*PIGEONS RESPOND TO PRODUCE PERIODS
IN WHICH REWARDS ARE
INDEPENDENT OF RESPONDING¹*

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Pecks by pigeons on a response key produced an ON state during which intermittent rewards were freely available, *i.e.*, independently of responding. Pecks during the ON state caused it to remain ON. If no pecks occurred, the state changed to OFF—the key color changed—and rewards were not presented. The state remained OFF until the next response. Thus, responses controlled the state in the chamber but did not cause immediate reinforcement. Four dimensions of the schedule were varied: the rates of response-independent rewards during ON; the duration of ON produced by each peck; the pattern of rewards during ON; and the presence *vs* absence of exteroceptive cues during ON and OFF. The results showed that rates of responding were primarily controlled by the duration of ON produced by each response. When each response caused a long period of ON, pecks occurred infrequently; when each response caused a brief period of ON, pecks were frequent.

Responding can be controlled by events that are independent of the response as well as by events that are caused by, or depend upon, the response (Skinner, 1948; Ferster and Skinner, 1957; Herrnstein, 1966; Brownstein and Pliskoff, 1968; Neuringer, 1970; Shull, 1970, 1971; Brownstein, 1971). These two operations—the dependent and independent presentation of reinforcing events—may be combined. For example, in studies of discrimination learning, a discriminative stimulus is sometimes presented independently of the organism's behavior. In the presence of the discriminative stimulus, reinforcement depends upon the response. Thus, the discriminative stimulus, which sometimes serves as a conditioned reinforcer, is response-independent, whereas the primary reinforcer depends upon responding. These relationships may be reversed in the following way: a response produces a discriminative stimulus during which primary rewards occur independently of behavior. Here, the discriminative stimulus depends upon the response, whereas primary reward occurs independently of re-

sponding. Such contingencies are common to human environments: for example, we wind a grandfather clock to know the time throughout the day. Winding is necessary; but then, every hour, the chimes ring independently of further responding.

This last combination of schedule contingencies has received relatively little attention. Ferster and Skinner (1957, p. 684-685) briefly described such a schedule: it was a chain variable-interval fixed-time schedule. Pigeons responded in the presence of one keylight color to produce, according to a variable-interval schedule, a second color on the key in the presence of which response-independent rewards were presented every minute. The pigeons responded rapidly in the first color but little in the second. Similar research has been done in a different area—one related to Sidman avoidance (Sidman, 1953). In studies by Thomas (1965) and D'Andrea (1971), the aversive stimulus, rather than electric shock as in Sidman's work, was a timeout from a period in which response-independent rewards were offered. As under a regular Sidman avoidance schedule, there was a response-timeout interval (analogous to Sidman's response-shock interval) and a timeout-timeout interval (analogous to the shock-shock interval). The general findings were that rats and pigeons responded to maintain the periods in which free rewards were available. In a related study,

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Baer (1960) permitted children to watch cartoon movies. Occasionally, the movies were interrupted (timeout) and the subject had to press a lever to reinstate the film. For some subjects, each press produced 5 sec of film "on" time, and, if the subject's interresponse times were shorter than 5 sec, the film remained on continuously. The main result was that subjects reliably responded with an average interresponse time of approximately 5 sec.

The present work extended the parameters of Baer's study and attempted to analyze the control exerted when responses produce periods during which rewards occur independently of responding. Pigeons' pecks to a response key produced a period of an ON state during which free rewards were presented intermittently. Pecks during ON caused the state to remain ON (as in Baer, 1960). In the absence of pecking, the state reverted to OFF (rewards never occurred) and remained OFF until the next response. Four dimensions of the schedule were varied: the rate of reward during ON; the duration of ON produced by each peck; the patterns of reward during ON; and the presence or absence of exteroceptive cues during ON and OFF.

EXPERIMENT I

METHOD

Subjects

Eight male White Carneaux pigeons, each with a wide variety of exposure to operant conditioning experiments (*e.g.*, percentage-reinforcement schedules and concurrent variable-interval schedules) were maintained at approximately 80% of their normal body weights by appropriate feeding after each experimental session.

