VARIABLES DETERMINING THE EFFECTS OF DELAY IN REINFORCEMENT^{1,2}

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Procedures were discovered for maintaining a small fixed-ratio performance under 24-hr delay in reinforcement, by appropriate manipulation of the length of delay, amount of food delivered, and size of the fixed ratio. Other experiments showed that (1) the parameters discovered in the first experiment could produce the same result without the complex history of the first procedures; (2) the same parameters of the delayed-reinforcement procedure could maintain an explicit chain of responses; (3) gradual increase in the delay in reinforcement from small to large values was not a necessary condition for achieving the major result, if large amounts of food were delivered as reinforcement and all of the behaviors were first under good control of the relevant stimuli with short delays.

The first experiments on delayed reinforcement by Skinner (1938), using intervals from 2 to 8 sec, demonstrated original conditioning and sustained behavior under short FI schedules but with as much as 50 per cent decline in rate of responding. In these experiments there was no explicit stimulus change associated with the delay procedure. Ferster (1953), in an experiment with pigeons, arranged the delay by a blackout between the response and its reinforcement. With the explicit delay stimulus and a gradual increase in the delay it was possible to sustain behavior with delays as high as 120 sec without any major weakness in the behavior. Ferster analyzed his results by appealing to accidentally-reinforced behavior during the delay stimulus. Later experiments by Azzi, Fix, Keller, and Rocha e Silva (1964) compared rates of emission of a delayed-reinforced response with and without a delay stimulus and showed that the behavior was more strongly maintained with than without an explicit delay stimulus. Their experiments confirmed the importance of the delay stimulus in maintaining accidentally-reinforced behavior.

The essential features of the delay-reinforcement paradigm suggest the relevance of the properties of chained responses. When an in-

terval, with a correlated stimulus, is interposed between a response and some consequence maintaining the response, a link has been effectively added to a chain of responses. Without a correlated stimulus, the schedule of reinforcement is a tandem schedule equivalent to the chain. Such a chain might be chain FR FI, where 50 responses (*e.g.*) produce a stimulus in whose presence some response is accidentally reinforced by the delivery of food following the delay stimulus.

The analysis of delayed reinforcement as a chain of responses, suggests the possibility of maintaining behavior under indefinitely long delays, if the proper parameters of the schedules could be found.

EXPERIMENT I

In the first experiment, a chain of responses and delay of food reinforcement was arranged by interposing an S^A interval after one of the conditioned reinforcements in the chain. The first experiment was designed to discover conditions for maintaining a response under a long delay, arbitrarily designated as 24 hr. In the first set of procedures, the performance was a chain of responses reinforced by successive deflections of a voltmeter to the maximum position. Later, when it proved impossible to maintain the long chain in strength, the performance was reduced to a small fixed ratio.

Subjects

Two adult rhesus monkeys which had served in other operant experiments (Ferster and Zimmerman, 1963) were used.

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Apparatus

Each monkey lived continuously in a 30 by 40 by 30 in. chamber except when removed by transfer cage for cleaning (approximately twice a month) and occasional apparatus repair. Water was continuously available from a bubbler at the rear of the cage. The floor was covered with 4 in. of sawdust. A shelf at the rear of the cage, approximately 15 in. off the floor, served as a perch. The intelligence panel served as the front of the cage and contained two keys, the face of a voltmeter which could be illuminated either red or white, and a hopper into which 1 g CIBA or D and G pellets were delivered from an automatic feeder. The left key was located just under the face of the voltmeter. The keys were Switchcraft lever-action switches with stainless steel handles. The right key was located just above a 1/2 in. diameter white jeweled light. Overall illumination was provided by three 6-w white lamps mounted on the front of the intelligence panel.

Procedure

The basic procedure consisted of a sequence on two keys. Responses on the first key, when it was red, were followed (*e.g.*, FR 75) by the delay interval, during which the color changed to white. At the end of the delay interval, the first key became dark and the second key became lighted. In the presence of the lighted second key, a certain number of key presses each produced a pellet of food (CRF). In the first part of the experiment, when the performance was a chain of responses reinforced by successive deflections of the meter, the schedule of reinforcement (by the meter deflection) was fixed ratio. For example, every 50th response advanced the meter one step. The size of the fixed ratio varied during the experiment as well as the number of steps that brought the meter to maximum deflection—one pellet for each step required. Responses during the blackout extended it, and responses during the delay produced a blackout as well as extending the delay intervals. These procedures prevented accidental reinforcement of key pressing and kept the level of S^A responding very low.

