

# Memory for patterning under a fixed-interval schedule of reinforcement

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The present study was an attempt to evaluate rats' long-term memory for patterning under a fixed-interval schedule of reinforcement. Rats were trained to respond for food under a multiple random-interval fixed-interval schedule of reinforcement. In the presence of one stimulus rats responded under a random-interval 40-sec schedule. In the presence of a second stimulus they responded under a fixed-interval 120-sec schedule, a schedule that engendered a postreinforcement pause followed by positively accelerated responding. During retention intervals of 3, 9, and 27 days, the rats continued responding under the random-interval schedule but not under the fixed-interval schedule. After the retention interval they were again exposed to the multiple schedule and responding in the fixed-interval component was evaluated for any loss of patterning. No loss of response patterning on the fixed-interval schedule was evident after a 27-day retention interval. The second part of the experiment was an attempt to interfere with the patterning by exposing rats to a random-interval 20-sec schedule in the presence of the stimulus previously associated with the fixed-interval schedule and then later testing for response patterning in the fixed-interval component. A loss of patterning was not evident after 1 to 8 interfering components, but patterning was degraded after 16 and 32 interfering components. The study suggests that rats have good long-term memory for schedule-controlled performance.

The study of animal memory has taken on great importance in recent years (e.g., Honig & James, 1971; Spear, 1978; Spear & Campbell, 1979). Although much of the research has examined animal short-term or working memory (e.g., Medin, Roberts, & Davis, 1976), a growing body of research has shown that animals may retain information over long periods of time. For example, Hoffman, Fleshler, and Jensen (1963) found that tonal generalization gradients in pigeons in a conditioned suppression procedure were relatively unchanged after 2.5 years. Gleitman and Holmes (1967), using a conditioned suppression procedure, found no retention decrement in rats after a 90-day retention interval. Rats have been shown to retain memory of reinforcement magnitude over long delays. Contrast effects were evident in a runway situation when rats were shifted from a large to a small reinforcer after a 26-day retention interval but not after a 68-day retention interval (Gonzalez, Fernhoff, & David, 1973). Rats have also been shown to retain information about spatial locations for relatively long periods of time (Olton, 1978).

The present study was an attempt to evaluate rats' memory for schedules of reinforcement. Each schedule of reinforcement generates its own unique pattern of responding (Ferster & Skinner, 1957). For example, a fixed-ratio schedule produces a postreinforcement pause followed by a high constant response rate, and a fixed-interval (FI) schedule engenders a postreinforcement

pause followed by positively accelerated responding. Researchers have used schedules of reinforcement to study behavioral processes for decades, and it is known that animals retain knowledge of appropriate schedule performance from day to day. However, the extent to which memory for reinforcement schedules is retained over longer periods of time has not been systematically evaluated. Gleitman and Bernheim (1963) trained rats for 3 days on an FI 1-min schedule and examined fixed-interval patterning after a 24-day retention interval. After a 24-day layoff, rats showed a loss of patterning as a result of an increase in response rate during the first half of the fixed-interval. In the present study, we trained rats to respond on a multiple random-interval (RI) FI schedule of reinforcement for an extended period of time and then tested for retention of schedule-controlled performance. In the presence of one stimulus the rats responded under an RI 40-sec schedule, a schedule expected to generate a high constant response rate. In the presence of a second stimulus the rats responded under an FI 120-sec schedule, a schedule expected to generate a postreinforcement pause followed by positively accelerated responding. During a retention interval the rats continued responding under the RI schedule but not under the FI schedule. After the retention interval, the rats were again exposed to the multiple schedule and responding in the FI component was evaluated for any loss of patterning. The first part of the experiment revealed no loss of response patterning in the FI schedule after a 27-day retention interval. The second part of the experiment was an attempt to interfere with the patterning by exposing rats to an RI schedule in the presence of the stimulus previ-

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ously associated with the FI schedule and then later testing for response patterning in the FI component (retroactive interference).

## METHOD

### Subjects

Four male Sprague-Dawley rats (Camm Research) were maintained at 80% (288 to 340 g) of their free-feeding body weights throughout the experiment. The rats were given free access to water, were individually caged, and were kept on a 12:12-h light/dark cycle with lights on at 0600. The rats had previously been used by students in an experimental psychology class and were trained to press a lever for food on continuous reinforcement, fixed-ratio, and variable-ratio schedules.

### Apparatus

Four identical modular operant conditioning chambers for rats (Coulbourn Instruments) were housed in sound-attenuated cubicles. Each chamber had a food cup in the bottom center of the work panel, and the response lever was situated to the right of the food cup 22 mm from the side wall and 28 mm above the grid floor. A minimum force of approximately 0.24 N was required to operate the response lever. A 28-V houselight was located above the food cup near the top of the chamber. Reinforcement was delivered by a Gerbrands pellet feeder. White noise was continuously present to mask extraneous noise. Experimental sessions were controlled by an IBM-PC, Coulbourn Instruments Lab-Linc interface, and Pascal programming.

