INTERMITTENT REINFORCEMENT OF MATCHING TO SAMPLE IN THE PIGEON¹

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Skinner (1950) demonstrated the possibility of maintaining a complex chain of discriminative responses (matching to sample) under intermittent reinforcement. In his procedure, the pigeon illuminated two side keys by pecking at a center key. When the pigeon pecked one of the side keys, both side keys extinguished and the center key relighted. After 1 minute, the first response to the matching side key operated the food magazine and the color of the center key changed randomly. The experiments reported here extend the general technique of the intermittent reinforcement of the complex response to fixed-interval, variable-interval, fixed-ratio, and multiple schedules of reinforcement. The basic matching paradigm was altered so that each matching response was differentially reinforced. A conditioned reinforcement followed each S^D (matching) response, and a brief time out followed each S^Δ (nonmatching) response. Thus, each response to a side key is differentially reinforced, depending on whether or not the pigeon pecks the key color corresponding to the center key. The general technique has already been successfully used in maintaining another type of complex behavior, counting, under a fixed-ratio reinforcement, with a high degree of conformation to the reinforcement contingencies (Ferster, 1958).

Intermittent reinforcement has the same usefulness with a complex sequence of responses as with a simple response such as a simple peck. The performance can be sustained for long periods with minimal satiation effects; the base line is, in general, sensitive to a wide range of variables; and the performance provides a base line on which the effects of independent variables may be repeatedly tested. In addition, the control by these variables within the matching sequence can be measured at the same time as the over-all frequency of the behavior. The effect of a schedule of reinforcement on a complex response extends the generality of the principles of intermittent reinforcement.

METHOD

The subjects of the experiment were two White Carneaux cocks, 6 months old at the start, and approximately 20 months at the end, of the experiment. The general conditions of the experiment were the same as those reported elsewhere in pigeon experimentation (e.g., Ferster, 1953). The apparatus consisted of a standard pigeon experimental space with three keys, 1 inch in diameter, spaced with a center-to-center distance of 2 inches, 8.5 inches from the floor, and operated with a force of 15 grams. The keys were located in the center of the panel, with the magazine aperture directly underneath the center key. Each key could be illuminated independently by a red or white lamp mounted directly behind.

Matching Procedure

The session began with the center key illuminated randomly either red or white. The center-key light went out and the side-key lights came on when the bird pecked the center key. Pecking the side key whose color corresponded to the center key produced a 0.2-second illumination of the lights which normally accompanied the delivery of food in the magazine aperture (conditioned reinforcer). The magazine did not raise, however. Pecking the non-

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matching color turned off all of the lights in the box for 1 second (time out). Following either the time out or the conditioned reinforcement, the center key was relighted and the matching sequence began again. However, the stimulus setting changed only after conditioned reinforcements.

Although every correct response on a side key produced a conditioned reinforcement, the operation of the food magazine accompanied the conditioned reinforcement only intermittently. The schedule of reinforcement of the matching sequence refers to the schedule by which S^D side-key responses operated the food magazine. In fixed-ratio reinforcement, every n th matching response produced the food magazine, while intervening matching responses were followed only by the conditioned reinforcement. In fixed-interval reinforcement, the first matching response after n minutes produced the food magazine, while intervening matching responses produced only the conditioned reinforcement. The interval programmers and recorders did not run during time outs.

Plan of the Experiment

The matching performance was first developed on CRF. The number of matching responses required for reinforcement was then gradually increased until the schedule of reinforcement reached FR 17. Then, after a brief exposure to mult FI 10 FR 17 and FI 10, the size of the fixed ratio was varied systematically from FR 4 to FR 47 in one bird and FR 15 to FR 95 in the second bird. Figures 6 and 7 show the particular fixed-ratio values and schedule of changes. The matching performances were then compared under fixed-interval, variable-interval, and fixed-ratio schedules. After multiple-schedule performances of the matching response were developed, the effects of interval and ratio reinforcement could be compared within a single session in a single animal. The component schedules of the multiple schedules were also programmed separately to measure the interaction between the component schedules and to minimize and manipulate the interactions.