The procedures were designed to discover how to maintain a fixed ratio under a delay

in reinforcement set arbitrarily at 24 hr. Four variables had to be adjusted simultaneously. (1) *The number of steps in the initial chain leading to the delay stimulus (the white light).* The original plan was to examine the effect of the delay on conditioned reinforcers in various parts of the chain. At this stage, the meter deflected toward maximum on a fixed-ratio schedule. The exact schedules of reinforcement in effect at various stages are listed in the legends of Fig. 1 (M7) and Fig. 4 (M4). The delays weakened the behavior so greatly that the schedule of reinforcement on the left key was reduced to a simple fixed ratio, in which the meter advanced to the maximum deflection in one step. (2) *The size of the fixed ratio.* Even after the requirement was reduced to a simple fixed ratio, the number of responses required had to be adjusted depending on how much the delay weakened the behavior. The size of the fixed ratios throughout the experiment is given in the legends of Fig. 1-5. (3) *Amount of reinforcement.* The number of pellets delivered at the end of the chain had to be increased as the delay in reinforcement was increased so that a minimum maintenance food intake was possible. (4) *Delay in reinforcement.* It could not be known in advance how rapidly the delay could be increased without weakening the behavior, since the performance is a joint function of the size of the fixed ratio, the number of steps in the chain, and the amount of food. We, therefore, varied all parameters together using the fixed-ratio performance as a criterion.

It was not possible to control deprivation systematically because the animal had to be in the experiment continuously, particularly with long delays. In general, the animal's body weight depended on the strength of its behavior because long pauses reduced the frequency of food delivery.

Results

Figure 1 summarizes the results of the first 146 days of the experiment during which M7's delay in reinforcement reached 9060 sec (151 min). In general, the overall rate of responding decreased continuously, as the delay in reinforcement was increased. By the 60th day, when the delay in reinforcement reached 4260 sec (71 min), responding virtually ceased. The performance was reinstated by immediate

reinforcement and continued at an intermediate rate until it ceased by the 98th day at 9060 sec delay in reinforcement. Immediate reinforcement again reinstated the performance, but it was necessary to reduce the size of the fixed ratio to maintain responding. The continuation of this experiment, during which the delay was increased from 151 min to 24 hr, is described in Fig. 2. The data are plotted as the number of fixed ratios completed rather than number of responses because of the long delay in reinforcement and the low rates of responding. The number of pellets given for reinforcement was increased to 75 to compensate for the long delay interval. Even with the reduced fixed ratio and the increased food reinforcement, the rate of responding fell to the lowest values in the experiment in the

vicinity of the 50th day, but the delay in reinforcement was still increased to 6 hr on the 57th day. To maintain a minimum level food intake the number of grams of food per reinforcement was increased to 100. Responding all but ceased between the 52nd and 59th days. When the fixed ratio was reduced to 20, responding increased even though the delay in reinforcement was increased further to 10 hr. Thereafter, the performance was sustained at the maximum rate for the remainder of the experiment, even with the 24-hr delay on the 104th day. By the 160th day this animal's body weight reached 9 kg, essentially a free feeding weight, receiving almost 240 g of food each 24-hr period.

Figure 3 contains some sample cumulative records for M7 during the final period of the

Fig. 1-M7. A reduced cumulative record showing overall rates of responding for the first 146 days of the experiment. The abscissa is recorded as experimental time which does not include the delay interval. The continuous time from the start of the experiment is given below for each value of experimental time. Thus, the slope of the cumulative record is comparable throughout the graph because it does not include the delay time. The inserts at the top of the figure give the procedures at the various stages of the experiment for the length of delay and size of the fixed-ratio schedule. The discrepancy between continuous and experimental time reflects the large percentage of the total time spent in the delay.