Apparatus

A standard operant conditioning chamber contained a Plexiglas Gerbrands response key and a Gerbrands food hopper below the key. The key could be transilluminated by either a 7-W green bulb or a 7-W red bulb. Pecks on the lighted key of at least 15-g force were recorded and produced a feedback click from a relay mounted behind the front panel. Rewards consisted of 3 sec of access to mixed grain in the hopper; during rewards, the key was dark and the hopper was illuminated by

a 7-W white bulb. There were no houselights. Sessions ended after 30 rewards were presented. Relay equipment automatically controlled the experiment.

Procedure

Figure 1 shows a schematic diagram of the procedure. One of two conditions was always in effect in the experimental chamber: an OFF state during which the keylight was red and rewards never occurred, and an ON state during which the keylight was green and rewards were presented according to a response-independent variable-time (VT) schedule (Zeiler, 1968). Under a VT schedule, rewards are presented aperiodically, no matter what the subject happens to be doing. The pigeon's key pecks controlled the schedule condition and the color of the key. A response during OFF immediately changed the state to ON and the keylight to green. In the absence of further responding, the state remained ON for 10 sec (this value to be called the ON/peck duration) and then reverted to OFF. Pecks to the key during ON caused that state to remain until 10 sec after the last response in a sequence, at which time the state reverted to OFF. In brief, whereas a response did not produce the reward itself, responding was a necessary precondition for rewards to occur. Note that the present schedule differed in at least one significant way from the schedules employed by Thomas (1965) and D'Andrea (1971). In the latter cases, periods of free rewards would occur periodically whether or not the subject responded. In the present experiment, as in Baer (1960), the subject had to respond to produce such periods.

Fig. 1. A schematic diagram of the procedure in Experiment I. See text for explanation.

The independent variable in Experiment I was the average interreward time scheduled by the variable-time program: these VT values were 10 sec (or an average time between scheduled rewards of 10 sec), 30, 90, 180, 270, and

360 sec. Since the VT program was activated only during the ON state, the scheduled VT values refer only to the time spent in ON. The interreward times actually obtained by the subjects (total session time divided by total number of rewards presented) depended on the relative amounts of time in ON and OFF which, in turn, depended on the subjects' responses.

Table I shows the number of sessions given at each of the VT values and, in parentheses, the order in which the schedules were presented. Also shown in the table are the conditions in Experiments II, III, and IV (see below). Subjects 1, 5, 11, and 282 were removed from Experiment I for approximately 70 sessions, given experience in Experiment II, and then returned to Experiment I.

The main data were number of responses emitted during ON, number of responses during OFF, time spent in ON, and time spent in OFF. Arithmetic averages were calculated for each of these data during the last five sessions at each schedule value. This was done for all values in Experiments I, II, and IV and these averages are shown in Table II. The main data to be discussed are average overall interresponse times (IRTs) during the last five sessions—calculated by dividing the average total time during these sessions (ON + OFF time) by the average total number of responses emitted (ON + OFF re-

sponses). Also to be presented are average IRTs during the ON state alone (time spent in ON divided by responses emitted during ON) and average responses latencies during OFF (time spent in OFF divided by responses in OFF). Since each response in OFF caused the state to change immediately to ON, only one response could occur per OFF period; therefore, the term "response latency" will generally be used rather than interresponse time when referring to OFF responses. The session timer and other recording devices started only after the first response in a session. Scheduling and recording devices were inoperative during food presentation.

RESULTS

Figure 2 shows average overall interresponse times for each subject at each of the scheduled interreward times. There were large differences between subjects. For example, #280's IRTs averaged about 3 sec while #11's IRTs averaged about 15 sec. However, IRTs for most individual subjects did not vary consistently or greatly despite the 36-fold change in interreward time. The median of all subjects' IRTs, shown by large filled squares, yielded a shallow U-shaped function with a 9.5-sec maximum at VT 10-sec and a 6.5-sec minimum at VT 30-sec. As interreward times increased beyond 30 sec, there was a tendency for median IRTs to increase slightly, from 6.5

