THE EFFECT OF MULTIPLE S^A PERIODS ON RESPONDING ON A FIXED-INTERVAL SCHEDULE¹

P. B. DEWS

HARVARD MEDICAL SCHOOL

The effect of repeated interruption of FI responding by short S^A presentations on the pattern of increasing frequency of responding through the interval has been studied. Although the S^A profoundly changed the pattern of responding during their presentation, the general scalloped pattern of FI responding survived. The implication of these findings for understanding the role of chaining of responses in FI patterns is discussed. It is suggested that chaining is not a necessary condition for the scalloped pattern.

This is the first of a series of papers on behavior maintained by fixed-interval (FI) schedules of positive reinforcement (Ferster & Skinner, 1957, Chapter 5).

When organisms are exposed to FI schedules of reinforcement, a pattern of responding commonly emerges in which the frequency of responding increases through the interval (Ferster & Skinner, 1957, Chapter 5). This increase gives rise to a scalloped appearance of the cumulative responses: time curves. In discussions as to the genesis and maintenance of this pattern, recourse has been made to the concepts of chained responding and mediating behavior. A chain of responses is a sequence in which each response functions as a discriminative (or eliciting) stimulus changing the probability of occurrence of a further response. Mediating behavior is a sequence of responses between two events that serves to transmit the behavioral influence of one event to that of the other. The events may be responses, and the influence may be "transmitted" in time forward (as in the postulated mediating behavior between recorded responses on a DRL schedule) or backward (as when mediating behavior is suggested to "transmit" to a particular response the reinforcing effects of a delayed reinforcement) (Ferster & Skinner, 1957, p. 729). The two concepts of chained responding and mediating behavior are, of course, closely related. Most

mediating behavior is generally considered to be comprised of chained responding, and the early members of a chain of responses affect the later members because the intervening members constitute mediating behavior. To establish a sequence of responses as being chained or as constituting mediating behavior, however, it is not sufficient to demonstrate that the sequence is consistent and *could* so function; it must be explicitly demonstrated that changes in the sequence disrupt the chain or prevent mediation. This paper is concerned with the role of chained responding as mediating behavior in the maintenance of a progressive increase in rate through the interval.

If the orderly progression of rates of responding on FI were mediated by chaining of the recorded response, the rate in any short period, t_1 to $t_1 + \Delta t$, in the interval should be primarily determined by the rate in the preceding short period, $t_1 - \Delta t$ to t_1 . Under these circumstances, any influence that disrupts the responding for an appreciable period during the interval should destroy the orderly progression of rates through the interval. It was arranged that an S^A was repeatedly presented during each FI. This came to disrupt the pattern of key-pecking responses during the presentation of S^A . It has been found that the statistical increase in the tendency to respond through the interval, and even the general scalloped pattern of individual intervals, survived this program of repeated interruptions. Therefore, the chaining of key-pecking responses must not be necessary for the maintenance of this common characteristic of FI responding.

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MATERIALS, METHODS, AND PROCEDURE

The subjects were four male White Carneaux pigeons, maintained in the usual way at close to a "running weight" of about 80% of their weight on free feeding. The apparatus, response, and food reinforcer were standard. The key was transilluminated by white lights. The "houselight" (HL) was a 25-watt GE type 101 F bulb projecting from the top of the rear wall (*i.e.*, that opposite to the wall carrying the manipulandum and magazine) of the pigeon compartment. All birds had had extensive and varied exposure to a variety of schedules before these experiments; they had all been subjected to FI procedures for protracted periods.

The basic schedule was FI 500 sec TO 250 sec. That is, the first response made after the key had been transilluminated for 500 sec led to presentation of food; following food presentation, there was a 250-sec period during which there were no lights in the chamber; then the key was transilluminated, and another cycle was in progress. (A 900-sec, limited-hold contingency was included in the program; but because this apparently was never actually operative in concluding an interval during this series of experiments, it will not be considered further.) The daily session consisted of 11 FI — TO cycles. Responses made in the first cycle were not used for computational purposes. Thereafter, responses were cumulated over the 10 fixed intervals in 50-sec compartments; that is, all responses occurring in the first 50 sec following onset of transillumination of the key in all 10 intervals were recorded on one digital counter, then all occurring in the second 50 sec on a second counter, and so on through the 10 compartments comprising the 500-sec fixed interval. These compartments and the corresponding time periods will be referred to by the ordinal numbers of their chronological sequence.

Procedure

In the first part of the experiment (Procedure 1), there was no HL. The birds were subject to the FI 500 sec TO 250 sec for: Bird 40, 64 sessions; Bird 44, 66 sessions; Bird 152, 26 sessions; and Bird 204, 22 sessions.

In the second part of the experiment (Procedure 2), the HL was present during

alternate 50-sec periods through the interval; specifically, the HL periods were 2, 4, 6, 8, and 10. At the end of the 10th period, which coincided with the end of the interval, the HL continued until a response occurred. This response was reinforced, of course. Thus, no response made in the absence of the HL was reinforced; and so the periods without HL may be referred to properly as S^A periods. This procedure was continued for a number of sessions: Bird 40, 34 sessions; Bird 44, 22 sessions; Bird 152, 37 sessions; and Bird 204, 35 sessions.

