FIXED-INTERVAL STIMULUS CONTROL¹

MICHAEL D. ZEILER

EMORY UNIVERSITY

Pigeons were exposed to three stimuli simultaneously, with responses to one of them, the positive stimulus, followed by food presented according to a fixed-interval schedule (FI 2-min, FI 4-min, FI 8-min, or FI 16-min). Over 90% of the total responses emitted were to the positive stimulus within a few sessions. When the birds were then studied under each of four fixed intervals, responding continued to be confined primarily to the same stimulus independent of interval size. In subsequent conditions, the three stimuli changed positions after each quarter of the interval. If the position changes did not require a response, response rate and the percentage of responses occurring to the positive stimulus decreased. If the changes did depend on a response, the complete interval appeared to be divided into four smaller intervals with a pause and then positively accelerated responding following each position change. Position changes produced by a response to any stimulus decreased control by the positive stimulus, and changes produced only by a response to it increased the percentage of responses made to that stimulus. All of the data suggested that the stimulus conditions contiguous with reinforcement controlled behavior.

The interest in schedules of intermittent reinforcement that emerged early in the analysis of operant behavior immediately resulted in experiments using intermittent reinforcement to establish differential responding with respect to stimuli (Skinner, 1938). Either of two procedures, one involving the simultaneous presentation of several stimuli and the other involving the appearance of one stimulus at a time, might have illustrated persistent responding to a stimulus occasionally correlated with reinforcement and extinction of responses to a stimulus correlated with nonreinforcement. However, the successive procedure became the prevailing method. The definition of discriminative stimuli as stimuli in whose presence reinforcement is or is not available for responses suggests the continued emphasis on successive discriminations in operant research, since "presence" does not comfortably describe the simultaneous discrimination situation in which all stimuli appear concurrently.

To provide information about simultaneous discriminations, the present research investi-

gated the development and maintenance of stimulus control when responses were reinforced according to a fixed-interval schedule of food presentation. A fixed-interval schedule involves the delivery of food for the first response occurring after a fixed period of time without reference to whether responses did or did not occur earlier. The simultaneous discrimination paradigm permitted the joint observation of changes in the rate of responding throughout the interval as well as in the distribution of responses among the different stimuli.

The interest in fixed-interval schedules involving the simultaneous presentation of several stimuli stemmed from Ferster's (1960) and Dews' (1963) experiments on fixed-interval reinforcement of matching-to-sample. These investigators reported positively accelerated rates of responding together with relatively inaccurate matching-to-sample. Thus, although the reinforcement of a single matching response at the end of the interval was the event responsible for producing responses early in the interval, these responses often were not to the stimulus that matched the sample. In other words, the fixed interval did not produce a high degree of stimulus control by the discriminative stimuli correlated with reinforcement, although it did engender responses be-

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fore the time that reinforcement was available. Different properties appear responsible for the maintenance of responding and for the occurrence of stimulus control over those responses. Because matching-to-sample involves a constantly changing positive stimulus (which stimulus is correct depends on the particular sample present), there is no way of knowing whether a low level of stimulus control would occur whenever animals must choose between simultaneously-presented stimuli and responses are reinforced according to a fixed interval, or whether it characterizes only the complex matching procedure. Nevin's (1967) study with a discrete trial analogue of a fixed-interval schedule fits the second alternative: he found substantial control when one stimulus was correlated with reinforcement. However, since food presentation followed the first correct response emitted after a fixed number of trials, the behavior may be different from that occurring when animals are free to respond at any time and reinforcement depends on the first correct response following a fixed time period.

The present experiment, therefore, used the usual form of fixed-interval schedule. The procedures included intervals in which the spatial positions of the stimuli were constant between successive reinforcements and conditions in which the stimuli changed positions after each quarter of the interval. These manipulations revealed how constancy and periodic changes in the stimulus display influenced both the rate of responding and stimulus control during the interval.

METHOD

Subjects

Four adult White Carneaux pigeons, two male and two female, were maintained at 80% of their free-feeding weights throughout the experiment. The birds had not served in other experiments.

Apparatus

Three translucent 0.8-in. (20-mm) diameter response keys (R. Gerbrands Co.), each operated by a minimum force of 12 g (0.12 N) were mounted 3 in. (76 mm) apart, center-to-center. A 2-in. (51-mm) square aperture below the middle key provided occasional access to Purina Pigeon Checkers, the food used as the standard diet. White light illuminated the

aperture, and the keys were dark during the 4-sec food magazine cycles.