### Procedure

Each rat was randomly assigned to an operant chamber. The rats first received one session of an RI 10-sec schedule of reinforcement. In the presence of the houselight, the first response after an average of 10 sec delivered a 45-mg Noyes food pellet, turned off the houselight, and turned on the white feeder light for 5 sec. The rats were given one session of RI 20-sec, one session of RI 30-sec, and six sessions of multiple RI 30-sec FI 30-sec schedules. In the multiple schedule, the first response in Component 1 (steady houselight) after an average of 30 sec delivered food, and the first response after 30 sec in Component 2 (houselight flashing on for 0.3 sec and off for 0.3 sec) also delivered food. Component 1 was 120 sec in duration. Component 2 terminated following the delivery of food. A 10-sec blackout separated components. Each session started with Component 1 (RI 30-sec), and the two components alternated throughout the session. Responses during the 10-sec blackout and 5-sec feeder cycle had no scheduled consequences. Each session terminated after 20 total components. Next, the FI schedule was increased to 60 sec (multiple RI 30-sec FI 60-sec) for four sessions and then to 90 sec (multiple RI 30-sec FI 90-sec) for eight sessions. The RI schedule was increased to 40 sec (minimum of 0 sec, maximum of 80 sec) and the FI to 120 sec for four sessions. The rats were then maintained on a multiple RI 40-sec FI 180-sec schedule for 18 sessions, and each session terminated after a total of 24 components. The FI schedule terminated automatically without food after 240 sec if no response was emitted during Component 2 (a limited-hold 60 sec).

For the next 21 sessions the multiple RI 40-sec FI 180-sec schedule was arranged so that the first six components were RI 40-sec, the second six FI 180-sec, the third six RI 40-sec, and the last six FI 180-sec. Because of low response rates in the FI component, the FI was reduced to 120 sec. The rats were maintained on this multiple RI 40-sec FI 120-sec schedule for 58 sessions before the first delays were introduced. Sessions were conducted 7 days a week.

**Delay intervals.** Following the 58th session of the multiple RI 40-sec FI 120-sec schedule, the rats were given two daily sessions, in each of which they were exposed to only six components of the RI 40-sec schedule. On the following session (FI delay of 3 days) the multiple RI 40-sec FI 120-sec schedule was reinstated. After five sessions of the multiple schedule, the rats were given eight (six-component) sessions of the RI 40-sec schedule only, followed again by the multiple schedule (FI delay of 9 days). After five sessions of the multiple schedule, the rats were given 26 (six-component) sessions of the RI 40-sec schedule only, followed again by the multiple schedule (FI delay of 27 days).

**Interference.** In an attempt to interfere with fixed-interval patterning, the multiple schedule was arranged so that an RI 20-sec schedule, rather than the FI 120-sec schedule, was programmed in Component 2. Each RI 20-sec component was in effect for 120 sec in the presence of the flashing houselight. The first interference condition had six RI 40-sec components followed by one RI 20-sec component before the session terminated. The second interference condition had six RI 40-sec followed by two RI 20-sec components. The third condition had six RI 40-sec followed by four RI 20-sec components. The fourth condition had six RI 40-sec, six RI 20-sec, six RI 40-sec, and two RI 20-sec components (a total of eight RI 20-sec interference components). The fifth condition was in effect for two sessions: The first session had six RI 40-sec, six RI 20-sec, six RI 40-sec, and six RI 20-sec components. The second session had six RI 40-sec followed by four RI 20-sec components (a total of 16 RI 20-sec components). The last interference condition included 32 RI 20-sec components over three sessions. On the day after each interference condition, a regular multiple-schedule session was conducted in which the FI 120-sec schedule was again contained in Component 2. At least two regular sessions were conducted between interference conditions.

## RESULTS

The data of interest were those that reflected fixed-interval patterning in the FI 120-sec component of the multiple schedule. In this report we analyzed the index of curvature and postreinforcement pause within the FI 120-sec schedule. Responses within sixths of the FI 120-sec schedule were recorded and the index of curvature was computed. The index of curvature is a statistic that reflects the degree of positively accelerated patterning within FI schedules (Fry, Kelleher, & Cook, 1960). A value of 0 indicates a constant response rate across segments of the FI, and higher values (reaching 0.83 when the fixed interval is divided into sixths and all responding is limited to the last segment) indicate greater curvature. Postreinforcement pause was the time accumulated from the onset of each FI 120-sec component until the second response.