RESULTS

First Development of CRF

The matching performance developed over approximately 69 sessions, during which the accuracy of the matchings fell from approximately chance levels under continuous reinforcement to a ratio of one S^A for every 10 or 20 S^D responses. During this early development of the performance, one cannot be sure whether the progressive development of the matching behavior is due to exposure to the differential contingencies of the matching procedure or to the fixed-ratio schedule.

Performance Under Varying Fixed Ratios

The progressive decline in the number of S^A responses during the first exposure to the fixed-ratio schedules may have been due either to the extended reinforcement or to the effects of the fixed-ratio schedule. Therefore, the data for Bird 5Y was not used to report the effect of the schedule of reinforcement on the amount of S^A responding. Bird 6Y's first exposure to the matching performance provided this bird's only performance on small fixed ratios.

The fixed-ratio reinforcement of the matching behavior produced the same general results as with a simpler response. The highest sustained matching rates occurred on smaller fixed ratios. At larger fixed ratios the birds paused after reinforcement and then responded abruptly at the characteristic fixed-ratio rate of responding of between 0.5 and 1 matching

sequence per second. At the largest fixed ratios, the birds paused after reinforcement for long periods. Once they began matching, however, the actual rates of responding usually remained constant, even when pausing after reinforcement was extreme. The fixed-ratio performance on the matching schedules differed from the similar procedures on simple pecking in the slight curvature which occurred occasionally just before the terminal rate of matching was reached and the lower terminal rates of responding.

Figures 1 and 2 show fixed-ratio performances for 5Y, representing the stable performance at the end of this bird's exposure to each of the fixed ratios. In Fig. 1, the performances are well-sustained on FR 10 to FR 26. Differences in over-all rates of responding are due to pauses after reinforcement rather than actual running rates. Figure 2 shows the final performance (last two sessions) under FR 47, the highest value of the fixed ratio programmed for this bird. The pause after reinforcement becomes progressively longer throughout the session, producing a decline in over-all rate. The fixed-ratio character of the performance becomes distorted at times, particularly where there often is prolonged desultory responding after reinforcement as well as an extended acceleration before the bird reaches the terminal rate of matching.

Figure 1. Bird 5Y. Final performances under FR 10 to FR 26. The final two experimental sessions under each procedure are shown.

The second bird in the experiment, 6Y, sustained its performance at larger fixed ratios than 5Y, but otherwise showed a similar result. Figure 3 shows the final performance on fixed ratios from 11 to 60. The performance generally conforms to the basic fixed-ratio pattern, but occasional curvature occurs before the terminal rate of matching is reached as pausing develops on FR 60. Figure 4 shows a performance on FR 95, the largest fixed ratio programmed for this bird. The pausing after reinforcement becomes extreme, occasionally over 60 minutes; but, as in the typical fixed-ratio schedule, several ratios are run off with little or no pausing. The major discrepancy from the standard fixed-ratio performance is the long period following reinforcement during which the bird pecks at a low rate before reaching the terminal rate of responding. In spite of the large amount of pausing and the very

Figure 2. Bird 5Y. Final performance in the last two sessions on FR 47, showing a strained performance.

low over-all rate of responding, the performance was stable and was maintained over many experimental sessions.

Figures 5 and 6 show the degree to which the bird's performance conformed to the stimulus-reinforcement contingencies. The curves show the relationship between each magnitude of the fixed ratio and the ratio of S^A to S^D responses at the final performance. The four points at the various values of the fixed ratio represent mean values for the final four sessions at that fixed ratio. The accuracy of the matching increases with larger fixed ratios, from FR 15 to FR 20. Thereafter, the number of S^A responses begins to rise at fixed ratios above 60 for 6Y. This increased S^A level at higher fixed ratios was not recorded for 5Y,

Figure 3. Bird 6Y. Complete daily sessions, giving the final performance on FR 11 to FR 60.

Figure 4. Bird 6Y. Final performance on FR 95, showing a strained performance.

whose largest fixed ratio was 47. Even at the largest values of the fixed ratio, however, the number of S^A responses is considerably less than that occurring on CRF or at the short fixed ratios. For 6Y, the order of determination of the various points can somewhat account for the result. The values at the smaller fixed ratios were taken early in the experiment and possibly confound the early development of the effect of the size of the fixed ratio.