All of the keys could be transilluminated with pairs of white, red, blue, or green 7-w lamps. Either all three keys were white, or each was a different color (red, blue, or green). The location of the colors changed after food presentations and also at other times as described for specific procedures. The six possible spatial orders of the three colors occurred according to a repeating mixed sequence of 48 steps. Occasionally, two successive steps established the same spatial sequence of colors.

Standard electromechanical equipment controlled all procedures automatically, while a cumulative recorder and counters recorded the data. White noise masked extraneous sounds.

Procedure

Of the five sessions conducted each week, four lasted until each bird received 30 food presentations, and the fifth lasted for 10 food presentations so that all birds could be run in an 8-hr period.

Acquisition of stimulus control. Initially the keys were white and a response to any operated the feeder. The schedule was then changed to fixed interval (FI): the first response occurring after the time specified by the interval had elapsed produced food. Each bird had two sessions of FI 1-min, and two sessions of FI 2-min. The schedule was then kept at FI 2-min for Bird 103, but was changed to FI 4-min for Bird 71, to FI 16-min for Bird 101, and to FI 8-min for Bird 102. These schedules continued for 22 sessions.

The keys were then transilluminated with the red, blue, and green lights, and the birds obtained food according to the fixed-interval schedule for the first response occurring to one of the colors (S+) after the interval elapsed. The S+ was blue for Bird 71, red for Birds 101 and 103, and green for Bird 102; the same S+ was maintained throughout the experiment. The positions of the stimuli changed only after food presentations.

Maintained stimulus control with simple fixed intervals. Counting the first schedule with the three colors described above, each bird was studied with four different intervals. Schedules were changed periodically so that a bird received FI 2-min, FI 4-min, FI 8-min, and FI 16-min twice each. The criterion for changing schedules was that visual inspection

Table 1
Sequence of Conditions

<i>Quarterly Position Change</i>	<i>Bird 71</i>	<i>Bird 101</i>	<i>Bird 102</i>	<i>Bird 103</i>	<i>Sessions</i>
1. None	FI 4-min	FI 16-min	FI 8-min	FI 2-min	30
2. None	FI 8-min	FI 4-min	FI 2-min	FI 16-min	25
3. None	FI 2-min	FI 8-min	FI 16-min	FI 4-min	20
4. None	FI 16-min	FI 2-min	FI 4-min	FI 8-min	21
5. None	FI 2-min	FI 8-min	FI 16-min	FI 4-min	20
6. None	FI 8-min	FI 4-min	FI 2-min	FI 16-min	18
7. None	FI 4-min	FI 16-min	FI 8-min	FI 2-min	26
8. None	FI 16-min	FI 2-min	FI 4-min	FI 8-min	28
9. Response-independent	FI 16-min	FI 2-min	FI 4-min	FI 8-min	25
10. Response-independent	FI 4-min	FI 16-min	FI 8-min	FI 2-min	21
11. Response-independent	FI 2-min	FI 8-min	FI 16-min	FI 4-min	19
12. Response-independent	FI 8-min	FI 4-min	FI 2-min	FI 16-min	26
13. None	FI 8-min	FI 4-min	FI 2-min	FI 16-min	21
14. Response-independent	FI 8-min	FI 4-min	FI 2-min	FI 16-min	15
15. Response-dependent to any color	FI 8-min	FI 4-min	FI 2-min	FI 16-min	15
16. Response-dependent to S+	FI 8-min	FI 4-min	FI 2-min	FI 16-min	10
17. Response-dependent to any color	FI 8-min	FI 4-min	FI 2-min	FI 16-min	10

revealed stable cumulative records without changes in the distribution of responses among the stimuli for all of the birds for at least five sessions. The latter criterion was based on the percentage of the total responses that occurred to S+: the percentage of S+ responses on each of the last five sessions had to vary by no more than one percentage point from the median session of the five. Note that all birds were kept on a condition until the last one stabilized. Table 1 shows the sequence of schedules and the number of sessions with each.

Simple fixed intervals with position changes each quarter. In the next procedure, the spatial positions of the three stimuli changed after each quarter of the interval (response-independent position change). The first response to S+ occurring after the fourth quarter elapsed produced food. Each bird had four different fixed intervals under this procedure. The criteria for schedule changes were as described above.