Table I
Number Of Sessions In Each Condition And Order Of Presentation

Subjects		1	5	11	45	26	280	281	282
Experiment I	VT 10: ON 10	25 (3)	21 (9)	25 (3)	25 (3)	38 (5)	25 (3)	39 (5)	22 (9)
	VT 30: ON 10	44 (1)	44 (1)	43 (1)	42 (1)	43 (1)	51 (1)	51 (1)	51 (1)
	VT 90: ON 10	21 (2)	21 (2)	21 (2)	21 (2)	21 (2)	21 (2)	21 (2)	21 (2)
	VT 180: ON 10	26 (9)	25 (10)	26 (9)	23 (4)	23 (4)	24 (4)	23 (4)	25 (10)
	VT 270: ON 10		25 (3)		23 (6)	24 (3)	23 (6)	25 (3)	25 (3)
	VT 360: ON 10	64 (10)		59 (10)	36 (5)	21 (6)	36 (5)	22 (6)	
Experiment II	VT 90: ON 1	10 (6)	10 (6)	10 (6)					10 (6)
	VT 90: ON 2	10 (4)	10 (4)	10 (4)					10 (4)
	VT 90: ON 4	14 (7)	13 (7)	13 (7)					14 (7)
	VT 90: ON 30	14 (5)	14 (5)	14 (5)					14 (5)
	VT 90: ON 90	14 (8)	15 (8)	14 (8)					14 (8)
Experiment III	FT 90: ON 10				50 (7)	50 (7)	50 (7)	50 (7)	
Experiment IV	VT 90: ON 2				80 (10)		80 (10)	80 (10)	
	VT 90: ON 10				45 (8)		45 (8)	45 (8)	
	VT 90: ON 30				95 (9)		95 (9)	95 (9)

Fig. 2. Overall average interresponse times (IRTs) for each subject as a function of the scheduled times between response-independent rewards. The large filled squares show the medians of the eight subjects' performances. Overall IRT was calculated by dividing average total time in a session (ON + OFF times) by average total number of responses per session (ON + OFF responses).

sec at VT 30-sec to about 9 sec at VT 360-sec. Thus, variations in interreward time had only small effect on average IRT.

Figure 3 presents the average time between responses in ON and OFF separately (see also Table II). Average IRTs during ON were always greater than average response latencies in OFF. In ON, IRTs decreased from 51 sec at VT 10-sec to approximately 11 sec at VT 90-, 180-, and 270-sec, and again increased to 17 sec at VT 360-sec. In OFF, average latencies were about 3 sec at all values.

All OFF responses had to be preceded by 10 sec of no responding in addition to the OFF latency itself. Thus, although the OFF latency—defined as the time between onset of OFF stimulus and emission of a response—was 3 sec, the average time between an OFF response and the previous response was in fact 10 sec + 3 sec = 13 sec. This last value does not differ greatly from the 11-sec IRTs emitted during ON at intermediate VT values, suggesting, perhaps, that OFF latencies and ON IRTs belonged to a single distribution. However, responding during ON was

Fig. 3. Group median interresponse times in ON (upper) and response latencies in OFF (lower) shown separately as functions of the scheduled times between response-independent rewards. ON IRTs were calculated by dividing average time in ON by average number of responses emitted in ON. OFF latencies were calculated by dividing average time in OFF by average number of OFF responses. The lines through each median show the ranges of the eight subjects' IRTs and latencies. Note that the scale of the OFF ordinate (lower) is four times that of the ON ordinate (upper).

much more variable, both within and between subjects, than responding during OFF (Figure 3 and Table II). For example, at VT 360-sec, ON IRTs varied between 6.2 sec (#280) and 1985.4 sec (#11). The same two subjects' response latencies during OFF were 2.2 and 4.4 sec, respectively, again providing the range of values. In brief, all subjects generally responded with an average latency of about 3 sec whenever the OFF stimulus was presented. During the ON stimulus, however, some subjects responded very rapidly while others responded rarely.

Figure 4 shows selected cumulative response records for Subjects 26, 11, and 280. Rates of responding by the first two subjects were approximately constant within and across conditions. Slow, steady responding, with ap-

Fig. 4. Cumulative response records for Subjects 26, 11, and 280. The values to the right of each curve show the average interreward time scheduled by the variable-time program.

proximately constant IRTs (11 sec for #26 and 15 sec for #11), was the rule. The schedules paced responding for these as well as most other subjects. The records of #280 differ in that rates of responding were much higher (average IRTs varied between 1 and 5 sec) and there were occasional high bursts of responses. To a lesser extent, Subjects #281 and #5 also demonstrated high response rates.