Fig. 2-M7. The final development. Overall rates of responding are presented as the cumulative number of fixed ratios completed per unit time because they are so low. The insert in the middle of the graph gives the animals' body weight at the indicated times during the experiment.

experiment (see Fig. 2, days 166-176) when the performance was strongly maintained on FR 120 with 240 pellets as reinforcement. Once responding began, the terminal rate was rapidly reached, except in very few instances as in the third fixed-ratio segment of Record B. Local rates of responding are predominantly fixed ratio in character. The strength of the behavior is indicated by the interval between the end of the delay and the comple-

tion of the fixed ratio leading to the next delay. Most of the experimental time was taken by the delay intervals (not shown in the cumulative records) so that the total amount of time represented by Record B is over six days.

M4's performance was much more weakly maintained than M7's. By the 135th day (Fig. 4) this monkey's behavior all but ceased (much like M7's) and it was necessary to reduce the size of the fixed ratio to 20 (one step of the voltmeter) to preserve a level of food intake which would keep the animal alive under the 6330-sec delay in reinforcement then in effect.

The remainder of M4's performance during the period when the delay in reinforcement reached 24 hr is shown in Fig. 5. The FR 20 schedule reinstated the performance from the low rate recorded at the end of Fig. 4, and the higher rate of responding and the large number of pellets delivered per reinforcement increased this monkey's body weight from 4.2 kg to almost 5.5 kg by the 32nd day. The long delay did result in a loss of behavior once the

Fig. 3. A sample cumulative record showing M7's performance after a stable performance had developed after 24-hr delayed reinforcement on FR 50. The recorder does not run during the delay interval, hence the 24-hr interval occurs between the final response in the fixed ratio and the oblique mark indicating the reinforcement.

M 4

Fig. 4-M4. A reduced cumulative record showing overall rates of responding for the first 146 days. The abscissa is recorded as experimental time which does not include the delay interval. The continuous time from the start of the experiment is given below for each value of experimental time. Thus, the slope of the cumulative record is comparable throughout the graph, because it does not include delay time. The inserts at the top of the figure give the procedures at the various stages of the experiment for the length of delay and size of the fixed-ratio schedule.

M 4

Fig. 5-M4. The final development. Overall rates of responding are presented as the cumulative number of fixed ratios completed per unit time because they are so low. The insert at the middle of the graph gives the animal's body weight at the indicated times during the experiment.

performance was reliably maintained under intermediate delays. It was deemed necessary, however, to reduce the size of the ratio almost to continuous reinforcement to continue a maintenance level of food intake. Later, it proved possible to increase the size of the ratio to 10 with 240 pellets per reinforcement, and still maintain the performance.

EXPERIMENT II

Experiment II was designed to determine whether the general conditions of Exp I could have maintained some behavior adventitiously during the 24-hr delay interval.

If the parameters of this experiment did maintain a chain of explicit responses equivalent to the parameters of the delayed-reinforcement experiment, we would be further disposed to consider the responses maintained by long delays as special cases of chained schedules. An explicit chain of responses was therefore set up. It was identical in every detail to the delayed-reinforcement procedure of Exp I except that a response terminated

the delay interval, and produced the stimulus, which was the occasion on which food was delivered. If behavior could be maintained on a chain FR 50 FI 24-hr schedule, it would then be known whether accidentally reinforced responses could contribute to the performance under the delayed-reinforcement conditions.

Procedure

The apparatus and general procedure remained as in the previous experiment except that the food-key light came on as a result of the first response after 24 hr. This is a chained FR FI CRF schedule. The total sequence was as follows: the red light changed to white after the 50th response. In the white light the first response on the same key after 24 hr turned on the food-key light, and 200 pellets were delivered one at a time each time the food key was depressed.

