JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR VOLUME 7, NUMBER 1 JANUARY, 1964

ADJUSTING FIXED-RATIO SCHEDULES IN THE SQUIRREL MONKEY

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On an adjusting schedule of reinforcement, a parameter of the schedule is varied as a function of some characteristic of the animal's performance. In Experiment I, the fixed-ratio response requirement was varied as a function of the time that elapsed before the animal started responding in each fixed-ratio (initial pause). When initial pauses were shorter than a specified duration, the response requirement was increased; when they were longer than the specified duration, the response requirement was decreased. Specified durations of 1, 2, 4, 8, and 15 min were studied. The average response requirement maintained by each monkey was directly related to the length of the specified duration of initial pause. In Experiment II, the fixed-ratio response requirement was constant, but reinforcement occurred only when the initial pause was longer than a specified duration. The average durations of initial pauses were directly related to the length of the specified duration and to the response requirement. Meprobamate consistently decreased the average durations of initial pauses.

On fixed-ratio (FR) schedules of reinforcement, the animal is reinforced whenever it completes a specified number of responses (the response requirement). Performance on FR schedules is characterized by an initial pause followed by an abrupt change to a high response rate maintained until reinforcement; the average duration of the initial pause is directly related to the FR response requirement (Ferster and Skinner, 1957). The phenomenon of long initial pauses at large response requirements is called ratio strain.

On an adjusting FR schedule of reinforcement, the response requirement is varied as a function of the animal's performance. For example, Ferster and Skinner (1957) described an adjusting FR schedule in which the response requirement was varied as a function of the initial pause in each ratio. During the initial pause, the response requirement slowly decreased; the first response increased the requirement by five responses. If initial pauses were long, the FR response requirement would be low; however, the frequency of reinforcement would be limited by the duration of the initial pauses. If the animal continuously responded at a high rate, the frequency of reinforcement would be high at a given response requirement; however, the response requirement would be continually increasing. The birds did not go to either of these extremes. Each pigeon adjusted to FR response requirements of about 400 responses without developing prolonged initial pauses.

An adjusting schedule can be considered as comprising two component schedules. For example, an adjusting FR schedule comprises both the basic FR schedule of primary reinforcement and the schedule that varies some parameter of the FR schedule. Ferster and Skinner (1957) noted that in their adjusting FR schedule, the schedule that varied the FR value had some of the characteristics of an interval schedule; *i.e.*, the probability of reinforcement increased as a function of time since the previous reinforcement.

The purpose of the present experiments was to analyze adjusting FR schedules of the type described by Ferster and Skinner (1957) in terms of their component schedules. The results suggest that this type of adjusting schedule can be considered as a second-order schedule in which FR performance is reinforced according to a DRL schedule.

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METHOD

Subjects

Three male squirrel monkeys (*Ss*) were maintained at 75 to 80 per cent of their free-feeding weights, which ranged from 603 to 648 g. The *Ss* had previously been trained on ratio schedules ranging up to FR 200.

Apparatus

The 9 by 9 by 7.5 in. experimental chamber was enclosed in a picnic icebox; the icebox was enclosed in a large ventilated chamber that almost completely attenuated extraneous sounds (Gill, Fry, and Kelleher, 1962). An aluminum lever[2] was mounted in the wall of the experimental chamber. When *S* pressed the lever with a force of 14 g or more, a response was recorded. During experimental sessions, two 6-w lamps provided general illumination, and each response produced the audible click of a relay. The reinforcement was 8-sec access to 0.5 cc of liquid food (Herndon, Greenberg, Van Loon, Kelleher, Cook, and Davidson, 1958). A solenoid operated dipper delivered the food to a small recessed cubicle below and to the right of the lever. During reinforcement, the experimental chamber was dark, while the recessed cubicle was illuminated by a 6-w lamp.

General Procedure

Experimental sessions were conducted daily from Monday through Friday. On weekends, supplementary feedings maintained *Ss* at appropriate body weights. Water was continuously available in the home cage and in the experimental chamber. Durations of the daily sessions were 3 hr for Monkeys K38 and K14 and 5 hr for Monkey K12.

Experiment I

The purpose of this experiment was to determine the FR value to which *Ss* would adjust as a function of the specified duration of the initial pause.

Procedure. The FR response requirement could range from a minimum of 10 to a maximum of 1,000, taking the following arbitrarily chosen intermediate values: 50, 100, 110, 130, 160, 200, 250, 310, 380, 460, 550, 650, 750, and 870. The response requirement increased whenever two successive initial pauses were shorter than the specified duration. The response requirement remained constant if initial pauses shorter than the specified duration alternated with initial pauses longer than the specified duration. The response requirement decreased whenever two successive initial pauses were longer than the specified duration; however, at FR 1,000 a single pause longer than the specified duration decreased the response requirement to FR 870. Each session started at FR 10. Required initial pause durations (required pauses) of 1, 2, 4, 8, and 15 min were studied. The number of sessions at each required pause are shown in Table 1.

Table 1

Sessions in which different required pause times (min.) were in effect in Experiment I.