### Delay Intervals

Figure 1 shows the effects of interposing delays of 3, 9, and 27 days between sessions of the FI 120-sec schedule. Baseline data were taken from the multiple RI 40-sec FI 120-sec session immediately preceding each delay condition. The average baseline index of curvature in the FI 120-sec schedule for the 4 rats ranged from 0.33 to 0.40, and the average postreinforcement pause ranged from 28 to 49 sec. The data in the body of the figure are from the first regular multiple schedule session following each delay condition. Figure 1 shows that delays of up to 27 days had no effect on the index of curvature or on the postreinforcement pause in the FI 120-sec schedule. A one-way repeated measures analysis of variance also showed no significant change in index of curvature [ $F(2,6) = 0.18$ ] or postreinforcement pause [ $F(2,6) = 2.85$ ]. Baseline absolute response rate in the FI component for the 4 rats ranged from 11 to 28 responses/min. Absolute response rate in the FI component was generally lower than the baseline response rate following each delay interval. A high constant response rate was observed in the RI component of the multiple schedule.

**Interference**

Figure 2 shows the effects of substituting up to 32 RI 20-sec components for the FI 120-sec components. Baseline data were taken from the multiple RI 40-sec FI 120-sec session immediately preceding each interference condition. The average baseline index of curvature in the FI 120-sec component for the 4 rats ranged from 0.38 to 0.44, and the average postreinforcement pause ranged from 39 to 57 sec. The data in the body of the figure are from the first regular multiple schedule session following each interference condition. Figure 2 shows that as the number of interfering components increased there was a decrease in the index of curvature and the postreinforcement pause. A one-way repeated measures analysis of variance showed a significant decrease in index of curvature [ $F(5,15) = 8.76, p < .01$ ] and postreinforcement pause [ $F(5,15) = 8.15, p < .01$ ] across the 32 interfering components. There appeared to be little change in these measures until 16 and 32 interfering components had been presented. Posttests (Tukey's) revealed that indexes of curvature following 1, 2, 4, and 8 interfering components were significantly higher ( $p < .05$ ) than cur-

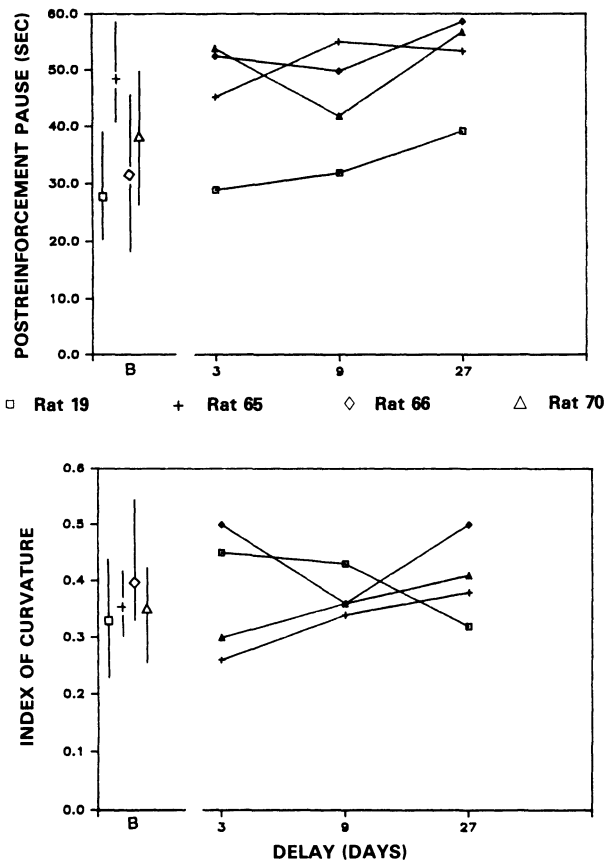


Figure 1. Postreinforcement pause and index of curvature under the fixed-interval 120-sec component of the multiple schedule following 3-, 9-, and 27-day retention intervals (delay). During the retention interval rats were exposed only to the random-interval 40-sec component of the multiple schedule. The data above the B represent the mean and range postreinforcement pause and index of curvature during baseline sessions.