Results

The first two bars in each panel of Fig. 6 give the result of altering the procedure from

Fig. 6. Median, interquartile range and range of the length of time required to complete the fixed ratio under the indicated conditions. The number in each bar indicates the number of sessions for that procedure. A horizontal line on each bar gives the median value. The first two bars of the graph compare the average time to complete a fixed ratio during the delay procedure and during a comparable chain. The third bar in each panel shows the result of delivering the food pellets at the end of the chain without requiring any response on the food key.

delayed reinforcement to a chain. The major datum is the time required to complete the fixed-ratio performance in the first member of the chain. The monkeys almost always completed the fixed ratio normally once they started to respond. The first bar gives statistics of the final performance on the delayed-reinforcement procedure of Exp I. The number in the bar gives the number of sessions on which the statistics are based. The data were recorded subsequent to the results shown in Fig. 1-5. M7 responded with much shorter pauses after reinforcement than M4, as in Exp I. The second bar of each panel shows the result of changing the procedure to a chain in place of the delayed-reinforcement procedure. Not only does the chain continue to maintain M7's performance as before, but it reduces M4's median time by over 1000 min. The third bar will be presented in Exp III.

Figure 7 shows the range of the fixed-interval performances during the 24-hr white light interval, previously the delay stimulus, but now the second member of the chain. Three fixed-interval segments are given for each monkey illustrating the largest, median, and smallest number of responses. As with the

performance in the first (fixed-ratio) component of the chain, M7's behavior is more strongly sustained than M4's. Both animals, however, show substantial enough amounts of responses emitted during the 24-hr period for a stable fixed-interval performance. Responding occurred predominantly at the beginning and end of the 24-hr interval.

EXPERIMENT III

Because the response, with reinforcement delayed, was the same form as the response which delivered food it was decided to determine whether the direct reinforcement by food pellets had any inductive effects on the first member of the chain. The very special conditions which had to be arranged in Exp I, in order to maintain even a small amount of behavior under delayed reinforcement, suggested that any substantial inductive effects were unlikely; yet a control experiment could evaluate this factor.

Apparatus and Procedure

The apparatus and procedure returned to the conditions of Exp I, except that no response on key 2 was required for the delivery of food at the end of the delay. The sequence was as follows: in the red light the 50th response changed the color to white. The white light remained on as in Exp I for 24 hr. At the end of the 24 hr the food pellets dropped into the food hopper at a rate of approximately 1 per sec until all the pellets had been delivered.

Results

The third bar of Fig. 6 shows that the non-response contingent delivery of food did not weaken the fixed-ratio performance. M4's performance remained substantially as before while the median time required to complete a fixed ratio for M7 decreased by 500 min. There is no reason to believe, therefore, that the frequency of occurrence of the performance maintained under delayed reinforcement is increased by induction from the food key.

EXPERIMENT IV

In Exp I, the delay in reinforcement was increased slowly, paced with the monkeys' performance. The question remains as to whether the careful adjustment in the delay

Fig. 7. Cumulative records for M7 and M4 showing the fixed-interval performances during the chain FR 50 FI 24-hr. procedure. The scale of the record given by the coordinates is considerably reduced over those typically employed.

was necessary once performances were stably maintained on short delays. An experiment was, therefore, carried out to determine how a sudden shift from a short delay to an 18-hr delay would affect the animals' performance, given the conditions of amount of food and size of fixed ratio that were determined to be adequate for maintaining a performance on long delays in the previous experiment.

Apparatus and Procedures

The subjects of these experiments were three naive adult dog-faced baboons (*Papio Papio*). The experimental space and general conditions remained the same as in the previous experiments. The initial procedure was designed to produce a sustained FR 50 performance with reinforcements delayed 30 min (10 min for B2). A series of intermediate procedures was used to develop performances maintained with 30-min delays. First the white light (later to be the delay stimulus) came on for 30 min, followed by the food-key light. In the presence of the food-key light 40 responses on the food key were each reinforced (CRF) by a pellet of food. A 2-hr blackout followed the 40th pellet and the cycle repeated. Any response during the time out extended it for 5 min. No behavior was required of the baboon except to press the food key. The first key, with reinforcement later to be delayed by the white-light interval, was present continuously but only produced a 5-min blackout which extended the white-light period by 5 min. Responses on the food key in the absence of the food-key light had the same result. The delay procedure was begun only when the frequency of responses fell to near zero during the time out after the food delivery and during white light (later to be the delay stimulus). By this time, the animals pressed the food key reliably whenever the food-key light came on. The first time the delay was introduced the stimulus over the first key was red and turned white as a result of a single response (CRF). The white light remained on for 30 min, followed by the food-key light, 40 continuous reinforcements on the food key and a 2-hr time out as described above. The fixed ratio was then slowly increased, paced to the baboons' performance, until it reached 50. Then all of the parameters of the experiment were adjusted to prepare for the shift to an 18-hr delay in reinforcement. The fixed ratio re-

mained at 50, the delay at 30 min, but the number of pellets per reinforcement was increased to 200 and the time out to 18 hr.