Sessions	*Required Pause*	*Sessions*	*Required Pause*
1-17	2	42-78	4
18-27	1	79-87	2
28-33	4	88-104	1
34-41	8	105-127	15

Results. The cumulative response records in Fig. 1 show representative performances for Monkey K38 at various required pauses. The required pause for each record is indicated by the scale at the upper left of each frame of the figure. For example, in the upper frame of Fig. 1, the required pause was 1 min. Each of the first eight reinforcements in the session shown in this frame were obtained before an initial pause exceeded 1 min. Thus, the response requirement increased from FR 10 for the first reinforcement to FR 250 for the eighth reinforcement. Then, the response requirement remained at FR 250 for several reinforcements because initial pauses of more than 1 min alternated with initial pauses of less than 1 min. In a later part of this record, successive initial pauses of more than 1 min reduced the response requirement to FR 10 again.

As shown in Fig. 1, at the start of each session the response requirements increased rapidly until a relatively large response requirement was in effect. For the remainder of each session, there were cycles of decreasing and increasing response requirements. As the required pause was increased, however, higher maximum response requirements were reached early in each session, and fewer pauses ex-

[2]The lever was manufactured by Lehigh Valley Electronics, Allentown, Pa. (LVE 1352 rat lever).

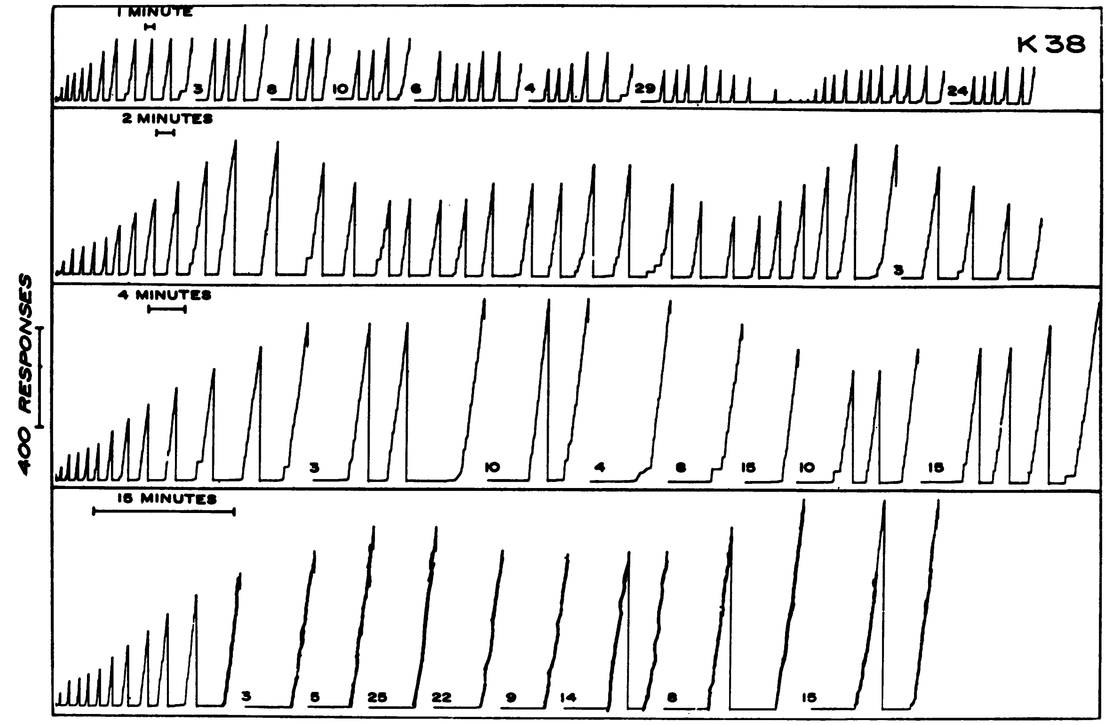

Fig. 1. Representative performances of Monkey K38 at various required pause times; the required pause times are indicated in each frame of the figure. The ratio values could range from FR 10 to FR 1,000; each session started at FR 10. Where the records are broken, the numbers indicate the minutes of pausing that have been omitted from the record. The recording pen reset to the bottom of the record following each reinforcement; the recorder did not run during reinforcement.

ceeded the required pause. Note that many of the record segments have a step-like appearance.

Figure 2 shows representative performances for Monkey K12. In general, these records are similar to those of Monkey K38. In the records of Monkey K12, however, the step-like appearance of many ratio segments is more apparent (as at *a*, *b*, *c*, and *d*). This resulted from runs of responses at a very high rate alternating with brief pauses.

Figures 3 and 4 show representative performances for Monkey K14. At required pauses ranging from 1 min to 15 min, the performances of Monkey K14 were similar to those of other animals. At the required pause of 15 min, however, Monkey K14 characteristically paused briefly following reinforcement and then responded at a stable rate of about 40 responses per min. Because of this response pattern, Monkey K14 maintained FR 1,000 throughout most of each session.