On both procedures, there was no clear trend in the day-to-day changes in performance after the first few sessions. Ordinarily, the birds were subjected to five daily sessions per week. Definitive information was assembled from the last 10 "control" days, a "control" day being defined as one that was preceded by a day on which an identical session had been run. At least 10 sessions on each procedure had occurred before the first of the last 10 control days, except for Bird 204 on the simple FI 500 sec TO 250 sec. For this bird, the 10th session was included.

RESULTS

On the simple FI 500 sec to 250 sec procedure, all birds developed the characteristic FI performance (Fig. 1). Following introduction of alternative periods with HL, the rate of responding gradually fell in the absence of the HL (Fig. 1).

Figure 2 shows the mean rates of responding in the successive 50-sec compartments during the last 10 control days. Since there were 10 intervals per session, each bar is the mean of 100 periods of 50 sec. Responding is clearly suppressed in the no-HL periods of Procedure 2. In spite of this, the overall tendency to respond in the successive HL periods shows a progressive increase highly similar to that in the corresponding periods during operation of Procedure 1 when there were no intervening S^A periods. There is even a progressive increase in mean responding during consecutive S^A periods. If the rates of responding in the S^A periods are multiplied by 3.5, the pattern of the bar graph becomes as shown in Fig. 3. It crudely reproduces the pattern with no S^A periods. The figure 3.5 was obtained from a proportionality formula:

$$\frac{\sum (R's \text{ in periods } 1, 3, 5, 7, 9 \text{ on Procedure 1})}{\sum (R's \text{ in periods } 2, 4, 6, 8, 10 \text{ on Procedure 1})} = \frac{\sum (R's \text{ in periods } 1, 3, 5, 7 \text{ on Procedure 2}) \times [S^A]}{\sum (R's \text{ in periods } 2, 4, 6, 7, 10 \text{ on Procedure 2})}$$

where $[S^A]$ is the S^A factor; it is an estimate of the extent to which the stimuli correlated with nonreinforcement suppress the tendency to respond. This formula assumes that the effect of S^A is linearly multiplicative with the tendency to respond, that is, that the S^A re-

Fig. 1. Tracings of complete sessions on Procedure 1 and on Procedure 2 for all four birds. For each bird, the session on Procedure 1 is shown above the session for Procedure 2. The presence of the houselight on Procedure 2 is indicated by the downward off-setting of the cumulative record. The pairs of records are, from above down, respectively, from Birds 40, 44, 152, and 204.

duces the frequency of responding by a fixed percentage irrespective of the absolute rate of responding. The justification for this assumption is the faithfulness with which the constant factor converts the bar graph of Procedure 2 to resemble that of Procedure 1 at all periods through the interval.

There was no general increase in rate of responding in the presence of the HL as

compared to corresponding periods of intervals on Procedure 1 such as those occurring when S^A periods are superimposed on a VI base line (Ferster, 1958; Reynolds, 1961). On the contrary, the rate in corresponding (non-S^A) 50-sec periods averages slightly lower

Fig. 2. Mean rates in successive 50-sec compartments of FI. The bar graphs show each bird singly, as labelled; the bottom row shows the simple arithmetic means, period by period, for the four birds.

than that on Procedure 1 (Fig. 2). The individual 50-sec HL periods tended to show "miniature" FI patterns of responding, as the enlarged sample in Fig. 4 shows, particularly for Birds 40 and 204. The rates in the terminal parts of the later (in interval) 50-sec periods

were frequently higher than any on Procedure 1 (Fig. 1). This increase in rate may be related to that on other schedules when time outs are introduced.

DISCUSSION

The general pattern of FI responding is not disrupted by the interposition of repeated S^A periods during the interval. Therefore, chaining of responses from moment to moment consecutively through the interval is not necessary for maintenance of the overall scalloped pattern characteristic of FI responding.

Fig. 3. Bar graph of mean rates on Procedure 2 when S^A rates have been multiplied by 3.5. This bar graph should be compared with those of the bottom row of Fig. 2.

The rate of responding during the period $t_i + \Delta t$ is not determined predominately by the rate of responding in period $t_i - \Delta t$; for many values of t_i , it is much more importantly determined by the absolute position of t_i in the interval. In other words, there appears to be an underlying gradient of increasing tendency to respond that continues through the interval; this gradient is manifest in the responding both in the presence and absence of the HL, even though the absolute response rates differ by a factor of several-fold depending on the stimulus conditions. This is remi-

niscient of a "goal-gradient" (Hull, 1932) type of hypothesis. It should be noted that here we are concerned specifically with a *temporal* gradient that should be susceptible to quantitative validation.