In the final procedure, the length of delay in reinforcement (the white stimulus) was changed in one step to 18 hr and the time out after food delivery reduced to 4 hr. At no time during the experiment had a key press been followed by food by less than 30 min.

Results

The statistics for the final performances are given in the first panel of Fig. 8. Performances were easily maintained under the 10- and 30-min delay procedure. The median time to emit the required 50 responses is somewhat less than 250 min for B1 and B2 and less than 1 min for B3. These values are considerably lower than those recorded in the previous experiments with longer delays. The second panel shows the result of lengthening the delay suddenly to 18 hr. Except for B1, the time required to complete the fixed ratio increases but the magnitudes are not larger than in the previous experiments (see Fig. 6). Continued exposure to the 18-hr delay in reinforcement for B1 and B3 (shown in the third panel) did not materially change the result.

Figure 9 contains cumulative records showing details of the transition from 30-min to 18-hr delay in reinforcement for B3. Under 30-min delays this animal had shown the most sustained performance of the three baboons (panel 1 of Fig. 8), and the cumulative curves in Record A show performances similar to those generated by FR schedules. The records resemble FR performances in pigeons with insufficient reinforcement. (Ferster and Skinner, 1957, p. 63). The transition to 18-hr delayed reinforcement is shown in Record C. The performances in Record B correspond to the second panel of Fig. 8 and those of Record C to the third panel. The 18-hr delay occurred for the first time after the first segment of Record B and long pauses, desultory responding, and intermediate rates appear immediately in the second segment in place of the heretofore sustained responding. With further reinforcement under 18-hr delay in reinforcement, key presses became progressively grouped together, as is typical of an FR schedule, but the pause before the FR is completed remains long. In the final performance of Record C, the trend to a typical FR pattern

Fig. 8. An overall summary of the time to complete the FR requirement under short delays in reinforcement, a sudden shift to long delays, and the final performance on long delays. The first panel shows performances for B2 under 10-min delays and for B1 and B3 under 30-min delay. The number in each bar indicates the number of sessions included and the horizontal line gives the median. The extent of the bar indicates the interquartile range and the extent of line indicates the extreme values. The second panel shows the same statistics for the first 19 sessions on the 18-hr delayed-reinforcement procedure. The third panel shows the result of continued exposure to the 18-hr delayed-reinforcement procedure. B2 was not continued so far in the experiment, hence there is no measurement given for it in the third panel.

continues although instances still occur frequently of key presses occurring at low rates and in the middle of long pauses.

B1 and B3 showed considerably less disruption by the long delay in reinforcement of the FR pattern of responding than B2. Figure 10 shows the cumulative records of the final 10 sessions for each baboon. Rates of responding are well maintained and of a fixed-ratio character except for the curvature, irregularities in the grain of the performance, and a rate of responding slightly lower than occurs typically under immediate reinforcement.

DISCUSSION

The first experiment demonstrated a stable performance, reliably maintained when a 24-hr interval was interposed between the response and reinforcement. The final performance was generated by using a large amount of food (equal to a two- or three-day food ration), a gradual increase in the delay of reinforcement (particularly during the early stages of the experiment), and a reduction in the size of the fixed-ratio schedule to values much smaller than those used at the start.

Even though the performance was maintained stably and continuously over many sessions, the behavior was weak under 24-hr delayed-reinforcement procedure. Pauses were characteristically a day or more in length and the large fixed ratios and long chains used early in the experiment could not be maintained. Even though rates of responding were bi-valued and the grain approximately of the character usually obtained with fixed-ratio schedules, the performances differed significantly from those usually recorded with immediate reinforcement. The performances under delayed reinforcement resemble those obtained with chained schedules, in which the first member is a fixed-ratio schedule reinforced by the stimulus for some other schedule of reinforcement (Ferster and Skinner, 1957).