Analysis of response-dependent and response-independent position changes. For the rest of the experiment, Bird 71 had the FI 8-min, Bird 101 had the FI 4-min, Bird 102 had the FI 2-min, and Bird 103 had the FI 16-min schedule. Table 1 shows the sequence of conditions. First, the stimulus positions changed only after food presentations, and then there were quarterly position changes independent of responses. Next the position changes de-

pended on a response. The interval did not progress to the next quarter until a response to any stimulus terminated the current quarter. In the next condition, only responses to S+ terminated each quarter. Finally, the quarters again terminated with a response to any color. Food presentation always followed the first response to S+ occurring after the fourth quarter ended. The criteria for schedule changes were as described above.

RESULTS

Acquisition of Stimulus Control

The birds first had the red, blue, and green stimuli after their behavior had stabilized under fixed-interval schedules; the initial shaping of responding and adjustment to the intervals occurred with white keys. Figure 1 shows the percentage of total responses made to S+ in the first 10 sessions with the three colors. Over 90% of the responses were to S+ by the third or fourth session. Responses in the first sessions were mainly on a single key with the bird switching keys (when S+ was located elsewhere) after a prolonged run of responses. By the third session, the birds tracked S+ across the three keys. Only Bird 101 dropped below 80% S+ responses in sessions after the early ones. The birds emitted over 90% of the responses to S+ by the tenth session.

Fig. 1. Percentage of responses to S+ in the first 10 sessions.

Maintained Stimulus Control with Simple Fixed Intervals

The filled circles of Fig. 2 show the mean percentage of total responses occurring to S+ with the four fixed intervals for the last five sessions under both exposures to each interval. The mean data closely approximated individual sessions, since the percentage of responses to S+ on individual days was within 5% of the mean on at least 95% of the sessions for each bird. The percentage of responses to S+ was not affected systematically by interval size.

Fig. 2. Mean percentage of responses to S+ with simple fixed intervals (filled circles) and with quarterly response-independent position changes (open circles).

On an absolute basis, both S+ responses and responses to the other stimuli (S-) increased in successive quarters of each interval. The percentage of S+ and S- responses was not related systematically to particular quarters of the interval: in some sessions the percentage of S- responses declined in successive quarters, in others it increased, and in still others it did not change in any orderly manner. No summary measure could adequately represent the individual sessions. Ferster (1960) reported similar variability with fixed-interval reinforcement of matching-to-sample.

Considering only S- responses, the birds did not distribute their responses randomly between the two stimuli. Instead, every bird always responded more to one than to the other. The same stimulus controlled the majority of S- responses in every session.

Quarterly Response-Independent Position Changes

When the stimuli changed positions after each quarter of the interval without reference to responses, the open circles of Fig. 2 reveal that the mean percentage of S+ responses for the last five days with each interval decreased somewhat from the level maintained previously. The percentage continued to be unrelated to the size of the fixed interval. The decrease in S+ responses, although small, was consistent in that for all birds there was no overlap in the percentages for the last five sessions of this and the preceding condition under each interval value. The increased S- responses could not be attributed to changes in stimuli that occurred after a peck was initiated, because they occurred at various parts of each quarter. There continued to be no systematic relation between the percentage of S+ and S- responses and particular quarters of the interval.

Figure 3 shows that the total number of responses declined considerably from the level maintained previously. These data are the means of the last five sessions with each interval. Again, the data were representative of individual sessions. There was always at least a 21% decrease in responses, with as much as a 30-fold decrease with the FI 16-min schedule for Bird 103. Where the number of responses always was an orderly function of interval size without position changes, the function was not equally orderly with the position changes.

Fig. 3. Mean number of responses per interval with simple fixed intervals (filled circles) and with quarterly response-independent position changes (open circles).

Figure 4 shows cumulative records for the session of the simple fixed interval preceding the first with position changes, and for three sessions with position changes. The behavior shown for two birds also characterized the other subjects. The simple fixed interval (A) generated a post-reinforcement pause followed by positively accelerated responding. By the second session with position changes (B), the rate decreased and became more irregular. By Session 14 (C), the rate decreased still further and there were multiple periods without responses within intervals. In the final session (D), the rate was quite low. As can be seen in the records, the number of responses in successive quarters varied unsystematically, although usually there was little responding in the first quarter. The low rates and erratic patterns of responses shown in D continued when the interval values were changed.