Figure 5. Bird 5Y. The degree of control by the matching procedure, represented by the ratio of S^A to S^D responses, is plotted against the magnitude of the fixed ratio. Each point is the mean value for an experimental session, and each determination is represented by the final four sessions on the procedure.

Figure 6. Bird 6Y. The degree of control by the matching procedure, represented by the ratio of S^A to S^D responses, is plotted against the magnitude of the fixed ratio. Each point is the mean value for an experimental session, and each determination is represented by the final four sessions on the procedure.

I wanted to see whether the amount of S^A responding was related to the degree of straining of the fixed-ratio performance. Therefore, I plotted the mean time per reinforcement for the largest fixed-ratio schedule in each bird against the amount of S^A responding. Such a correlation is shown in Fig. 7 for Bird 5Y, whose S^A responses were not higher during its strained ratio. One exception occurs in the session where the mean time between reinforcements reached 6 to 7 minutes. Bird 6Y, shown in Fig. 8, made more S^A responses in some of the experimental sessions when the mean time between reinforcements exceeded 8 minutes.

Figure 7. Bird 5Y. The S^A level of the matching procedure is presented as a function of the mean time between reinforcements (amount of straining on the FR 47 schedule). Each point is the mean value for a complete experimental session.

Figure 8. Bird 6Y. The control of the performance of the matching procedure is presented as a function of the mean time between reinforcements (amount of straining on the FR 95 schedule). Each point is the mean value for a complete experimental session.

Multiple Fixed-interval, Fixed-ratio

Matching behavior could be brought under stimulus control in the same way as a multiple schedule of reinforcement. Figure 9 shows a final performance for 5Y on mult FI 10 FR 10. The performance was recorded after a long history of exposure to the multiple schedules, as

Figure 9. Bird 5Y. Record A. The final performance on mult FI 10 FR 15. The key lights were steady during the fixed interval and flickered during the fixed ratio. The recorder and the fixed-interval programmer did not run during the time outs. Record B. The multiple schedule with pausing at the start of the fixed-ratio component.

well as interpolated periods of reinforcement on the simple components of the multiple schedule. The fixed-ratio and fixed-interval schedules alternate simply, except for an occasional instance where two interval schedules follow each other. Responding begins immediately after reinforcement in the fixed interval. A consistent and marked pause characterizes the start of nearly all the fixed-interval segments. The length of the fixed-interval segments varies somewhat because the interval programmer did not run during time outs. Record B is a mult FI 10 FR 15 performance showing pausing in the fixed-ratio component (induction from the interval schedule). Fixed ratios of the same order of magnitude sustained the matching behavior without pausing when they were programmed without the intervening fixed-interval performances. Bird 6Y's performance on the same multiple schedule is shown in Fig. 10, and the performance is similar to that of 5Y for a more abrupt shift to a slightly higher terminal rate.

Figure 10. Bird 6Y. Final performance under mult FI 10 FR 10. The two segments contain the first and last 14 reinforcements of the experimental session. The key lights were steady during the fixed interval and flickered during the fixed ratio. The recorder and the fixed-interval programmer did not run during the time outs.

Fixed-interval Reinforcement

The exposure to reinforcement on the simple FI schedules did not at once produce the final characteristic fixed-interval performance. In 5Y, the rate of responding was low and steady, with no conformation to the temporal pattern of reinforcement after 20 sessions on FI 10 (Fig. 11, Record A). Many sessions later, after exposure to mult FI FR and mult VI FR schedules, and single components of the multiple schedules, the return to the FI 10 resulted in the more sustained performance shown in Record B. The over-all rate falls during the session, and the pattern of responding varies a great deal from reinforcement to reinforcement. The pause after reinforcement is frequently marked, and scalloping is consistently present. After further exposure to the multiple schedule, this bird finally reached a more stable fixed-interval performance, illustrated by the complete daily session shown in Fig. 12.

Bird 6Y developed a stable fixed-interval performance after less exposure to the fixed-interval and multiple-schedule contingencies than Bird 5Y had had. Figure 13 shows the first session on fixed-interval reinforcement after the final performance recorded on the multiple FI FR schedule (Fig. 10). Except for the tendency early in the session to continue responding just after reinforcement, a stable and normal fixed-interval performance quickly emerges.