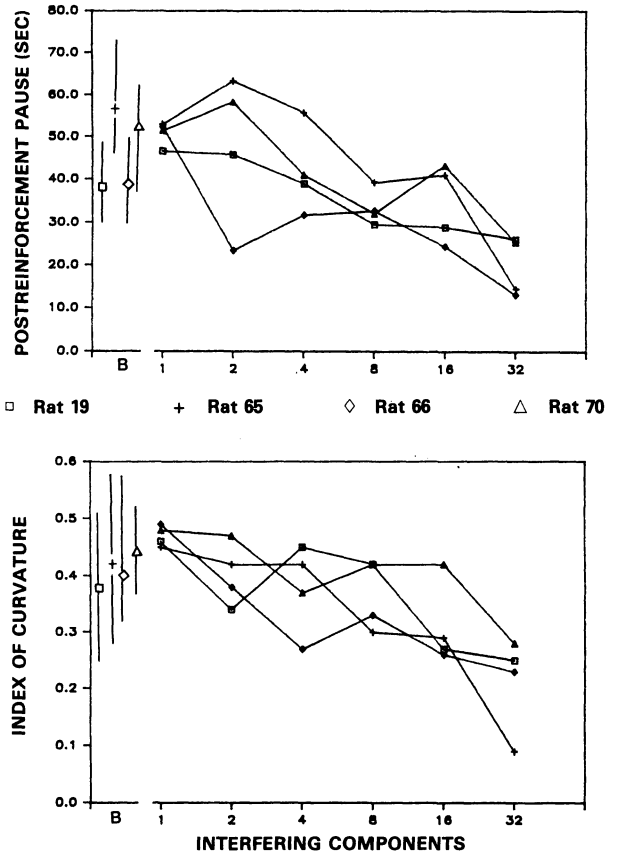


Figure 2. Postreinforcement pause and index of curvature under the fixed-interval (FI) 120-sec component of the multiple schedule following 1 to 32 interfering components. During an interfering component rats were exposed to a random-interval 20-sec schedule in the presence of the stimulus previously associated with the FI 120-sec schedule. The data above the B represent the mean and range postreinforcement pause and index of curvature during baseline sessions.

vature following 32 interfering components and that curvature after 1 component was higher ( $p < .05$ ) than after 16 components. The postreinforcement pauses following 1, 2, and 4 interfering components were significantly longer ( $p < .05$ ) than the pause following 32 components. Baseline absolute response rate in the FI component for the 4 rats ranged from 10 to 24 responses/min. Absolute response rate in the FI component was generally higher than baseline response rate following each interference condition.

**DISCUSSION**

In the present study, rats were given extensive training on a multiple schedule of reinforcement. A high constant response rate was observed in the presence of a stimulus associated with an RI 40-sec schedule. Typical fixed-interval response patterning was observed in the presence of a stimulus associated with an FI 120-sec schedule: a postreinforcement pause followed by positively accelerated responding. For periods of 3, 9, and 27 days the rats responded on only the RI 40-sec schedule, and memory for the FI 120-sec schedule was then assessed: The rats showed no loss of response patterning in the FI component following

any retention interval. Studies have shown that rats retain information over long periods of time for magnitudes of reinforcement (Gonzalez et al., 1973), spatial events (Olton, 1978), and stimuli associated with shock in a conditioned suppression procedure (Gleitman & Holmes, 1967). The present data show that rats also retain memory for schedule-controlled performance over relatively long retention periods. Gleitman and Bernheim (1963) reported a disruption in fixed-interval patterning after a 24-day retention interval, a disruption that resulted from an increase in response rate during the early portion of the fixed interval. However, the rats in that study were given only 3 days of training on the FI schedule before the retention period. The rats in the present study had an extensive period of training before retention tests began. We also observed a decrease, rather than an increase, in absolute response rate during the first session following a retention interval.

Not only did the rats in the present study maintain good fixed-interval response patterning after a 27-day layoff, but patterning proved relatively resistant to disruption from the interfering effects of another schedule of reinforcement. In the presence of the stimulus associated with the FI schedule, the rats were exposed to 1 to 32 components of an RI 20-sec schedule of reinforcement. On the day after the presentation of the interfering components, the rats were reexposed to the FI 120-sec schedule and patterning was evaluated. Relatively little change in post-reinforcement pause and index of curvature was observed until 32 interfering components were presented. Even after the presentation of 32 RI 20-sec components, a substantial degree of fixed-interval response patterning was observed. Thus, not only was long-term memory for fixed-interval patterning evident, but it was relatively resistant to the effects of retroactive interference.

Studies have shown that memory for events may be maintained over long periods of time if subjects are reexposed to stimuli associated with the originally learned task (Campbell & Jaynes, 1966; Campbell & Randall, 1976; Silvestri, Rohrbaugh, & Riccio, 1970). For example, rats trained on a multiple variable-interval 15-sec extinction schedule of reinforcement retained the light/dark discrimination better when they were periodically exposed to the schedule or to stimuli associated with the schedule (Campbell & Randall, 1976). In the present study, fixed-interval response patterning may have been quickly reinstated following delays or interfering components when rats were reexposed to the first or second FI component of the session. Another possibility is that daily exposure to the stimuli associated with Component 1 may have helped to reinstate memory for the schedule associated with Component 2.

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