \frac{Kr_1}{r_1 + mr_2 + r_0} \quad (2)$$

where r_1 and r_2 are rates of reinforcement for each component of the multiple schedule. The parameter m can vary between 0 and 1.0 depending upon the degree of interaction between the components. As components alternate more rapidly (shorter component durations), m approaches 1. This has the consequence of reducing responding, P_1 . Contrast is indeed explained, but such a modification of Equation 1 could not explain the elevation in absolute rate of responding with short component durations over the rate with long component durations in the present experiment (the upward-to-the-left slope of the solid lines in Figures 3A and 3B). The addition of the

term m in the denominator predicts a reduction in pecking with decreased component durations.

Furthermore, a wholly economic account of contrast, such as that of Equation 2, makes no distinction between one sort of response and another, except as the constant K may perhaps reflect effortfulness. Equation 2, for instance, predicts contrast with bar pressing of pigeons as well as key pecking, and is disconfirmed by reports of failure to obtain contrast when pigeons bar press (*e.g.*, Westbrook, 1973). The biological account of contrast, on the other hand, does take account of the particular response. Because a stimulus associated with food is not known to excite bar pressing in the pigeon, we should not find contrast with that response (although such a finding awaits only the design of a bar that does interact with the pigeon's behavior during the signal).

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