Figure 11. Bird 5Y. Record A. First exposure to FI 10 just after reinforcement on mult FI 5 FR 17. The recorder and the fixed-interval programmer did not run during the time outs. Record B. Intermediate performance on FI 10 after additional reinforcement on various values of the multiple schedule.

Figure 12. Bird 5Y. The last recorded performance of the experiment on FI 10, showing the final stable performance. The key lights were steady during the fixed interval and flickered during the fixed ratio. The recorder and the fixed-interval programmer did not run during the time outs.

Figure 13. Bird 6Y. First session on FI 10 following the final performance on mult FI 10 FR 10. The two segments of the record on the first and last seven reinforcements of the session, respectively.

The extent to which the birds were controlled by the matching contingencies depended on whether the matching was reinforced on interval or ratio reinforcement schedules. Even in the multiple schedules, less S^A responding occurred on ratio than interval schedules. These data are represented in Fig. 14 and 15, where the number of S^A matching responses

Figure 14. Bird 5Y. Over-all summary of the experiment, giving the degree of control of the performance by the matching procedure under the various components of the multiple schedules. The schedules and the number of sessions are presented in the order in which they are determined. The extended exposure to the fixed-ratio schedules occurred just following the first FI 10 and is not included in the figure. Each point represents the average value for one of the final four sessions on each schedule.

Figure 15. Bird 6Y. Over-all summary of the experiment, giving the degree of control of the performance by the matching procedure under the various components of the multiple schedules. The schedules and the number of sessions are presented in the order in which they were determined. The extended exposure to the fixed-ratio schedules occurred just following the first FI 10 and is not included in this figure. Each point represents the average value for one of the final four sessions on each schedule.

relative to the S^D matching responses is presented for the last four sessions of each procedure of the experiment. The data for the extended period of fixed-ratio reinforcement have already been presented in Fig. 5 and 6. Throughout the experiment the level of S^A responding is higher during the interval reinforcement schedules than it is during the fixed-ratio schedules. This was true of the simple schedules as well as multiple schedules, where the two components were programmed.

Much of the variation from procedure to procedure was due to inductive effects between the components of the multiple schedule. The early exposure to interval schedules produced S^A levels more characteristic of the immediately preceding fixed-ratio schedules. Conversely, when the fixed-ratio performances showed inductive effects from the fixed interval in the form of unusual pausing after reinforcement and lowered terminal rates, the S^A levels in the ratio components of multiple schedules were often elevated.

The S^A levels varied during successive quarters of the 10-minute, fixed-interval period. Figure 16 shows these data for both birds. The bars give the average values for the session for the fixed-ratio and fixed-interval performances. In the fixed-interval performances, the most accurate matching occurred during the last quarter of the fixed interval, when the S^A level was lower than the average value for the entire interval. The peak value occurred in the second quarter, corresponding, frequently, to the period of acceleration in the fixed interval.

The variability of each measurement is given by the median and interquartile range. The larger variation in the earlier parts of the fixed interval occurs because of the small number of responses from which the S^A level is determined.

DISCUSSION

Intermittent reinforcement of matching to sample on fixed-ratio, fixed-interval, variable-interval, and multiple schedules of reinforcement produced performances normally generated by these schedules with a simple response. Fixed-ratio reinforcement of matching to sample produced sustained responding at small fixed ratios. As the size of the fixed ratio was increased, pausing occurred after reinforcement following an abrupt shift after reinforcement to the terminal fixed-ratio rate. As with the typical fixed-ratio performance, the bird is either pausing after the reinforcement or responding at the terminal fixed-ratio rate. At the largest fixed-ratio schedules, when extreme pausing developed after reinforcement, occasional scattered responding and intermediate rates occurred before the terminal fixed-ratio rate was reached.

The accuracy with which the bird matched the sample depended upon the size of the fixed ratio. The largest number of S^A responses occurred on CRF and decreased to the lowest recorded values between FR 15 and FR 20. One of the birds that was exposed to fixed ratios above 50 showed a subsequent increase in the level of S^A responses at the higher fixed ratios. In one bird that was exposed to continuous reinforcement and the small fixed ratios only during the early part of the experiment, the high S^A level on CRF and on small fixed ratios

Figure 16. Distribution of S^A responses during the fixed-interval component of the multiple schedules. The medians and interquartile ranges are given for eight sessions after a final performance had developed on the multiple schedule. The bars give the median and interquartile range over the entire interval (and ratio).

is possibly confounded with the order of exposure to the schedules. However, continued reinforcement, in itself, probably was not responsible for the decrease in the level of S^A responding. Subsequent experiments on matching to sample, where birds were reinforced on CRF for long periods of time as a preliminary to exposure to other procedures, confirm the inaccuracy of the matching performances on CRF reported under the conditions of this experiment.

