# DELAY OR RATE OF FOOD DELIVERY
## AS A DETERMINER OF RESPONSE RATE

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Pigeons were confronted with two keys: a green food key and a white changeover key. Food became available for a peck to the green key after variable intervals of time (mean = 113 seconds). A single peck on the changeover key changed the color of the food key to red for a fixed period of time during which the timing of the variable-interval schedule in green was suspended and the switching option eliminated and after which the conditions associated with green were reinstated. In Experiment 1 a single food presentation was obtainable during each red-key period after a minimum delay timed from the switch. This delay and the duration of the red-key period were held constant during a condition but varied between conditions (delay = 2.5, 7.5, 15, or 30 seconds; red-period duration = 30, 60, 120, 240, or 480 seconds). In Experiment 2 additional food presentations were scheduled during a 240-second red-key period with the delay to the first food delivery held constant at 30 seconds, and the delays to later food deliveries varied over conditions. Considering the data from both experiments, the rate of switching to red was a decreasing function of the delay to the first food, the delay to the second food, and perhaps the delay to the third food after a switch. There was no clear evidence that the rate of food in the red-key period made an independent contribution. The ordering of response rates among conditions was consistent with the view that each food presentation after a response adds an incremental effect to the rate of the response and that each food presentation's contribution is a decreasing function of its delay timed from the response.

*Key words:* delay of reinforcement, rate of reinforcement, changeover delay, response rate, key peck, pigeons

The simplest procedure for operant conditioning (continuous reinforcement) includes the following features: each instance of a response, such as a key peck, produces and is closely followed by a reinforcer, such as food. As a result, the rate of the response is increased to and maintained at a level above what would prevail in the absence of the procedure. While the effect on response rate is clear enough, there is considerable dispute about exactly what aspects of the whole procedure are most important. Some accounts have emphasized the amount of time between particular instances of the response and reinforcer—that is, the delay of the reinforcer—as the major controlling variable (Catania, 1971; Dews, 1962; Hull, 1943; Skinner, 1948; Spence, 1947; cf. Renner, 1964). Other accounts have empha-

sized the more molar relationship between the rate of responding and the rate (or density) of the reinforcer (Baum, 1973; Herrnstein, 1969; Rachlin, 1978). Because each response under continuous reinforcement produces food, the rate of food varies directly with the rate of the response. Most other schedules of reinforcement also arrange a positive correlation between response rate and reinforcer rate. Perhaps high rates of responding engendered by most operant procedures result from experiencing such positive correlations rather than from experiencing the short delays between particular instances of the response and reinforcer. In most operant procedures these two possible sources of control are confounded, and so it is necessary to modify the procedure to determine the independent contribution of each kind of variable.

The power of the delay-of-reinforcement variable has been demonstrated most clearly by procedures where the delay of reinforcement induces behavior that reduces the total density of the reinforcer below what would have occurred in the absence of such behavior

(Ainslie, 1975; Lea, 1979; Mowrer & Ullman, 1945). For example, given a choice between two responses, one producing a short delayed, small amount of food and the other producing a longer delayed, larger amount of food, pigeons have responded consistently so as to obtain the more immediate, smaller amount of food even though doing so has reduced the total density of food below the maximum obtainable (Rachlin & Green, 1972). Analogous results have been obtained with human children (Mischel & Metzner, 1962). In a complementary way, rats and pigeons have repeatedly emitted a response that avoided an otherwise immediate shock even when such responding has produced enough extra delayed shocks so that the total density of shocks in the situation actually increased (Gardner & Lewis, 1977; Hineline, 1977). These kinds of observations raise the possibility that rate of reinforcement might not participate directly in the differential reinforcement of responding.

Following in this tradition, the present experiment (Experiment 1) was designed to study the effects of delayed food reinforcement on the rate of a response under conditions where the response produced either an increase, no change, or a decrease in the average rate of food. The purpose was to see if there was any detectable effect of the correlation between response rate and food rate. A pigeon could respond to one schedule obtaining food at variable intervals of time averaging two minutes (a VI 2-min schedule), or it could switch to another schedule that provided a single food reinforcer after a fixed interval of time since the switch. Once the pigeon switched to the second schedule, it had to remain there for a fixed amount of time after which the original VI schedule and the switching option were reinstated. Thus, each switch produced a fixed period of time away from the VI schedule (the imposed period) during which a single food presentation occurred after a delay timed from the switch (the delay interval). Both the delay interval and the duration of the imposed period were varied independently over blocks of sessions so that each delay was combined with several different imposed-period durations. The imposed-period duration determined whether, and by how much, switching would affect the average rate of food delivery. When the imposed period was shorter than 120 sec, switching would increase the rate of food de-

livery above the average obtainable in the VI schedule. When the imposed period was longer than 120 sec, switching would decrease the rate of food delivery. For both variables the longest duration was about sixteen times longer than the shortest duration. It was thus possible to assess the potency of the delay-of-food variable relative to that of the rate-of-food variable over comparable ranges.

The procedure of Experiment 2 was similar except that additional food reinforcers were scheduled during the imposed period. The number of food presentations during the imposed period and the timing of those presentations were varied over blocks of sessions to determine the effects of reinforcers and time after the first food delivery.

## EXPERIMENT 1

### METHOD

*Subjects*

The subjects were three adult male domestic pigeons maintained at about 80% of their free-feeding weights. They had continuous access to water and grit in their separate homecages. They had had extensive experience with variable-interval schedules of food reinforcement.

*Apparatus*

A sound-attenuating shell enclosed the experimental cubicle which was 31 cm long by 36 cm wide by 36 cm high. Two translucent keys were mounted 25 cm above the floor behind 2.5-cm diameter holes through the front wall of the chamber. The keys were 13 cm apart, center to center, and could be transilluminated with red, green, or white light. The keys required a minimum pressure of .2 N to operate the electromechanical control and recording circuits located in an adjoining room. When the keys were lighted, a sufficiently forceful peck produced a brief click from a relay mounted behind the front wall. A houselight centered near the top of the front wall provided low-level general illumination in the chamber. Centered below the keys, 10 cm above the floor, was a rectangular opening through which the pigeon could gain access to mixed grain when a hopper was raised, the feeder opening illuminated, and the keylights and houselight darkened. White noise and a ventilating fan helped mask extraneous sounds.

## Procedure

Because of the pigeons' prior experience no particular pretraining was needed.

