STIMULUS PROPERTIES OF FIXED-INTERVAL RESPONSES¹

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Responses in the first component of a chained schedule produced a change to the terminal component according to a fixed-interval schedule. The number of responses emitted in the fixed interval determined whether a variable-interval schedule of food presentation or extinction prevailed in the terminal component. In one condition, the variable-interval schedule was in effect only if the number of responses during the fixed interval was less than that specified; in another condition, the number of responses had to exceed that specified. The number of responses emitted in the fixed interval did not shift markedly in the direction required for food presentation. Instead, responding often tended to change in the opposite direction. Such an effect indicated that differential food presentation did not modify the reference behavior in accord with the requirement, but it was consistent with other data on fixed-interval schedule performance. Behavior in the terminal component, however, did reveal sensitivity to the relation between total responses emitted in the fixed interval and the availability of food. Response rate in the terminal component was a function of the proximity of the response number emitted in the fixed interval to that required for food presentation. Thus, response number served as a discriminative stimulus controlling subsequent performance.

Key words: response-number discrimination, response-number differentiation, fixed-interval schedule, chained schedule, stimulus control, unitary responses, dynamic effects, key peck, pigeon

The fixed-interval (FI) schedule combines a time specification with a single response requirement: responses are irrelevant until a fixed time period has elapsed, and then the next response results in reinforcer delivery. Even though only one response need occur, many more are emitted, and these responses then may become part of the complex of variables that determine the nature of performance. Ferster and Skinner (1957) attributed discriminative stimulus properties to the number of responses emitted in an interval: the number of responses is important because certain numbers previously were correlated with reinforcer delivery (p. 134). Responding that brings the total count closer to those numbers is reinforced by the production of that count, because response number has both discriminative and reinforcing stimulus properties. The implication is that organisms can respond differentially to differing numbers of responses as antecedent events.

No data bear directly on whether response number can have stimulus properties with FI schedules. However, Rilling (1967) demonstrated that pigeons could discriminate between two different FI schedules, and he found a correlation between the number of responses emitted in an interval and discriminative performance. These data provide indirect support for the possibility of response number as a discriminative stimulus in FI schedules. Data demonstrating that responses can be a discriminative stimulus when directly imposed in ratio schedules (*e.g.*, Hobson, 1975; Pliskoff and Goldiamond, 1966; Rilling, 1967; Rilling and McDiarmid, 1965) have no counterpart with interval schedules because response number has never been directly imposed as a requirement in such schedules.

Reynolds (1966) reported a procedure for studying discriminative properties of response-produced stimuli. The first component of a chained schedule ended after two responses. The second (terminal) component of the chain involved either a variable-interval (VI) schedule of food presentation or extinction. Which of these alternatives prevailed depended on the time between the two responses of the

¹The research was supported by Grant BMS75-09532 from the National Science Foundation. Reprints are available from either author, Department of Psychology, Emory University, Atlanta, Georgia 30322.

first component. If the time had exceeded 18 sec, the VI schedule was in effect; otherwise, the extinction condition was imposed. Reynolds found that although the interresponse times (IRTs) emitted in the first component usually were too short to produce the VI schedule, response rates in the second component plotted as a function of the IRT in the first resulted in a sloping gradient indicative of stimulus control by a continuum (in this case the response-produced stimulus continuum of IRTs). The lack of change in the IRT distribution in the first component indicated that IRTs were not differentiated as a result of their different consequences, while the gradients in the second component indicated that IRTs did have discriminative stimulus properties.

In the present experiment, this procedure was modified so that the first component of the chain was an FI schedule. Whether a VI schedule or extinction prevailed in the second component depended on the number of responses emitted in the first. If response numbers shifted in the direction of the requirement, it would indicate that response number was a reinforceable property of FI performance. If the response rate in the second component was a function of the proximity of the response number emitted in the first component to that required for the VI schedule to prevail, that would indicate discriminative stimulus control by the number of responses emitted in the interval.