On the average, between 80 and 86% of each session was spent in the ON condition at all VT values (Figure 5, top). The remainder of the session was spent in OFF. Since the VT schedule was activated only during ON, the overall average times between obtained rewards were longer than the scheduled VT values (Figure 5, middle). The differences between obtained interreward values and scheduled values were due to the time spent in the OFF state. Although the absolute

values of these differences increased as the scheduled time increased, Figure 5, bottom shows that the ratios of obtained to scheduled interreward times decreased and approached asymptote at about 1.13. For VT values longer than 30 sec, the obtained interreward time was approximately 1.13 times greater than the scheduled time.

In the present experiment, VT value had little consistent effect on responding over the range of values explored. Median rates of responding did not vary greatly as interreward times were manipulated. Rates of responding were usually low and stable; high rates sometimes occurred. Whereas interresponse times during ON varied greatly, response latencies during OFF were very stable and consistent within and across subjects. On the average, responses occurred 3 sec after the presentation of OFF.

EXPERIMENT II

Experiment II examined rates of responding as a function of the duration of ON time produced by each response.

METHOD

Subjects

Four pigeons (1, 5, 11, and 282) were arbitrarily selected and temporally removed from Experiment I and used in Experiment II.

Apparatus

Same as in Experiment I.

Procedure

The procedure was the same as in Experiment I except that the ON time produced by each peck was varied while the VT program during ON was always VT 90-sec. The values of ON/peck were: 1, 2, 4, 30, and 90 sec. Thus, for example, during the 30-sec ON/peck condition, if a response occurred during OFF (red keylight and rewards never presented) the key color changed to green and remained green for at least 30 sec. During the green ON time, response-independent rewards were presented on a VT 90-sec schedule. Responding during ON caused a continuation of ON until 30 sec after the last response in a series, at which time the state reverted to OFF.

The number of sessions at each condition and order of conditions are shown in Table

Fig. 5. The upper curve shows the median proportion of time spent in ON. These data were obtained by calculating each subjects' average proportion of time in ON (ON time divided by ON + OFF times) and taking the median of the eight subjects' performances. This was done for each scheduled interreward time. The middle graph shows the median times between obtained rewards. These data were calculated by dividing total session times (ON + OFF times) by the number of rewards obtained per session. The lower curve shows the ratio of obtained to scheduled interreward times.

I. The numbers of sessions per condition were fewer than in Experiment I because large effects were obtained rapidly.

RESULTS

Figure 6 shows each subjects' average inter-response times as functions of ON/peck times. The 10-sec ON/peck data were obtained in Experiment I. IRTs for three of the four subjects approximated the ON/peck values. This was also true for the fourth subject, #5, at ON/peck values of 1, 2, and 4 sec; however, #5's IRTs did not continue to increase as ON/peck increased to 90 sec. Group median IRTs, shown at the top of Figure 6, were slightly longer than the ON/peck times at 1-, 2-, and 4-sec values and shorter at the 10-, 30-, and 90-sec values. To a first order of ap-

proximation, the time between responses equalled the duration of ON time produced by each response.

As in Experiment I, response latencies during OFF were considerably shorter and less variable than IRTs during ON. Figure 7 shows median IRTs during ON and median latencies during OFF. Also shown are the range of performances at each ON/peck value. (See Table II for individual data.) In both cases, the times between responses increased as the ON/peck time increased. However, the median increase was much greater during the ON state (3.7 sec to 202.3 sec) than during OFF (1.3 sec to 6.5 sec). The paced

Fig. 6. Overall average interresponse times for each subject at each ON/peck value. The top graph shows the group median values. Overall average IRT was calculated as in Figure 2.

Fig. 7. Group median interresponse times in ON (upper) and response latencies in OFF (lower) as functions of ON/peck durations. ON IRTs and OFF latencies were calculated separately as in Figure 3. The lines through each median show the ranges of IRTs and latencies. Note that the scale of the OFF ordinate (lower) is four times that of the ON ordinate (upper).

responding was therefore due to the relatively long IRTs in ON and the increase in ON IRTs as ON/peck time increased. Again, as in Experiment I, the variation in ON IRTs was extremely large compared with that in OFF latencies. All subjects responded at most values within a few seconds of the presentation of the OFF stimulus. During the ON stimulus, however, responding was in some cases rapid and in others very infrequent.