Patterns of responding characteristic of fixed-interval reinforcement developed only after prior exposure to the multiple FI FR schedule. As with other multiple schedules (Ferster & Skinner, 1957), the alternating reinforcements on the fixed-ratio schedule contributed to the development of the pause at the start of the fixed-interval component of the multiple schedule. The level of S^A responding under the fixed-interval reinforcement of matching to sample was considerably higher than under the fixed-ratio schedule. Both fixed-ratio and fixed-interval performances could be produced within a single session in the manner of a multiple FI FR schedule. The performance in the two components resembled those typically occurring on the single component. The pause and acceleration in the fixed interval were comparable with the standard performance recorded with a simple response. The terminal rates in the FI of the multiple schedule were, however, frequently higher than those on the FR. In the final performance under the multiple FI FR schedule, when the inductive effects on the FI from the FR reinforcement had been minimized, the matching accuracy on the FI was little better than chance.

Inductive effects between the two components of the multiple schedule were recorded during the early exposure to the multiple FI FR schedule. These were seen first as a low level of S^A responding in the fixed-interval component as a result of the previous reinforcement on the fixed-ratio component. After further reinforcement on the multiple schedule, the inductive effects were in the opposite direction, increasing S^A levels in the fixed-ratio component and pausing at values of the FR at which the performances had been well-sustained under the simple FR schedule.

One possible factor in the differences between the level of S^A responding on the fixed-interval and fixed-ratio schedules is the effect of S^A responding on the over-all frequency of reinforcement. Since the interval programmers continued to run during the time outs, the number of S^A responses occurring did not affect the over-all frequency of reinforcement. Even without a time out, however, S^A responses on a fixed-ratio schedule decreased the over-all frequency of reinforcement. The high level of S^A responding under the shorter fixed ratios may occur because the over-all frequency of reinforcement is initially so high that S^A responding has relatively little effect.

While the performances under these schedules of reinforcement resemble the performances typically occurring with a simple response, the size of the fixed ratio that the birds are able to sustain is smaller and the orders of magnitude of the rates of responding are lower. This is true even though each matching-to-sample sequence consists of a chain of two responses: pecking the center key followed by a side-key response. The behavior involved in choosing the matching side key and that of switching from one key to another probably accounts for the difference in rates of responding.

The levels of S^A responding recorded here are somewhat higher than those reported by Blough (1959). The most obvious difference in procedure, which may account for the difference in results, is that Blough used a very short magazine cycle and I used a 4-second cycle. With the shorter magazine cycle, a larger number of matching responses is required to

produce the bird's daily ration, somewhat comparable with that required in fixed-ratio schedules.

SUMMARY

Fixed-ratio, fixed-interval, and variable-interval reinforcement of matching to sample produced the typical performances normally obtained with these schedules of reinforcement. The birds matched inaccurately at CRF and small ratios, but the accuracy increased to maximum values at FR 15 to FR 20. The level of S^A responses was considerably higher under the interval than ratio schedules. Fixed-ratio and fixed-interval performances could be produced under stimulus control in the manner of a multiple schedule, with performances and levels of accuracy characteristic of those occurring on the simple components.

REFERENCES

- Blough, D. S. Delayed matching in the pigeon. *J. exp. anal. Behav.*, 1959, **2**, 151-160.
Ferster, C. B. The use of the free operant in the analysis of behavior. *Psychol. Bull.*, 1953, **50**, 263-274.
Ferster, C. B. Intermittent reinforcement of a complex response in a chimpanzee. *J. exp. anal. Behav.*, 1958, **1**, 163-165.
Ferster, C. B., and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
Skinner, B. F. Are theories of learning necessary? *Psychol. Rev.*, 1950, **57**, 193-216.

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