METHOD

Subjects

Three White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. One, P-6, had an extensive experimental history with a variety of reinforcement schedules and exteroceptive stimuli; the others were experimentally naive.

Apparatus

The experimental chamber was modified from the pigeon unit described by Ferster and Skinner (1957). The 19-mm diameter response key (R. Gerbrands Co.) could be transilluminated by either two red or two blue 1.1-W lamps. The key was centered 25 cm from the floor, and was operated by a minimum force of 0.20 N. A 5-cm square aperture centered

10 cm below the key provided occasional access to Purina Pigeon Checkers, the birds' standard diet. During the 3.5-sec feeder cycles, a 1.1-W lamp illuminated the aperture, and the keylight was turned off. Continuously present white noise helped mask extraneous sounds. Control and recording equipment was housed in an adjacent room.

Procedure

Each cycle of a two-component chained schedule began with the onset of the red keylight. The first response emitted after 3 min elapsed (FI 3-min schedule) changed the key color to blue. When the key was blue, either food was presented for the first response occurring at variable intervals averaging 45 sec (VI 45-sec schedule) or responses had no scheduled consequences (Extinction). After 30 sec (not counting food presentations) the key again became red, and the next cycle began. Sessions lasted for 25 cycles in Baseline 2, and for 40 cycles in all other conditions. In all conditions, the FI 3-min schedule was in effect in the initial component of the chained schedule.

Baseline 1. Food was always available according to the VI 45-sec schedule in the second (blue) component. The number of responses emitted in the first component was irrelevant. Thus, the birds obtained food on an average of twice in every three cycles.

Discrimination Condition 1. The VI 45-sec food presentation schedule was in effect in the second (blue) component only if the bird met a response number requirement during the first (red) component. The number criterion for each bird was the average number of responses emitted per fixed interval in the last nine sessions of Baseline 1 ($P-6 = 60$, $P-131 = 65$, $P-137 = 112$). For P-131, this criterion set the maximum number of responses that could be emitted in the preceding FI for the VI 45-sec schedule to be in effect in the second component. Such a condition is referred to as $R < n$, as it specified the ceiling on response numbers eligible to be followed by food presentation. When the number of responses exceeded the criterion, extinction was in effect in the second component. For P-6 and P-137, the criterion set the minimum number of responses that could be emitted in the fixed-interval component for the VI 45-sec schedule to be in effect in the second component. Such a condition is referred to as $R > n$, as it specified the

floor on response numbers eligible to be followed by food presentation. When the number of responses failed to reach the criterion, extinction was in effect in the second component. Thus, the number of responses emitted during the FI 3-min schedule determined whether the schedule in the succeeding 30 sec was a VI 45-sec schedule of food presentation or was extinction.

Because the VI 45-sec schedule did not arrange the availability of food during each 30-sec component that followed a fixed interval that conformed to the criterion, the absence of food presentation did not signal that the period involved extinction rather than the VI schedule. This was arranged to help ensure that the only stimulus correlated with the availability of food in the second component was the number of responses emitted in the immediately preceding fixed interval. The VI programmer ran when either VI or extinction was in effect, but food presentations set up during extinction were cancelled.

Baseline 2. The schedules of Baseline 1 were reimposed. The VI 3-min schedule of food presentation was in effect during the second component independent of the number of responses emitted during the fixed interval.

Discrimination Condition 2. The criterion response numbers were as in Discrimination Condition 1, but the response requirements were reversed for each bird. Bird P-131 now had the $R > n$ condition, and P-6 and P-137 had the $R < n$ condition.

A condition was maintained until performance met the following stability criterion. Mean second-component rates (total responses per session in that component divided by total time in the component) were computed separately for each bird for each session. The median of the means was then calculated for three consecutive sessions. The behavior was judged stable when three consecutive medians (involving nine sessions in all) showed no consistent increase or decrease. A condition was maintained for all birds until each bird met one criterion. The number of sessions per condition was: Baseline 1 = 31, Discrimination Condition 1 = 48, Baseline 2 = 37, Discrimination Condition 2 = 55.