Fig. 8. The upper graph shows the median proportion of time spent in ON, calculated as in Figure 5. The lower graph shows median obtained interreward times at each ON/peck value, calculated as in Figure 5.

Figure 8 shows that the percentage of time spent in ON (time in ON divided by total session time) increased with ON/peck duration (top) and therefore that the average time between obtained rewards decreased with increasing ON/peck durations (bottom). Thus, a comparison of Figures 7 and 8 indicates an inverse relationship between IRTs and obtained interreward times. IRTs increased as ON/peck times increased but as interreward times decreased.

The effects of ON/peck duration were achieved rapidly. Figure 9 shows the logarithm of the average daily interresponse times at each ON/peck value for Subject #11. The logarithmic coordinate permits all of the data to be seen clearly. Stable performance was often reached within the first one or two sessions and the effects of different ON/peck durations were clear. Data from the three other birds were similar although they generally took slightly longer to reach stability.

Patterns of responding were very similar to those in Experiment I. Interresponse times were regular with occasional fast bursts of responses.

In the present experiment, the duration of ON time produced by each response exerted strong and fairly consistent control over interresponse times. Response latencies during OFF were similar within and across subjects. Relatively little responding occurred during the ON stimulus in three of four subjects. Responding was paced by the duration of the ON stimulus.

EXPERIMENT III

Experiment III examined rates and patterns of responding as a function of the pattern of scheduled rewards.

METHOD

Subjects

Four pigeons (280, 281, 26, and 45) were used after they finished Experiment I (see Table I).

Apparatus

The same as in Experiment I.

Procedure

The procedure was the same as in Experiment I with one exception. Rewards were scheduled by a 90-sec fixed-time (rather than variable-time) schedule. When exactly 90 sec of green light ON time had elapsed, a reward was presented. A 10-sec ON/peck value was used. The main question was whether this fixed-time (FT) schedule would produce break-and-run patterns of responding as found under fixed-interval schedules (*e.g.*, Schneider, 1969). Fifty sessions were given.

RESULTS

Figure 10 shows cumulative records from the next to last, or forty-ninth session (there was a cumulative recorder malfunction in the last session) for Subjects 280 (upper) and 26 (lower). Break-and-run patterns of responding were obtained for both 280, a rapid responder, and 26, a slow responder. The other two subjects were generally slow responders and they demonstrated the same break-and-run patterns. These patterns are analogous to

Fig. 9. Logarithm of the average interresponse times during each session for Subject 11. The ON/peck durations are indicated to the right of each curve.

Fig. 10. Cumulative response records for Subjects 280 and 26 when the schedule of response-independent rewards was fixed-time 90-sec, *i.e.*, a reward was scheduled every 90 sec in ON.

those usually obtained under fixed-interval schedules of reinforcement.

EXPERIMENT IV

A single key color was used in Experiment IV. Consequently, the birds received no differential exteroceptive cues during ON and OFF conditions.

METHOD

Subjects

Three pigeons (280, 281, and 45) were used after they completed Experiment III (see Table I). Subject 26 was not used because of illness.

Apparatus

The same as in Experiment I.

Procedure

The basic procedure was identical to that in Experiment II except that the keylight was always green. Thus, although there were ON and OFF conditions, the birds were given no exteroceptive cues correlated with the conditions. The VT schedule during ON was always VT 90-sec. Three values of ON/peck time—2, 10, and 30 sec—were given (see Table I).

RESULTS

Figure 11 shows average interresponse times as functions of ON/peck times for each subject. As ON/peck increased, IRTs increased in two of the three subjects. The medians of these three subjects' IRTs were approximately half those in Experiment II at the same ON/peck values. Thus, although IRTs increased with ON/peck duration, the IRTs were systematically shorter than when exteroceptive cues were provided.

The differences between OFF latencies and ON IRTs were much smaller than in Experiments I and II. Figure 12 shows that response latencies and IRTs increased similarly in both ON and OFF conditions. Furthermore, unlike Experiments I and II, response latencies during OFF were longer than IRTs in ON for all subjects at all values. Thus, whereas paced responding in the previous experiments resulted from a relatively short latency in OFF followed by long IRTs in ON, the same type of responding was not found in the present experiment. Here, as ON/peck time increased, IRTs in ON and response latencies in OFF increased together. The medians of the percentages of time spent in ON were 70% (2-sec ON/peck), 89% (10-sec ON/peck), and 80% (30-sec ON/peck). The median obtained interreward times were 126 sec (2-sec ON/peck), 105 sec (10-sec ON/peck), and 108 sec (30-sec ON/peck).