At the start of each session the left-hand key, designated as the food key, was illuminated green and the right-hand key, designated as the switching key, was illuminated white. The green key was associated with a VI 2-min schedule of food reinforcement (nominal value). That is, a peck to the green key could produce food after a variable interval of time had elapsed since the last food delivery; pecks during the interval had no effect on food delivery. Sixteen intervals were selected to provide a roughly constant probability of food as a function of elapsed time since the last food presentation (Fleshler & Hoffman, 1962) and were arranged in the following order as a continuously repeating series (the starting point varied unsystematically from day to day). The actual values were: 280, 42, 25, 147, 62, 10, 124, 402, 36, 86, 19, 179, 209, 59, 16, and 105 sec (mean = 113 sec). Each reinforcer consisted of 5-sec access to food. This VI schedule for the green food key continued until interrupted by the end of the session or by a peck on the white switching key.

A single peck on the switching key changed the color of the food key to red and stopped the timing of the VI schedule for green. It also darkened the changeover key for the duration of the red-key period during which pecks to the changeover key had no effect. The food key remained red for a specified fixed duration that was constant for a block of sessions but varied between blocks from 30 sec to 480 sec. After a fixed interval of time had elapsed since the onset of the red keylight, a peck to the red food key produced reinforcement (i.e. 5-sec access to food). Pecks during this interval had no effect on food delivery, and so food availability could be considered to have been arranged by a fixed-interval schedule timed from the red-light onset or by a changeover delay. The delay to food availability timed from the onset of red was constant during a block of sessions but varied between blocks from a few seconds to 30 seconds. The shortest delay was arranged by scheduling food for the first peck to the red food key after a switch. The actual time from a peck on the switching key to contact with the food under this minimum delay condition appeared to be about 2 or 3 sec, based on vi-

sual observations. At the longer delays, obtained delays approximated scheduled values.

In Experiment 1 only one food reinforcement was available during each red-key period. Nevertheless, the pigeon had to remain in the red-light condition after obtaining the one reinforcer until the fixed duration of red elapsed. After the end of the red-light period, the food-key color changed back to green and the switching key was reilluminated, thus making the continuous switching option again available during the green keylight.

Table 1 summarizes the combinations of red-period durations and delays to food from the onset of red that were examined. Also shown are the order of conditions and the number of sessions comprising each. Several conditions were studied more than once, and several conditions were examined after completing Experiment 2.

Sessions were conducted seven days per week. The chamber was dark before the start of each session and after the delivery of the fortieth food delivery, which ended the session.

## RESULTS

Figures 1 and 2 show representative cumulative records generated by one of the pigeons during selected conditions. The records in Fig-

Table 1

Order of conditions in Experiment 1 and the number of sessions at each. (The conditions are ordered continuously with those in Experiment 2.)

| Condition Red Period Duration Delay to Food | Order | Number of Sessions |
|---|---|---|
| 30 sec Red | | |
| 2.5 sec | 9 | 11 |
| 15 sec | 6, 8 | 25, 15 |
| 60 sec Red | | |
| 7.5 sec | 3, 25 | 10, 20 |
| 15 sec | 2, 4 | 70, 10 |
| 30 sec | 1 | 50 |
| 120 sec Red | | |
| 2.5 sec | 10 | 10 |
| 15 sec | 5, 7 | 15, 15 |
| 240 sec Red | | |
| 2.5 sec | 11 | 7 |
| 7.5 sec | 13 | 50 |
| 15 sec | 12 | 15 |
| 30 sec | 20 | 30 |
| 480 sec Red | | |
| 2.5 sec | 22 | 10 |
| 7.5 sec | 23 | 20 |
| 15 sec | 21, 24 | 25, 20 |

ure 1 were chosen to indicate the effect of varying the duration of the red period while holding constant the delay to food at 15 sec. The records in Figure 2 were selected to illustrate the effect of the delay to food.

Several points are notable. First, the rate of switching to red decreased as a function of increasing red-period duration and as a function of increasing delays to food. But the delay variable appeared to exert a stronger effect over the ranges studied. That is, when food was delayed 15 sec, periods of responding in green alternated with switches to red, so that the bird obtained some of its food in each color. This pattern persisted over the range of red-period durations despite the fact that the rate of food in red was four times greater than that in green when the red period was 30 sec and four times less than that in green when the red period was 480 sec. In contrast, with the red
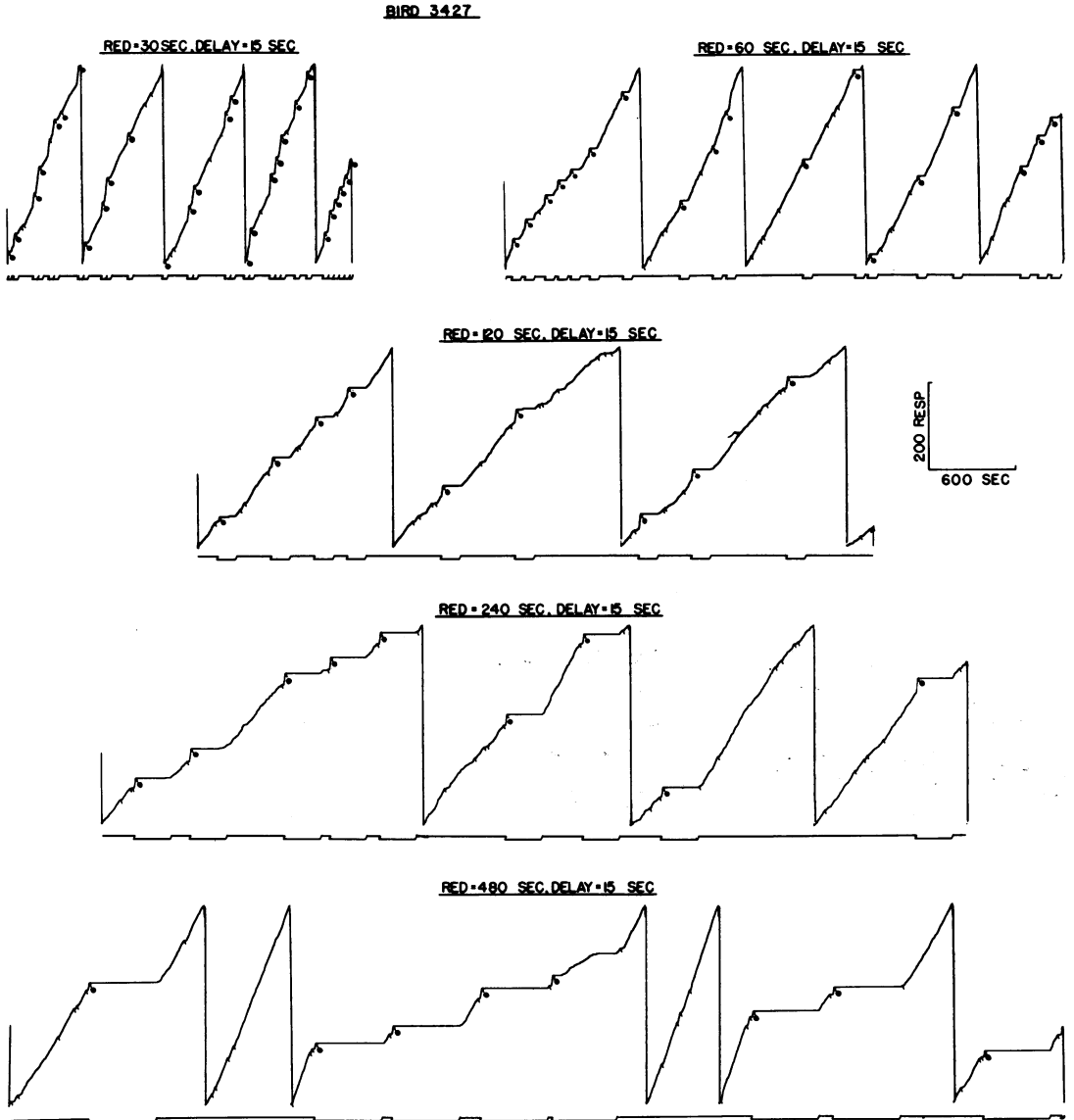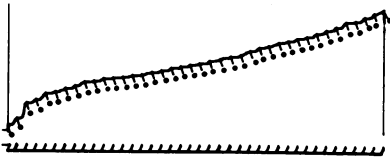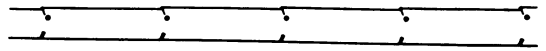