RESULTS

Baseline Conditions

The cumulative records of Figure 1 are representative of the performances of all of the

Fig. 1. Representative cumulative records for P-131 from the last session of each condition. The event pen deflected during the 30-sec terminal component. Deflections of the response pen during the fixed-interval component indicated emission of the criterion response number (one during baseline conditions). Deflections of the response pen during the terminal component indicated food delivery. The response pen reset at the completion of each component.

Fig. 2. Number of fixed-interval components in the last nine sessions of each condition falling into each 20-response class interval. Conditions are arranged from top to bottom in order of occurrence.

birds. During the baseline conditions, the records resembled those typical of FI and VI schedules. The FI resulted in a pause at the onset of the red keylight followed by an increasing rate of responding; the VI resulted in a fairly stable rate. There were no marked changes between the two baseline conditions. The first and third rows of Figure 2 show the distribution of response numbers emitted per fixed interval in the two baseline conditions. The total number of responses emitted in each FI component was classified into 12

class intervals (bins), the first 11 being 20 responses wide and the twelfth containing all intervals exceeding 220 responses. The frequency distributions were based on the last nine sessions of each condition, thereby involving 360 intervals in Baseline 1 and 225 intervals in Baseline 2. The distributions were approximately normal, showing no marked skewness in either direction. The mean, median, and mode of each distribution fell in the same class interval for each of the subjects.

Discrimination Conditions

Fixed-interval component. Figure 1 indicates that the differential reinforcement of response number during the two discrimination conditions did not alter the pattern of responding during the first component of the chained schedule. The rate of responding during the second component was often more variable than during the baseline conditions.

Responding in the FI component was affected by differential reinforcement. Rows 2 and 4 of Figure 2 indicate that the distributions shifted in the direction of lower response numbers when the condition was $R > n$; this was clearest for P-6 (Discrimination Condition 1), but it occurred for the other birds as well. Distributions changed minimally under the $R < n$ conditions. Mean response number also revealed this opposite effect. For two of the three birds, the highest mean responses occurred in the $R < n$ condition when the requirement for food presentation involved decreased responses, and the smallest occurred in the $R > n$ condition when the requirement involved increased responses. Thus, although the differentiation requirement exerted an effect on the number of responses emitted, it was opposite in direction to the number of responses required for food presentation for two of the three birds. Bird P-131 did show a small change in mean response in the direction of the requirements.

Distributions of response numbers were plotted in nine-session blocks throughout each discrimination condition. Whenever the final distribution of Figure 2 was affected, the distributions shifted from baseline within the first nine-session block.

Second component. Responses in the second (blue) component were recorded as a function of the number of responses emitted in the preceding FI. Thus, there could be as many as 12 different response rates, depending on the number of class intervals of response number encompassing the FI performance. This procedure permitted plotting a generalization gradient in which response rate in the second component was a function of the number of responses emitted during the first component.

The gradients are shown in Figure 3. They were essentially flat during the baseline conditions, thereby indicating that the number of responses emitted during the preceding FI

component did not determine the rate of responding during the succeeding VI component. However, this changed during the two discrimination conditions. Except in Discrimination Condition 2 for P-137, response rates increased as a function of how well the responses emitted in the first component met the criteria. With the $R > n$ conditions, the more responses emitted during the FI the higher was the rate during the second component. In two of the three cases with the $R < n$ condition, the fewer responses emitted during the FI the higher was the rate during the second component. In short, graded response rates could be either a direct or an inverse function of responding in the FI component depending on the specific nature of the criterion.