*Analysis of Position Changes:
Response-Independent and
Response-Dependent*

To analyze further the effects of position changes, each bird had a single fixed interval while the conditions for producing position

Fig. 4. Cumulative records of responding under simple fixed intervals and with quarterly response-independent position changes. Bird 71 had FI 16-min, Bird 103 had FI 8-min. A: last session of simple FI; B: Session 2 of quarterly position changes; C: Session 14 of quarterly position changes; D: Session 25 of quarterly position changes. Responses to all stimuli cumulated, and the pen reset at each food presentation. In D, offsets of the response pen indicate position changes. The records are of the middle 2 hr of the sessions.

changes after each quarter of the interval were manipulated. There were four conditions: no position change, position change without reference to behavior (response-independent), position change produced by a response to any stimulus (response-dependent on any response), and position change produced only by a response to S+ (response-dependent on S+ responses).

Figure 5 shows the mean number of responses made to all stimuli and the percentage of the responses occurring to S+ in the last five sessions of each condition. The number of responses in the last five sessions were within 5% of the mean; the percentages in the individual sessions deviated by no more than five points from the mean. The abscissa shows the sequence of treatments. With respect to the total number of responses, response-indepen-

dent position changes produced the fewest responses, and the other conditions did not differ consistently from each other. With respect to accuracy of responding, the position changes dependent on a response to any stimulus produced the lowest percentage of responses to S+; next lowest percentage was produced by the response-independent condition. No position changes and changes dependent on S+ responses generated the most accurate responding. The preferences for one of the two stimuli uncorrelated with food presentation were accentuated with the conditions that produced the lowest percentage of S+ responses. There continued to be no systematic relation between quarters of the interval and the percentage of total response occurring to S+.

Cumulative records of responses when position changes depended either on a response to any stimulus or on a response to S+ were indistinguishable. Records for the final session of the latter condition are shown in Fig. 6. After each position change, the birds typically responded once to S+, then paused, and then gradually increased their response rate during the interval. The net effect was behavior that appeared to involve four successive fixed intervals. The exceptions to pausing followed by positive acceleration appeared when the positions were the same in successive quarters and there was no pause at the beginning of a quarter.

The least responding usually occurred during the first quarter of the interval. The records for each session showed that neither the second, third, nor fourth quarters produced consistently more responding, but that responding was substantial in each. Although averaged data indicated increased responding in successive quarters, these averages were not representative of even the majority of most individual intervals.

DISCUSSION

The sequence of procedures emphasized both stimulus control under simple fixed-interval schedules and the effects of quarterly position changes on behavior. Both of these aspects required detailed consideration.

With simple fixed intervals, from 90% to 100% of the responses occurred to the stimulus terminally correlated with reinforcement.

Fig. 5. Percentage of responses to S+ (solid bars) and average number of responses per interval (striped bar). Bird 71: FI 8-min; Bird 101: FI 4-min; Bird 102: FI 2-min; Bird 103: FI 16-min. Each abscissa indicates the sequence of conditions. RI: quarterly response-independent position changes; None: no quarterly position changes; RD: any: quarterly position changes dependent on a response to any stimulus; RD: S+: quarterly position changes dependent on a response to S+.

Fig. 6. Cumulative records of responding when quarterly position changes depended on a response. Bird 102: FI 2-min; Bird 101: FI 4-min; Bird 71: 8-min; Bird 103: FI 16-min. Responses to all stimuli cumulated, and the pen reset at each food presentation. Offsets of the response pen indicate position changes.

Fixed-interval schedules, therefore, did produce substantial and rapid stimulus control in a simultaneous discrimination. Nevin (1967) found equivalent results in that a discrete trial analogue of a fixed-interval schedule produced substantial stimulus control.

Ferster (1960) and Dews (1963) showed that fixed-interval schedules did not establish a high level of matching-to-sample, and therefore do not always produce substantial control by the stimuli terminally correlated with reinforcement. The factors responsible for these different results are unclear, and only tentative hypotheses are feasible at present. The most obvious is that in one situation (matching-to-sample) the specific stimulus correlated with reinforcement continually changed, whereas in the other (simultaneous discrimination) it was constant. If, in fact, it was the specific stimulus correlated with reinforcement that tended to control responding in the next interval in the matching studies, this would generate the inaccurate matching observed. Another possible reason for the difference is procedural. The studies of matching-to-sample involved frequent stimulus changes dependent on responses. Cor-

rect responses changed the positions of the stimuli and occasionally produced food, and incorrect responses produced brief timeout periods. Since occasional position changes dependent on any response reduced the accuracy of responding in the present experiment, it may be that frequent stimulus events depress stimulus control with fixed-interval schedules.