Fig. 1. Cumulative records from Bird 3427 under conditions selected to emphasize the effect of the red-period duration. The delay to food was constant at 15 sec. The records are from the session that gave the median rate of switching to red over the last five sessions of the condition. The slash marks on the response line indicate food deliveries. The event pen was up while the food key was green (the VI 2-min schedule); it was down during the red period. Dots indicate food in red.

## BIRD 3427

RED = 30 SEC, DELAY = 2.5 SEC

RED = 480 SEC, DELAY = 2.5 SEC

RED = 240 SEC, DELAY = 2.5 SEC

RED = 240 SEC, DELAY = 7.5 SEC

200 RESP

600 SEC

RED = 240 SEC, DELAY = 30 SEC

Fig. 2. Cumulative records from Bird 3427 under conditions selected to emphasize the effect of the delay to food. The records are from the session that gave the median rate of switching to red over the last five sessions of the condition. The slash marks on the response line indicate food deliveries. The event pen was up while the food key was green (the VI 2-min schedule); it was down during the red period. Dots indicate food in red.
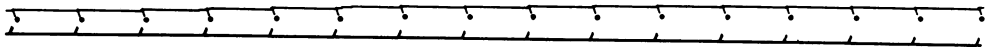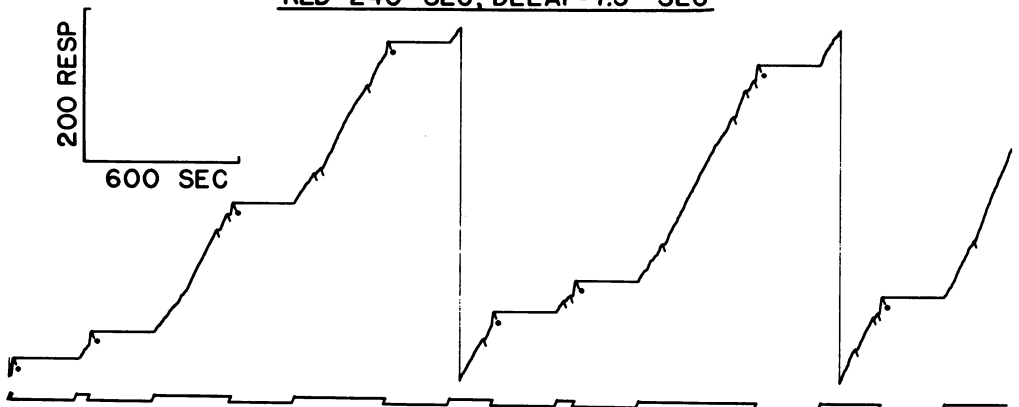
period constant at 240 sec, virtually the whole session was spent in red under the shortest delay and relatively little of the session was spent in red under the longest delays. A second point is that the pigeon seldom pecked the key during red after the single food presentation, suggesting that delivery of food in red was discriminative for nonreinforcement for the remainder of the red-key period. (It might be worth mentioning that this control took some time to develop during the initial condition. An earlier performance consisted of a pause after the food in red followed by key pecking before the end of the red period. When the red period ended, the pigeons switched quickly back to red and continued responding until another food presentation.) The third point to note from the cumulative records is that no obvious event or pattern of events in green predicts the moment when the pigeon will switch to red. For instance, switching is not restricted to periods when the green VI schedule is unusually lean.

Three conditions that generated relatively low rates of switching were studied further in an effort to establish this point (Conditions 15, 17, and 19 from Experiment 2). (The differences between Experiments 1 and 2 are irrelevant to this analysis.) From cumulative records of each of the last five sessions of these conditions, the average rate of food during the VI 2-min (green) period was determined in successive 1-min periods backwards from the switch. If switching became especially likely during lean periods of the VI 2-min schedule, the average rate of food would have been especially low during the period just prior to a switch. Instead, the rate of food was either unrelated to time prior to the switch or was actually higher during the preceding one minute. These latter cases resulted from a tendency for switches, when they occurred, to follow closely after a food presentation in green.

The rate of switching to red was calculated by dividing the number of switches to red by the time spent in green. Figure 3 shows the switching rates for each bird plotted over the delay interval (left-hand column) and over the red-period duration (right-hand column).

The rate of switching to red was a similarly decreasing function of the delay interval at all red period durations, a relation that was apparent in the cumulative records. The rate of switching also was a decreasing function of the red-period duration, although this effect was smaller and less reliable than the delay-interval effect.

The variability in performance within a session is indicated in the cumulative records. Some sense of the reliability of the five-session means can be gained by examining the correspondence between points representing different determinations of the same condition. Usually this correspondence was reasonably close relative to the effect of the delay-interval manipulation.