The first experiment was designed to generate the phenomenon in the first instance. It was necessary, therefore, to adjust all possible variables as a function of their effect on the performance. Experiments II, III, and IV

were designed to find necessary conditions as compared with the sufficient conditions of Exp I.

The large amount of food delivered was necessary to keep the animals alive when the delay in reinforcement reached long intervals. Amount of food was probably also a factor in maintaining the performance; the reinforcing properties of a conditioned reinforcer depend upon the frequency of food reinforcement in its presence (Autor, 1964). The relation between the monkey's performance and its level of food deprivation does not appear to confirm the general findings in the literature between strength of response and level of food deprivation (Perin, 1942; Ferster and Skinner, 1957; Clark, 1958). Once the delayed-reinforced behavior became weak, loss in body weight from the lower frequency of reinforcement did not appear to increase the frequency of the behavior.

The second experiment showed that the performance could be maintained as well under a chained schedule as under the delayed-

Fig. 9. Cumulative response curves showing the final performance under 30-min delays in reinforcement (Record A), the transition to 18-hr delay in reinforcement (Record B), and the final performance (Record C). All of the records are included in the order they were recorded.

FINAL PERFORMANCE

Fig. 10. Final performance on 18-hr delay for B1 and B3 after a one-step transition from 10- and 30-min delay.

reinforcement procedures with comparable values of the two schedules.

With one monkey there was some evidence that the change to the chained schedule maintained the FR schedule better than with the delayed reinforcement. It seems reasonable to conclude, therefore, that accidentally reinforced behavior during the delay stimulus cannot be excluded even under these long delays. The accidentally reinforced behavior may be an explicit factor in maintaining fixed-ratio performance in the manner of the arguments of the previous experiments by Ferster (1953) and Azzi *et al.* (1964). If it is possible to maintain an explicitly reinforced response in the present experiment, it also seems likely that some behavior would be accidentally reinforced and maintained during the delay

procedure in an analogous manner. Such behavior might be some arbitrary response as turning in circles, as observed with the pigeons; or it could be as simple a performance as looking toward the food key from time to time. In either case it seems likely that the control of these responses by the white light (the delay stimulus) would give the white light the functions of a discriminative stimulus and hence help sustain the performance on the fixed-ratio component of the chain.

The fourth experiment showed that the performance maintained with long delays in reinforcement does not depend on a gradual, paced increase in the length of the delay. So long as the baboons were under close control of the various stimuli and contingencies of the delay paradigm and with a

large amount of food (200 pellets), the sudden increase in the length of the delay from 10 or 30 min to 18 hr left the repertoire intact, although weakened. This result is in contrast with the procedures of Exp I, where responding virtually ceased several times under shorter delays, even with a gradual development of the delay interval. The difference between the procedures of Exp I and IV lay in the amount of food delivered per reinforcement and the care with which the stimulus control was established before the delay in reinforcement was lengthened. The preparatory procedures of Exp IV were designed to develop some initial control by white light. This initial control was established by following the delay stimulus with the food-key light and by extending the white light interval by a time out whenever a response occurred. At this intermediate stage, the white light controlled a negative operant, as defined by Findley (1962). Thus, the delayed-reinforcement procedure was not begun until the delay stimulus already controlled some of the baboons' behavior and all of the discriminative control necessary in the final procedure was intact.

The long delays weakened the behavior considerably (although still maintaining it), compared with 30-min delayed-reinforcement procedure. The delay is not simply a time out, interrupting the chain as with a time out after food reinforcement. Rather, it appears to be equivalent to adding behavioral requirements as in the long chains with tokens generated by Kelleher (1957) and the long sequences of schedules chained by Gollub (1958) and Findley (1962). The analysis of behav-

iors maintained under delayed reinforcement would best be made, therefore, by appealing to the variables of which the reinforcing properties of stimuli and chains of responses are a function (Kelleher and Gollub, 1962).

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