DISCUSSION

The sloping gradients obtained when response rate in the second component of the chained schedule was plotted against the number of responses in the first component indicated the occurrence of discriminative stimulus control in five of six cases. Evidently the number of responses emitted in the fixed-interval schedule could serve as a functional stimulus dimension (*cf.*, Terrace, 1966), as Rilling (1967) suggested in his correlational analyses.

Since total responses can exert discriminative control, Ferster and Skinner's (1957) hypothesis that the number of responses emitted serve a discriminative and reinforcing function in normal FI performance is not contradicted. Inconsistencies arise, however, when the nature of FI performance is considered in the context of what is more generally known about stimulus control. Since the schedule does not arrange for the differential reinforcement of any specified number of responses exceeding one, any number that occurs would be correlated with reinforcement. When two exteroceptive stimuli have no predetermined relation to reinforcement, the rate of responding typically is higher in the presence of one, *i.e.*, responding comes under stimulus control. Although there may be shifts in which stimulus controls the higher rate, one tends to do so for extended periods of time (Morse and Skinner, 1957). Yet, stereotypy of response number does not occur with FI schedules, as might be expected of a superstitious discrimination. The number of responses in successive

Fig. 3. Mean response rate in the terminal components of the last nine sessions of each condition. Rates are plotted as a function of the number of responses emitted in the preceding fixed interval. Dashed lines connect points separated by class intervals with no entries. The vertical lines in rows 2 and 4 indicate the criterion response requirement. Conditions are arranged from top to bottom in order of occurrence.

intervals varies widely and may even display orderly cyclicities (Dews, 1970). From this point of view, therefore, response number in the ordinary FI schedule does not display the characteristics of discriminative stimuli. But Dews' data indicate that many more than two response numbers are correlated with reinforcement. When a large number of values of an exteroceptive stimulus dimension are correlated with reinforcement, stimulus control is

not obtained (Reynolds, 1961; Zeiler, 1969); stimulus control requires differential reinforcement with respect to a subset of values. These considerations imply that even though the number of responses emitted in a fixed interval can have a discriminative function when there is explicit differential reinforcement (as in the present experiment), it may not characterize response number in the ordinary FI schedule.

Because responding in the fixed interval itself did not change markedly in the direction required for food presentation, response number did not appear to be a conditionable aspect of performance with the present procedure. Instead, the distributions and/or mean number either shifted in the opposite direction or changed minimally in the appropriate direction. In two of the three birds, the $R > n$ condition decreased responding, and the $R < n$ condition increased responding. Response-number distributions in the fixed-interval components of the present experiment began to shift during the first sessions of the discrimination conditions, whereas discrimination of response number took longer to develop. Although providing no indication that number was a differentiable property of FI performance, this result does follow from the Herrnstein and Morse (1958) hypothesis that the number of responses emitted in an interval has a dynamic relation to the numbers emitted previously. A large number of responses in an interval means that the probability of reinforcement per response (n reinforcements/ n responses) is low. Few responses in an interval means that the probability of reinforcement per response is high. The hypothesis is that responding depends on the previous probability of reinforcement per response: high probabilities (i.e., low responses in an interval) generate high response rates, and low probabilities (i.e., many responses in an interval) generate subsequent low rates. In the normal FI schedule, the result is both high- and low-response intervals and cyclicities in responding (cf., Zeiler, *in press*). In the present procedure, the number of responses per reinforcer was restricted at one end. With a minimum response requirement ($R > n$ condition), only high-response intervals were correlated with food presentation. Since these resulted in a low probability of reinforcement per response, low-response intervals followed. Or, with the maximum response requirement ($R < n$ condition), only low-response intervals were correlated with food presentation, thereby producing a high probability of reinforcement per response and subsequent high response intervals. In both cases, the re-

strictions were such as to establish conditions that biased performance in the direction away from that required for food presentation. This analysis neither squares with oversimplified preconceptions about the adaptive nature of behavior nor takes into account possible effects of extinction, but it does fit with other data on FI performance.

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Received 13 March 1975.

(Final Acceptance 1 July 1975.)