## DISCUSSION

The rate of switching from one source of food (green) to another source of food (red) varied as a function of manipulating two temporal parameters: the amount of time that the pigeon had to spend in red per switch and the amount of time after a switch until a food delivery. Of the two the delay variable was the more powerful since the rate of switching was a similarly decreasing function of the delay to food delivery at red-period durations ranging from 30 to 480 sec. These data thus extend the generality of previously reported data showing that the response rate for a stimulus, or the preference for a stimulus, decreases as a function of the time to food reinforcement following the stimulus onset when the rate of food delivery in the stimulus is held constant (Davison, 1968; Hursh & Fantino, 1973; Kendall, 1967). Since in Figure 2 the vertical axis was scaled in logarithmic units, the roughly linear decrease would translate into a negatively accelerated function in linear coordinates, consistent with much previous data (cf. Ainslie, 1975).

The power of the delay variable was demonstrated most forcefully at the shortest and longest red-period durations because it was under these conditions that switching rate had its greatest effect on the overall rate of food (cf. Fantino, 1966). For example, when the red period was 30 sec, increasing the rate of switching would cause the rate of food to increase from a low of about 30 food reinforcers per hr (all time spent in green) to a high of 120 food reinforcers per hr (all time spent in red). If higher rates of food presentation are assumed to be more reinforcing than lower rates, the correlation between food rate and switching rate could be expected to differentially reinforce relatively high rates of switching. Con-
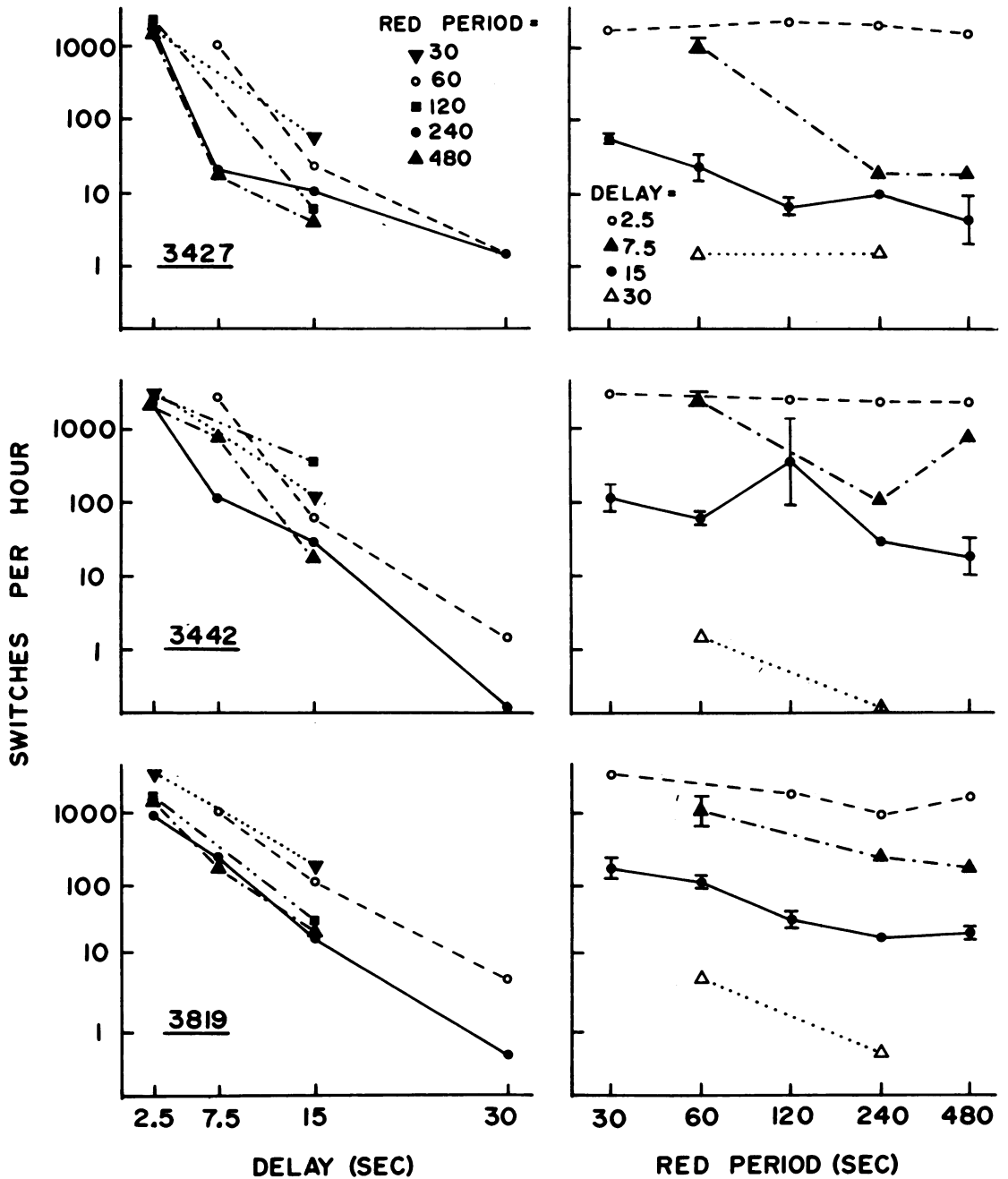
Fig. 3. Rate of switching to red (log scale) plotted over the delay to food in red with the duration of the red period as a parameter (left panel) and over the duration of the red period (log scale) with the delay to food in red as a parameter (right panel). The rate of switching to red was calculated for each condition by dividing the number of switches made in the last five sessions by the accumulated time in the green food-key period over the last five sessions. When the condition was studied twice, the plotted point is the geometric mean of the two determinations; the vertical lines bracketing points in the right-hand panel indicate the values from each determination. The shortest delay-to-food value was estimated to be 2.5 sec.

versely, when the red period was 480 sec, increasing rates of switching would cause the rate of food to drop from a high of 30 food re-

inforcers per hr (all time spent in green) to a low of 7.5 food reinforcers per hr (all time spent in red). We might expect this negative

correlation between switching rate and food rate to differentially reinforce relatively low rates of switching. In fact, consideration of efficiency, in terms of maximizing amount of food per time spent, might cause us to wonder why the pigeon would ever switch into the 480-sec red period. Nevertheless, the pigeons switched frequently into the 480-sec red period when food came quickly (delay = 2.5 or 7.5 sec) and switched rarely into the 30-sec red period when food came less quickly (delay = 15 sec). The pigeons performed efficiently, in the sense of obtaining near maximum rates of food, only when the delays supported such performance, that is, only when the short red periods contained relatively short delays to food and the long red periods contained relatively long delays. Thus, control by delay can account for both the efficient and nonefficient performances.