The present data suggested that stimulus positions had reinforcing properties. Quarterly response-dependent position changes divided the complete interval into four segments with each position after the first ending the preceding segment and providing a discriminative stimulus for the next. This arrangement was a chained schedule: in a chained schedule food follows the completion of a sequence of component schedules, each of which is correlated with a distinctive stimulus. Because of the irregular sequence of positions, any of the six possible spatial arrays of the three stimuli could be present at the time of reinforcement or in any of the four quarters of the interval. Thus, the procedure established a four-component chained schedule (plus a single response requirement at the end) with stimulus arrays

appearing in a variable order. The stability in response rate and pattern in successive components after the first was like that found by Kelleher and Fry (1962) with chained schedules involving three fixed intervals and stimuli arranged to appear in an irregular sequence. The two sets of data indicated that chained schedules involving variable orders of stimuli have very similar effects whether the animal is presented with one stimulus at a time or with three stimuli simultaneously. In fact, the present situation produced the more orderly intervals. Marr's (1969) report that the repetition of stimuli in a chained schedule improved fixed-interval behavior suggests that the orderliness may have been assisted by the occasional repetition of a position in different quarters of the same interval.

When position changes depended on a response to S+, only S+ responses were correlated either with the appearance of a new position or with the presentation of food, and responding was almost totally confined to that stimulus. When the position changes followed a response to any stimulus, responses to all three stimuli could be correlated with the appearance of a new position, and S- responding increased. Since most of the responses were already occurring to S+, most new positions continued to follow S+ responses. Control by S+ was diminished but not eliminated. One bird did sharply reduce the proportion of responses occurring to S+.

The appearance of a new position independent of responses meant that a reinforcing event occurred without reference to behavior. Just as food delivered at fixed time intervals independent of responding decreases the rate of a previously conditioned response (Zeiler, 1968a), the frequency of key pecking declined with the response-independent occurrence of a new position. Furthermore, as is usually found when reinforcing stimuli appear independent of responses, there was variability in behavior among subjects. In addition, this condition was like that involving new positions dependent on a response to any color with respect to stimulus control in that a response to any color could be most contiguous to the reinforcing event and thereby could be maximally reinforced. These two conditions, therefore, should be and were most alike in generating the least control by the stimulus correlated with food presentation.

The pigeons often responded immediately after a position change and then paused. Thus, the onset of a position change was a discriminative stimulus for a single response to S+, probably because the first response to S+ after the fourth position change resulted in food presentation. Comparisons with other data indicate that neither the momentary event of a changing position nor the number of such events served any discriminative function with respect to the total interval. When Segal (1962) correlated a distinctive stimulus with each quarter of a fixed interval, pigeons responded infrequently in the first three quarters and responded at a high rate in the fourth. Ferster and Skinner (1957) observed similar behavior when a stimulus changed continuously during each interval. These effects did not appear in the present study. If the number of changes had assumed such a discriminative function, responding would have been suppressed for most of the interval and then increased at the end. Instead, responding was substantial in the second, third, and fourth quarters with response-dependent changes and was suppressed throughout with the response-independent changes. The effects were consistent with those of response-dependent and response-independent stimulus arrays functioning as conditioned reinforcers, but offered no evidence for "clock" or "counter" functions. The mixed orders and repeated presentations of positions during the interval precluded the sequence of components from operating as a clock. The low level of responding in the first component of the chained schedule (the first quarter of the interval) can be attributed to the temporal remoteness from food presentation independent of the prevailing discriminative stimuli.

The various conditions revealed that stimulus control in fixed-interval schedules did not covary with the amount of responding, but did depend on the scheduled and adventitious conditions obtaining at the moment of food presentations and position changes. Response-independent position changes produced the fewest responses, but accuracy was higher than when the changes depended on a response to any stimulus, a condition that maintained considerable responding. Nevin (1967, 1969) and Zeiler (1968b) also concluded that stimulus control was independent of factors controlling response frequency. The conclusion seems justified that the stimulus events present at

the moment of reinforcement are powerful determinants of stimulus control with fixed-interval schedules. The consistently higher response rate to one of two stimuli when responses to neither were followed immediately by reinforcement showed that fixed intervals also maintained some stimulus control by events more remotely related to reinforcement.

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