Fig. 4. Two consecutive intervals from the final session on Procedure 2 for each of the four birds to show details of distribution of responses within 50-sec compartments. Conventions as in Fig. 1. Note the miniature FI scallops in individual HL periods (shown most clearly in the record of Pigeon 204) and the desultory responding in individual S^A periods. Note also the high terminal rates of individual HL periods late in the FI; these rates exceed any seen on Procedure 1 (cf. Fig. 1).

It may be argued that the FI pattern does depend on "response chaining" but that the response involved is not, or is not only, key pecking. This view would necessitate the further postulate that the response(s) comprising the continuous chain through the interval is compatible with, and uninfluenced by, rate of pecking, while being competent to determine rate of pecking. This is rendered untenable by examination of local changes in rate during the successive periods of the FI. There is a clear indication of scalloping in the S^D periods; miniature FI's emerge. During S^A periods, responding tends to be irregular, with some tendency for the rate to fall. A second type of mediating behavior would have to be postulated for the miniature FI and a third for control of S^A responding. All these mediating behaviors would have to be mutually independent except for their effects on key-pecking behavior. This stretches the credulity; surely, the burden of proof rests with anyone postulating such a collection of behaviors.

How could FI contingencies operate directly to produce a progressive increase in tendency

to respond through the interval? It has been shown that presentation of reinforcing stimuli can have a retroactive enhancing effect on responses (in the sense of making those responses more likely to occur in the future) that occurred as long as 100 sec previously (Dews, 1960). In those experiments, the tendency to respond was severely suppressed by reinforcement postponing contingencies in the schedule. The experiments point to the possibility that reinforcement following a response by periods even longer than 100 sec may lead to the maintenance of substantial rates of responding, provided the tendency to respond was not opposed by other factors. This sort of situation obtains under FI schedules of reinforcement. If reinforcement occurs at time T , responding during the period $T - t_1 - \Delta t$ to $T - t_1$ is reinforced, after a delay of t_1 , by presentation of the reinforcing stimuli; and so, responding during the corresponding period is maintained in subsequent intervals. If this view is correct, the progressive increase in rate of responding through the fixed interval would be based on a declining retroactive rate-enhancing effect of the reinforcing stimuli as the delay between response and reinforcement is increased (Dews, 1960). Of course, in any particular interval the fixed reference point for the organism must be the start of the interval rather than the future reinforcement; but under ordinary conditions, t_1 sec from the beginning of the FI uniquely defines an instant that is $T - t_1$ before reinforcement.

Two matters of rather general importance arise out of these findings. First, the view of the basis of the FI scallop just presented is contrary to the general opinion that accords overwhelming importance to the terminal inter-response time (the inter-response time concluded by the reinforced response) in determining the pattern of responding engendered by a schedule. It suggests a re-examination of the interpretations of the *modus operandi* of other schedules that have been based on the assumption of the pre-eminent importance of the final inter-response time. For example, the possibility should be considered that the high rates of responding engendered by fixed-ratio schedules (FR) may come about as follows: The higher the average rate of responding on an FR schedule, the closer, temporally, the initial response and

all subsequent responses in the FR are to reinforcement, and, therefore, the greater the retroactive enhancing effect of that reinforcement. This will tend to increase the rate of responding, which in turn will tend to bring the responses closer to reinforcement, which will increase the rate further. Thus, there is, in effect, a positive feedback situation, in which random increases in rate will tend to be self-enhancing. Similar interpretations can be given to other schedule performances that have been described; but their validation depends on specific quantitative information that is not now available. Further speculation is not merited at the present time.

Second, they emphasize the danger of casual attribution of mediating properties to behavior. In the desire to present a continuous causal account, there has been considerable tendency to "fill in" intervals of time with behavior presumed to bridge the gap. Much supposed "mediating behavior" has the status of a hypothetical intervening variable or, at best, as for "proprioception," of an intervening variable with hypothetical properties as a discriminative stimulus. It should be remembered that it is not enough to establish a mediating role to show that behavior occurs and that it could so function. It must be shown that disruption of that behavior abolishes or seriously impairs the consistent relationship of the events between which the behavior is supposed to mediate. Responding through the FI could plausibly function as mediating behavior, but apparently it does not do so importantly.

The information in this paper is based on a single value of FI and a single pattern of introduction of S^A periods. The fact that with these particular values the pattern of FI responding persists in the face of interruptions is competent to controvert the proposition that the FI performance is always dependent on "response - chaining"; yet, it would be desirable to have information on other durations of FI and other patterns of interruptions. Such information will be presented later.

A final point of interest, unrelated to FI, concerns the information the data presented give on the operation of stimulus control. It was noted that the bar graph for Procedure 2 could be made to resemble that for Procedure 1 by multiplying the rate of responding in the HL periods by a constant factor of 3.5.²

It is as though the "S^A properties" of the HL reduced the tendency to respond to 1/3.5 of its value in the absence of the HL, more or less independently of what the absolute value of that tendency to respond might be—at any rate over the range from its value at the beginning of the interval to that at the end. It would be of great interest to know whether this simple multiplicative effect of S^A control, and, indeed, other varieties of stimulus control, is generally applicable.

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