It might be argued that the relatively high rates of switching into the long red periods are due to additional, unscheduled reinforcers available after getting food in red. This argument is based on the observation that the pigeons seldom responded in red after the single food presentation (Figure 1), suggesting that the time in red after food functioned as a discriminated period of timeout from the food schedule. Perhaps such timeout periods are reinforcing because they give the animal time to engage in other kinds of activities that provide reinforcement (e.g., grooming, resting, and so forth). Responses that produce these timeout periods would be differentially reinforced if the gain in the total reinforcement from these other sources exceeds the loss from the lowered rate of food delivery. The data, however, provide little support for this kind of interpretation. For example, with the 240-sec red period, increasing the delay from the shortest value to 30 sec reduced the rate of switching from over 1000 per hr to a value usually less than one per hr. Yet the duration of the timeout period after food in red decreased a mere 12%, from just under 240 sec to 210 sec. Similarly, with the 480-sec period, increasing the delay from 7.5 to 15 sec caused a large decrease in switching rate even though the timeout period decreased by less than 2%, from 472.5 sec to 465 sec. The results to be presented from Experiment 2 argue further against the importance of the timeout period as a source of reinforcement for switch-

ing, since a similar effect of delayed food was demonstrated even though key pecking was generated throughout the red period by additional food presentations in red.

Although the delay to food was the more powerful of the two temporal variables over the ranges studied, the duration of the imposed period nevertheless exerted an effect on the rate of switching. A reasonable interpretation, then, is that both delay and rate of reinforcement affect response rate, though perhaps not equally. However, an alternative and more parsimonious interpretation is possible, namely, that the effect of changing the red-period duration is merely another instance of a delay-of-reinforcement effect, not a rate-of-reinforcement effect. This interpretation derives from the fact that even though only one food reinforcer could occur in a given red period, more than one food delivery followed each switch. The first food delivery occurred during the consequent red period and so, in a sense, was directly produced by the switch. But food presentations also occurred after the end of each red period, either in green or in later red periods, and these too followed the switch even though the switch did not directly produce them. It could be that each food reinforcement that follows a given response contributes to the strength of the response an amount that decreases as a function of its delay from the response. The total strengthening effect, then, would be a cumulative effect of the independent contribution of each delayed food delivery (Ainslie, 1975; Killeen, 1968; cf. also Catania & Reynolds, 1968; Eckerman & Hienz, 1974).

We may apply this reasoning to interpret the red-period duration effects in Experiment 1. In addition to controlling the rate of food delivery, the red-period duration determined the minimum time until the second food after a switch. The effect of varying the red-period duration, then, could be due to changes in the delays to food after the first food instead of to changes in the rate of food.

To support this idea it would be minimally necessary to demonstrate that the delay to the second food presentation after a switch affects the rate of switching independently of changes in either the delay to the first food presentation or in the rate of food. Some comparisons in Experiment 2 were designed to detect such an effect. For example, in one com-

parison exactly three food reinforcements were scheduled during a 240-sec red period. The first and third food presentations occurred, respectively, 30 and 210 sec after the switch. The delay to the second food presentation, which was constant over a block of sessions, but varied between sessions, was either 45 sec or 195 sec timed from the switch. Thus, the rate of food in red and the delay of the first food reinforcement were constant whereas the delay to the second food reinforcement varied. An effect of this manipulation would support the possibility that each of the food presentations that follow an instance of a response contribute a strengthening effect whose magnitude is a decreasing function of its delay.

## EXPERIMENT 2

### METHOD

*Subjects*

The subjects and apparatus were the same as in Experiment 1.

*Procedure*

The procedure was identical to that for Experiment 1 except that now additional food reinforcers were available after the first for key pecking in red. (To get the birds to peck in red after the first food, we delivered food independently of pecking during a few red-key periods during the first session under this general procedure.) The duration of the red period was 240 sec in all conditions of Experiment 2, and the number of foods varied from two to four. Figure 4 provides a schematic summary of the various conditions of food delivery in red. Also shown are the order of conditions and the number of sessions at each. The ordering of the conditions is continuous with those in Experiment 1 since the conditions of Experiment 2 were intermixed with those of Experiment 1.

### RESULTS

The conditions of Experiment 2 were designed to find out whether food presentations after the first contribute to the rate of switching and, if so, whether the size of each food presentation's contribution diminishes as a function of its delay from the switch. A clear answer should be given by the two conditions providing three food reinforcers (food at 30,
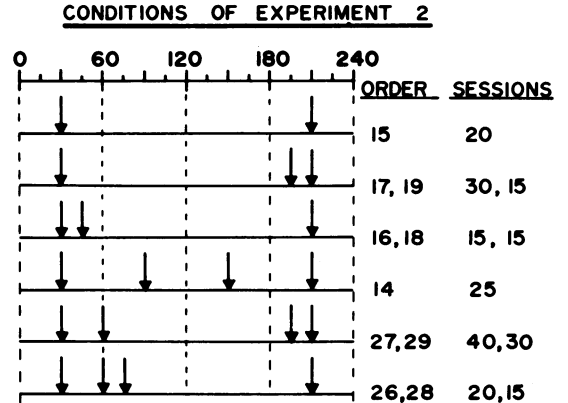


Fig. 4. Schematic of the temporal distribution of food presentations during the red period in Experiment 2. Each horizontal line represents the 240-sec red period produced by a switch. The downward-pointing arrows indicate food deliveries; their distance from the left represents the time from the switch that they became available for a peck to the red food key. To the right of each line are numbers indicating the order of the condition and the number of sessions at each. The ordering is continuous with the conditions in Experiment 1.

45, and 210 sec vs. food at 30, 195, and 210 sec) because these two conditions differed in the delay to the second food presentation while being identical in several other respects. They were alike, for example, in having the same times to the first food delivery (30 sec), the same times between successive food deliveries except for order (15 sec and 165 sec), and the same number of food deliveries (3) per each 240-sec red period. For similar reasons two of the conditions providing four food presentations during red (food at 30, 60, 75, and 210 sec vs. food at 30, 60, 195, and 210 sec) have the potential of providing a clear answer: the particular interfood intervals were the same except for order, but the remoteness of the third food presentation from the switch differed.