This experiment showed that the contingencies were alone sufficient to produce changes in responding: with no exteroceptive cues present, IRTs increased as ON/peck duration increased. This result is analogous to that in Experiment II where exteroceptive cues were provided. However, (1) IRTs varied over a smaller range in the present case than in Experiment II. (2) OFF response latencies in the present case were not relatively short

Fig. 11. Overall average interresponse times for each subject at each ON/peck value. Discriminative stimuli were not present during ON and OFF in this experiment. Overall average IRT was calculated as in Figure 2.

Fig. 12. Interresponse times in ON (upper) and response latencies in OFF (lower) for each subject at each ON/peck duration. ON IRTs and OFF latencies were calculated as in Figure 3.

and constant, as in Experiments I and II. And (3) the striking differences between ON and OFF IRTs seen in Experiments I and II were not found here.

DISCUSSION

Pigeons pecked a key to change the state in the chamber from OFF (rewards never presented) to ON (rewards presented independently of the birds' behaviors). Each peck produced a maximum period of ON time called the ON/peck duration. Pecks during ON caused that state to remain in effect. The major variables were (a) the average time between free rewards in ON; (b) the duration of ON produced by each peck, or ON/peck time; (c) the pattern of rewards during ON, *i.e.*, variable-time schedules *vs* fixed-time schedules; and (d) the presence *vs* absence of exteroceptive cues during ON and OFF.

The major results were: (1) the average time between responses (IRTs) did not vary systematically as the average time between rewards increased from 10 sec to 360 sec; (2) IRTs were controlled by the patterns of freely presented rewards (variable- *vs* fixed-time schedules); (3) high bursts of responses were sometimes observed; (4) IRTs were mainly controlled by the duration of ON produced by each response: interresponse times varied directly with ON/peck duration when exteroceptive cues were present; and (5) there was a closer relationship between ON time and IRTs when exteroceptive cues were present than when they were absent.

The observation that interresponse times were not affected by the frequency of rewards disagrees with results reported by Thomas (1965) for one pigeon and D'Andrea (1971) for two rats. As discussed in the Introduction, both of those studies employed a positive analogue to the Sidman avoidance schedule, with the aversive stimulus being a timeout from response-independent positive rewards. In Thomas' study, interresponse times decreased as interreward times increased; D'Andrea's results show the opposite, *i.e.*, a direct relationship between interresponse times and interreward times. Procedural differences between those two studies and the present work might be responsible for the different results; or, the small number of subjects used in those studies might be responsible. In the present experi-

ment, subjects sometimes demonstrated a small decrease in IRTs with increasing inter-reward times; other subjects demonstrated a small increase in IRTs. On the average, the function relating interresponse times to inter-reward times was relatively flat. Future research must extend the time between free rewards beyond the 360-sec value used here.

The present results are consistent with the effects produced by regular response-dependent variable-interval (VI) and fixed-interval (FI) schedules of reinforcement. When, in a given session or series of sessions, pigeons are confronted with only one value of a VI schedule, interresponse times are approximately invariant over a wide range of different inter-reinforcement values (Catania and Reynolds, 1968). However, FI schedules generate different patterns of responding than do VI schedules (Ferster and Skinner, 1957). Similarly, in the present work, the interreward value of the VT exerted little control over interresponse times but the FT schedule generated patterns of responding different from those under the VT.

The relatively rapid responding emitted occasionally might have been partly due to the extensive previous histories of the subjects under schedules that produced high rates of responding (Weiner, 1969*a*, 1969*b*) and partly due to "superstitious" responding generated by adventitious correlations between responses during ON and free rewards (Skinner, 1948; Zeiler, 1968; Neuringer, 1970). However, D'Andrea (1971) offered a partial test of the "superstition" hypothesis and obtained disconfirming evidence. D'Andrea instituted a minimum 3-sec delay between responses and free rewards thereby prohibiting adventitious correlations—and found that responding was unaffected by the delay.