The rate of switching to red was substantially and reliably higher when the second of three food presentations came 45 sec after the switch than when it came 195 sec after. This effect can be seen in representative cumulative records (Figure 5) and in the plots of average switching rates for each bird (Figure 6; the left-most pair of shaded bars). A similar, but less reliable effect, was observed when the third of four food deliveries was shifted in time. That is, for two of three birds (Bird 3427 and Bird 3442) switching rates were higher on the average when the third food presentation

came 75 sec after the switch than when it came 195 sec after; for the other bird (Bird 3819) shifting the time of the third food presentation had no detectable effect on switching rate. Thus, the rate of switching to red was a decreasing function of the delay to food after the first. However, this effect was less reliably demonstrated with a shift in the delay to a more remote food presentation than with a shift in the delay to a more proximal presentation.

The reliability of these differences was assessed further with an analysis of the variance in switching rates of the three birds combined. The logarithm of the switching rate on each of the last five sessions of each condition (first determinations only) was treated as an independent observation of each bird's performance on that condition. Thus, the design for the analysis consisted of two factors: 7 (Conditions) by 5 (Sessions), with Conditions and Sessions treated as repeated measures. The null hypothesis—that the observed differences were due to chance variation—was rejected whenever the probability of getting or exceeding the observed difference by chance was equal to or less than .05 ($p \leq .05$). Overall, switching rates differed significantly across conditions in red ($F = 24.81$, $df = 6/12$). Using the omega-
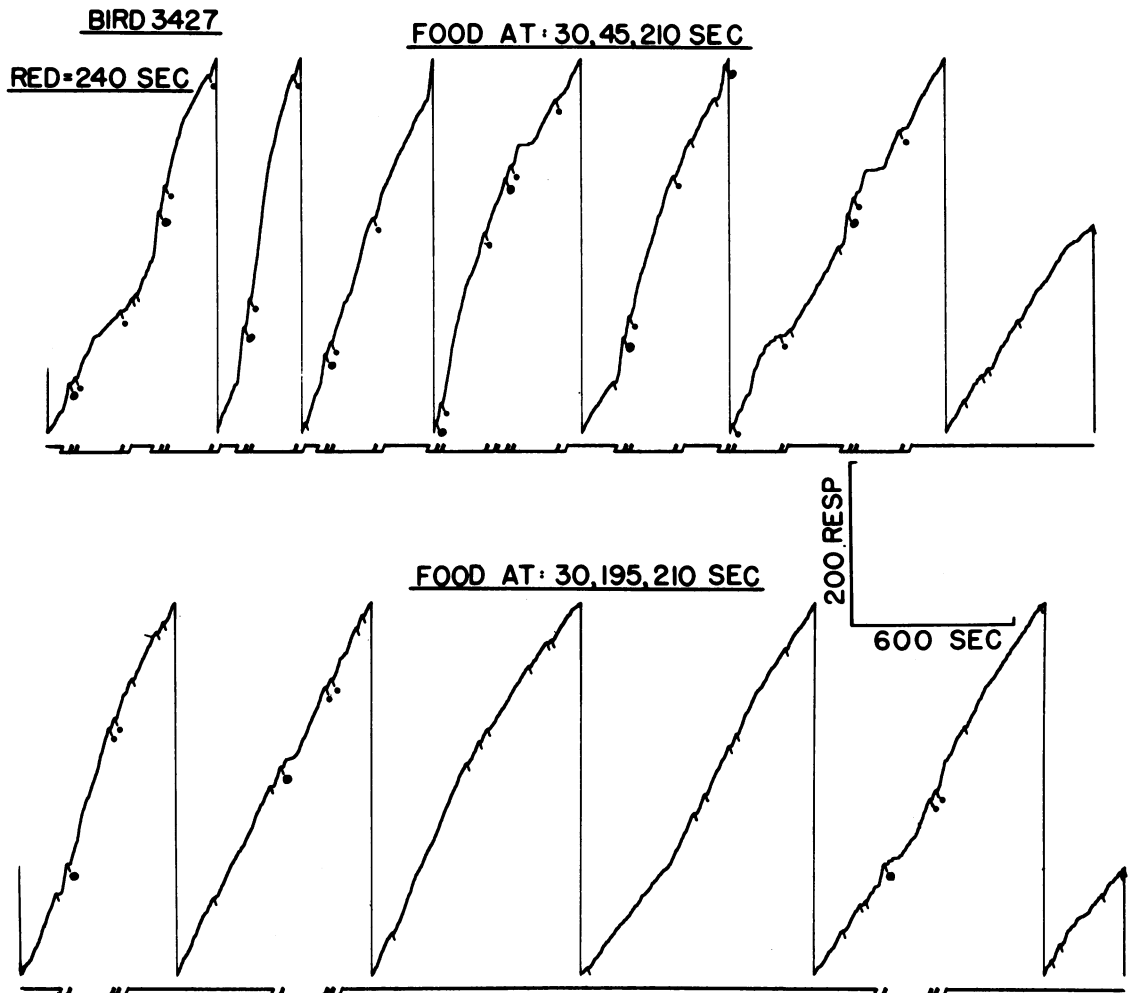


Fig. 5. Cumulative records from Bird 3427 under the two conditions that provided three foods per 240-sec red period. Each record represents the whole session that gave the median rate of switching to red over the last five sessions of the condition. The slash marks on the response line indicate food deliveries. The event pen was up while the food key was green (the VI 2-min schedule); it was down during the red period. Also, each food during the red period caused the event pen to deflect upward momentarily. Dots indicate food in red, with the larger dots indicating the first food after a switch.
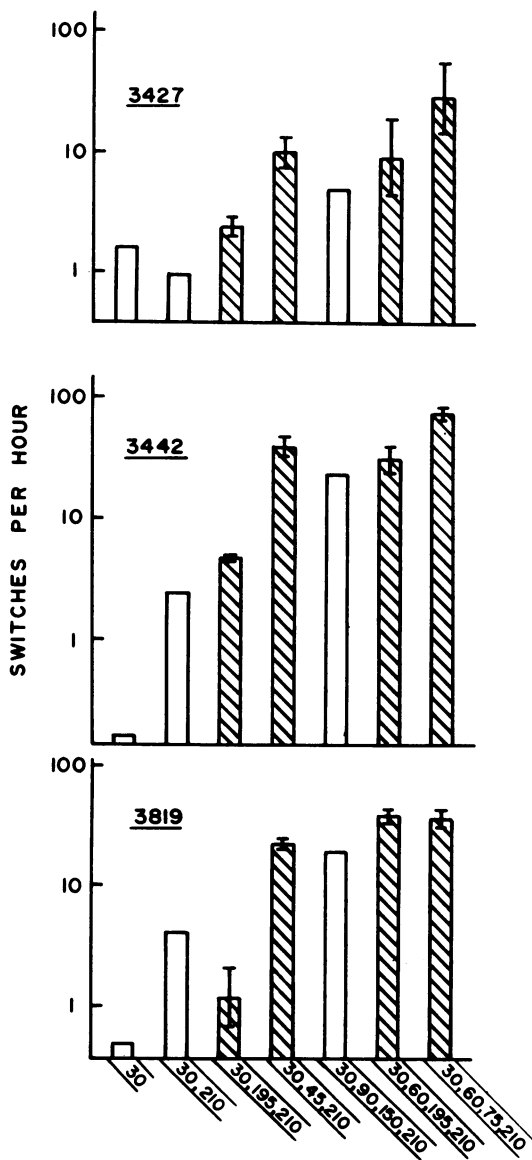
Fig. 6. Rate of switching to red (log scale) plotted over the different conditions of Experiment 2, and the one condition of Experiment 1 that provided one food at 30 sec during a 240-sec red period. The times to the food in red after the switch are indicated below each bar. The rate of switching to red was calculated for each condition by dividing the number of switches made in the last five sessions by the accumulated time in green over the last five sessions. When the condition was studied twice, the height of the bar represents the geometric mean of two determinations, with the individual determinations indicated by the brackets. Each of the two pairs of shaded bars indicates a comparison where the number of food presentations per red period and the interfood intervals (except for order) were the same.

squared statistic, the conditions of food in red accounted for 72% of the total variance in switching rates. Switching rates did not differ significantly as a function of their order within the last five sessions, nor was the Sessions by Condition interaction significant. This latter finding is consistent with the view that responding was stable over the last five sessions. Using a Newman-Keuls post hoc analysis, switching rates on a number of specific pairs of conditions differed significantly. Of interest here is the fact that the switching rates on the two conditions providing three food reinforcers (30, 45, 210 sec vs. 30, 195, 210 sec) differed significantly. But the switching rates on the two conditions providing four food reinforcers with the time to the third shifted (30, 60, 75, 210 sec vs. 30, 60, 195, 210 sec) did not differ significantly.

Analyses of variance were computed similarly for each bird separately. The results were as described for the grouped data except that the switching rates from the two conditions with four food presentations differed significantly for two birds, (Birds 3427 and 3442) but not for the third bird (Bird 3819). These analyses thus support impressions formed from inspecting the figure.

Additional evidence that the remoteness of food presentations after the first affects the rate of switching comes from comparing conditions of the red period that differed from each other only at times remote from the switch. For example, the three left-most bars in Figure 6 represent conditions providing, respectively from left to right, one, two, and three foods per 240-sec red period. But the additional food reinforcers after the first occurred with delays of at least 195 sec from the switch. That these remote reinforcers exerted little control is suggested by the fact that all three conditions produced low and roughly comparable rates of switching. That these remote reinforcers probably contributed a little bit to switching rate is suggested by the average tendency for switching rates to increase as the number of foods in red increased across these three conditions (a tendency seen most clearly in the data from Bird 3442 and least clearly in the data from Bird 3819).

DISCUSSION

The results of Experiment 2 are consistent with those of Experiment 1 in showing that

the rate of switching declines as a function of the delay between the switch and food even when the rate of food, defined as the number of food presentations during red divided by the time in red, remains constant. The novel contribution of Experiment 2 is in demonstrating this effect with food presentations after the first. The results are therefore consistent with our earlier suggestion that the effect in Experiment 1 of varying the duration of the red period was due to changes in the delay to food after the first food presentation rather than to changes in the rate of food during the red period.

It might be argued, however, that switching rate is controlled by the rate of food delivery in red but that the usual way of calculating rate obscures the systematic relation. The implication is that there might be some other way to calculate the rate of food delivery in red that would reveal a systematic relation between switching rate and this new calculation of food rate. A common approach in choice procedures has been to calculate rate of food delivery by first transforming each interfood interval so that short durations are given more weight than longer ones, and then calculating an average rate of food delivery from the sum of these weighted intervals. For example, preference between fixed-interval and variable-interval schedules has been predicted fairly well by considering the harmonic rates of food, that is, by considering the average of the reciprocals of the component interfood times (Killeen, 1968; MacEwen, 1972; McDiarmid & Rilling, 1965; cf. Fantino, 1977). However, an averaging rule that weights the interfood intervals merely in relation to their duration cannot provide an account of the difference in switching rates in the present study between the two conditions providing three foods during red (food at 30, 45, 210 sec vs. food at 30, 195, and 210 sec). This is so because in both conditions there was a 30-sec interval to the first food pre-

sentation and subsequent interfood intervals of 15 sec and 165 sec. Since these intervals are the same except for order, any calculation of food rate based on transformations of these intervals that ignores their order will give the same value for both conditions. The results from the two conditions where only the delay to the third food was varied urge a similar conclusion.

An alternative possibility is to differentially weight the interfood intervals by a quantity that decreases as a function of the interval's remoteness from the switching response and to calculate an average rate of food from the sum of these weighted intervals. Calculating rate of food delivery in this way should provide an account of switching rates in the present study. But it should be recognized that differentially weighting interfood intervals as a function of their remoteness from the switch is precisely what a delay of reinforcement gradient implies, namely that the remoteness of food presentations from a prior response matters. The important point is that this remoteness variable must be taken into account whether the temporal distribution of food reinforcers following the switch is described in the language of rate of food delivery or in the language of delay of food delivery. We suggest that the language of delay is preferable because it emphasizes simply and directly the importance of the remoteness factor.

As a final point, it is unlikely that either the average amount of work per food presentation or the availability of time for nonfood activities controlled switching in a significant way. The two conditions with three food presentations provide the clearest case. As Table 2 shows, the mean number of key pecks per food presentation in red did not differ systematically between the two conditions that provided three food presentations per red period, with the possible exception of Bird 3819. Thus, this measure of response output per food presenta-

Table 2

Mean number of responses per food in red when three food presentations occurred during a 240-sec red period.

| Delay to food from switch | Bird Number | | | | | |
| | 3427 | | 3442 | | 3819 | |
| | 1st Det | 2nd Det | 1st Det | 2nd Det | 1st Det | 2nd Det |
|---|---|---|---|---|---|---|
| 30, 45, 210 sec | 51 | 66 | 50 | 46 | 40 | 56 |
| 30, 195, 210 sec | 70 | 47 | 47 | 51 | 60 | 78 |

tion cannot account for the systematic differences in switching rates between these two conditions for all three birds. Further, the switching rate for the condition of red providing a single food delivery at 30 sec per 240-sec red period was not much different from the switching rate for the condition of red providing two food deliveries during the red period (at 30 and 210 sec). Yet in the single-food condition, key pecking stopped after the single food presentation, whereas in the two-food condition key pecking continued throughout the red period (compare Figures 2 and 5). Thus, the availability of a discriminated period of timeout from the food schedule does not seem to be an important source of control over switching.