A major finding was that interresponse times varied directly with the duration of the ON stimulus produced by each response. In other words, responding was paced by the ON stimulus. Baer (1960) and Thomas (1965) reported analogous results, whereas D'Andrea (1971) found that interresponse times first decreased and then increased as the analogue to ON time increased. Using a procedure different from both the Sidman avoidance schedules discussed above and the present schedule, Hake and Azrin (1969) reported pacing similar to the present.

The different exteroceptive stimuli during ON and OFF were partly responsible for the relatively close match between interresponse times and ON/peck durations in Experiments I, II, and III. When the stimuli were absent in Experiment IV, the matching relationship was not obtained. The stimuli might have served as discriminative cues. The red OFF stimulus could be considered an S^A , or timeout stimulus: rewards were never presented in its presence. And the green ON stimulus might have served as an S^D , or conditioned reinforcer: the green light preceded and was correlated with rewards. Responses during red caused an escape from a timeout stimulus and produced a green conditioned reinforcer; responding during green avoided the red timeout and increased the duration of the conditioned reinforcer.

However, these exteroceptive stimuli can not alone explain the pacing obtained in Experiments I, II, and III. In those experiments, why were most interresponse times approximately equal to the ON/peck durations? And why did interresponse times increase with increasing ON/peck times in Experiment IV where exteroceptive cues were not provided? Consider the following possible explanation.

Overall obtained frequency of rewards is given by:

$$\text{equation a: } R^0 = \frac{R^s}{\frac{\text{Time ON}}{\text{Time ON} + \text{Time OFF}}} \times \text{Time ON}$$

where R^0 is the overall obtained frequency of rewards (total rewards divided by total session time) and R^s is the scheduled frequency of rewards (rewards in ON divided by ON time). The number of rewards presented per unit of time ON ($R^s/\text{ON time}$) is a constant, determined by the VT schedule. Therefore, equation "a" can be rewritten:

equation b:

$$R^0 = K \left(\frac{\text{Time ON}}{\text{Time ON} + \text{Time OFF}} \right)$$

where K equals the scheduled frequency of response-independent rewards provided by the VT during ON. Equation "b" states that, for any scheduled value of K , the overall obtained frequency of rewards will vary with

$$\frac{\text{Time ON}}{\text{Time ON} + \text{Time OFF}}$$

Thus, as the time spent in ON increases, the overall obtained frequency of rewards increases; and as the time spent in OFF increases, there is a decrease in the obtained frequency of rewards.

The subjects' interresponse times determined the value of

$$\frac{\text{Time ON}}{\text{Time ON} + \text{Time OFF}}$$

Consequently, the subjects' IRTs determined the value of equation "b". For example, IRTs shorter than the ON/peck time caused an increase in ON time without causing a corresponding increase in OFF time. Therefore, when IRTs were shorter than ON/peck time, the value of "b" necessarily increased. On the other hand, IRTs longer than ON/peck caused increases in both ON and OFF times. As OFF time increased, the value of "b" decreased. An IRT exactly equal to the ON/peck duration resulted in the greatest possible increase in ON time without producing an increase in OFF. Thus, equation "b" shows that, at any given moment in the experiment, obtained frequency of rewards increased as IRTs approached the ON/peck duration. IRTs equal to ON/peck time produced the greatest possible increment in obtained overall frequency of reward. This analysis might partly explain the major finding in these experiments: average IRTs approximately matched ON/peck durations. As in other studies, the matching relationship was more precise when exteroceptive stimuli were present (Experiment II) than when they were absent (Experiment IV). Exteroceptive cues often increase the precision of control exerted by schedule contingencies. For example, exteroceptive "clocks" result in relatively few ineffective responses under fixed-interval schedules of reinforcement (Ferster and Skinner, 1957). And providing a cue stimulus correlated with availability of reinforcement under a variable-interval schedule results in approximately one response per reinforcement (Catania, 1969).

The major conclusions: (1) An operant response can be reinforced and maintained by ON periods during which rewards are inde-

pendent of responding. (2) The frequency of response-independent rewards exerts little control over rates of responding. And (3) responding is primarily controlled by ON/peck times: interresponse times approximately matched the maximum duration of ON produced by each response.

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