## GENERAL DISCUSSION

A simple interpretation of the present results can be expressed in the terminology of delay of reinforcement. The core idea is that each of the food presentations that follow in a series after the switching response contributes a reinforcing (or rate-enhancing) effect to the response, with the size of each reinforcer's contribution diminishing as a function of its delay timed from the switch. The total reinforcing effect, then, would be the sum of the independent contributions from each food delivery. This interpretation differs from one couched in the terminology of rate of reinforcement because rate of reinforcement ordinarily implies that the critical times are those separating successive reinforcers (the interreinforcer times). For the delay interpretation, in contrast, the critical times are all measured from the same starting point, namely the response.

To make the interpretation concrete, consider some conditions of Experiment 2. When the second food delivery was moved from 45 sec after the switch to 195 sec after, the rate of switching decreased. This effect would be interpreted as due to the second food delivery adding a smaller reinforcing effect to the switching response at the longer delay than at the shorter delay. Similarly, food reinforcers added to the red period at times remote from the switch had only small incremental effects on the rate of switching, presumably due to their long delays (compare the three left-most bars in Figure 6). Since the effectiveness of a reinforcer seems to vary roughly as the recip-

rocal of its delay (Ainslie, 1975; Baum & Rachlin, 1969; Chung & Herrnstein, 1967), the simplest description of a summative model would be $\Sigma(1/D_i)$, where $D_i$ represents the delay to the $i$*th* food timed from the switch and the $\Sigma$ indicates that the independent effect of each delayed reinforcer in a series adds to the total. This quantity, $\Sigma(1/D_i)$, was calculated for each of the seven conditions shown in Figure 6 by summing the reciprocals of the delays from the switch to each food presentation during the 240-sec red period. For example, when food was scheduled at 30, 90, 150, and 210 sec after the start of red, $\Sigma(1/D_i) = (1/30) + (1/90) + (1/150) + (1/210) = .056$. To see how well $\Sigma(1/D_i)$ ordered the switching rates of Experiment 2, a rank-order correlation coefficient (Spearman's rho) was calculated for each bird between switching rate and the quantity, $\Sigma(1/D_i)$. (When a condition was studied twice, the geometric mean of the switching rates from the two determinations was used in the correlation.) The rank-order correlations were, for Birds 3427, 3442, and 3819, respectively: .96, 1.00, and .86. For $N = 7$, a value of .71 or higher is significant at the .05 level.

In Experiment 1 increasing the duration of the red period caused the switching rate to decrease even though the delay to the single food presentation during that red period was held constant. As suggested earlier, the delay-of-reinforcement interpretation is that the red period imposed a minimum time between the switch into that red period and any later foods after the end of that red period. Thus, lengthening the red period would have reduced the incremental contribution of the second and later food presentations received after the switch. Since the contribution of the second and later reinforcers should be small relative to that of the first food reinforcer due to their longer delays, changing the red-period duration should have a smaller effect than comparable changes in the delay to the first reinforcer. The data (Figure 3) support this expectation. Thus, an interpretation emphasizing the summed effects of delayed reinforcers seems to offer a reasonable account of the present data.

The question of whether all food deliveries following the response contribute to the total reinforcing effect or whether there is some upper boundary in time beyond which food presentation is totally ineffective (Moore, 1979)

cannot be determined from the present data. The effect in Experiment 2 of shifting the time to the third food delivery from 75 sec to 195 sec was smaller and less reliable than the effect of moving the second delivery from 45 sec to 195 sec. But whether this difference reflects a continuously diminishing effect of more remote food presentations or an absolute upper boundary on the effectiveness of food presentations over time is unclear.

Killeen (1968) gave pigeons a choice between two stimulus conditions, one associated with a variable time until food and the other associated with a fixed time until food. Consistent with an earlier suggestion by McDiarmid and Rilling (1965), Killeen found that preference was systematically related to the harmonic rate of reinforcement in the stimulus settings, that is, to the mean of the reciprocals of the interfood times associated with each stimulus. However, since the stimulus remained on after a choice only as long as it took to collect a single reinforcer, the distribution of interfood times associated with a stimulus was identical to the distribution of delays timed from the onset of the stimulus. Thus, as Killeen recognized, preferences in his study were equally well-related to the sum of the reciprocals of the delays weighted by their relative frequency of occurrence. He noted that it would be necessary to schedule multiple food reinforcers during the stimulus period in order to determine whether preference is better prediced by some average of the interfood times or by the summed effect of the delays to each reinforcer in the series, all timed from the choice. The present data suggest that the delay interpretation might have the greater generality.

Considerable effort has gone into trying to determine if responding under avoidance-like procedures is usefully described as under control of the response-dependent reduction in the *rate* of shock (cf. Hineline, 1977). Using a procedure similar in conception to the one used here, except adapted for shock delivery, Lewis, Gardner, and Hutton (1976) were able to vary independently rates of shock and delays to shocks following in a series after a response. Rats could remain in one stimulus setting where shocks were occasionally delivered or they could switch to a different stimulus setting for a fixed period during which a series of shocks was also delivered. Comparable to the present results, the tendency to switch

seemed to depend on the delays from the switch to each of the shocks in the series, with more remote shocks exerting correspondingly smaller effects. Switching was not related to the distribution of intershock times during the switched-to stimulus setting, unless the distribution is formed by weighting each intershock time by some factor that decreases as a function of its remoteness from the switch. Thus again, including a delay or remoteness factor seems critical for an adequate description of the effects of events in time after a response.

Finally, it is unimportant for present interests whether the delayed food presentations are thought to reinforce the switching response directly, or whether they are thought to confer conditioned reinforcing value to the situation transition produced by the switch (i.e., the transition from green to red). The core idea would be preserved if we said that the conditioned reinforcing value of the transition from green to red varied directly as a function of the summed effects of the delayed food presentations that follow in a series after the transition, where again all delays are timed from the transition.

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