Figure 5 summarizes the results of this experiment. The graph shows the mean FR value (the number of responses per reinforcement for each session) as a function of required initial pause duration. Each point is the median of the mean ratios from the last five sessions at each required duration. The solid lines show determinations from Sessions 1-41; the dashed lines show determinations from Sessions 42-127. Because sessions began at FR 10, the mean ratios in Fig. 5 are all lower than they would be if the first part of each session were excluded in computing the mean. The mean ratio is directly related to the required pause time.

Discussion. This adjusting FR schedule can be analyzed in terms of frequency of reinforcement. By assuming that each *S* makes three responses per second following the initial pause (a reasonable empirical value), the maximum number of reinforcements possible in a 3 hr session if *S* adopted a particular pattern of pausing and responding, can be computed. Table 2 presents these values for four of the many possible patterns. Adjusting the ratio between FR 10 and FR 50 through-

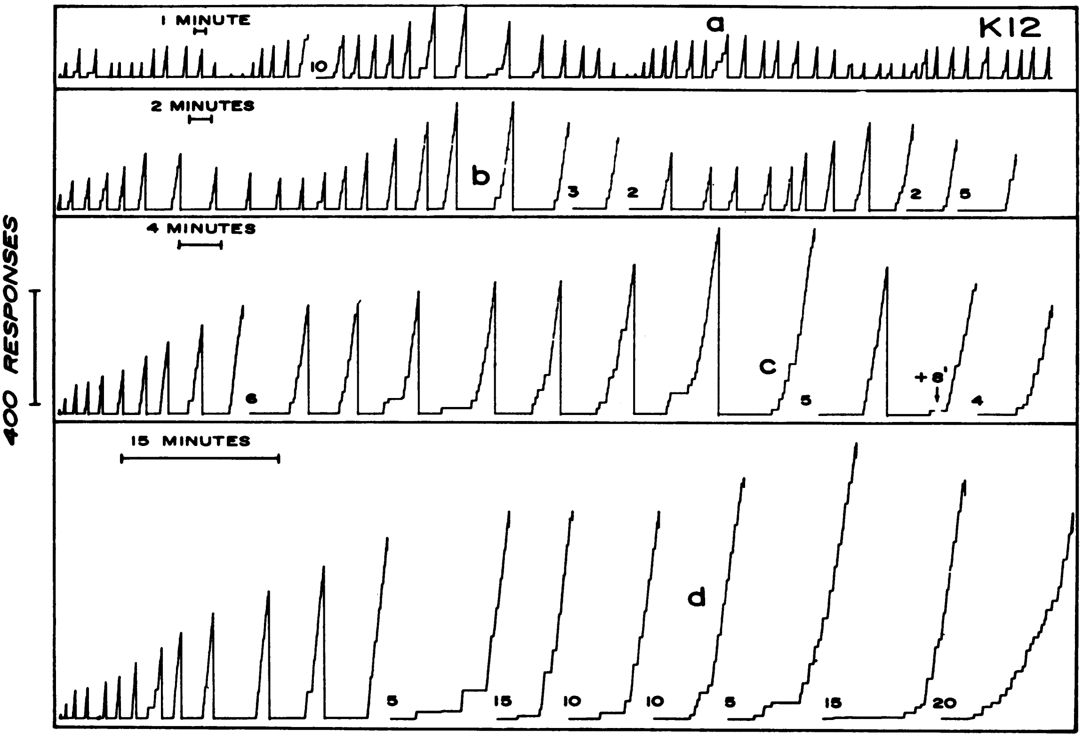

Fig. 2. Representative performances of Monkey K12 at required pause times ranging from 1 to 15 min.

out each session is the optimal pattern for maximizing reinforcement at required pauses up to 8 min. The results show, however, that *S* maintained FR 100 or higher even at a 1-min required pause. At an 8-min required pause, *S*s would receive almost as many reinforcements by responding continuously as by adjusting between FR 10 and FR 50; at a 15-min required pause, continuous responding maximized the number of reinforcements. Monkey K14 did respond continuously at the 15-min required pause, but with a relatively low response rate; the other two *S*s paused extensively.

Table 2

Maximum number of reinforcements that could be obtained in a 3-hr session if the monkey adopted particular patterns of pausing and responding. It is assumed that the response rate is three per second when the monkey is responding.

	Required Pause (Min.)				
Response Pattern	*1*	*2*	*4*	*8*	*15*
Continuous Responding	42	42	42	42	42
Maintain 10	163	87	49	23	13
Adjust 10-50-50-10	272	156	84	44	24
Adjust 10-50-100-100-50-10	228	138	78	42	24

Two characteristics of the adjusting FR schedule probably opposed the development of optimal patterns of pausing and responding at required pause times of 8 min or less. First, each session started at FR 10, and continuous responding over the first few minutes of the session resulted in a relatively high frequency of reinforcement. Thus, each *S* usually reached a response requirement of FR 100 or more before an initial pause was longer than the required pause. Second, it was apparently difficult for the S to pause for only slightly longer than the required pause. Presumably this difficulty increased as the required pause was increased. Both of these characteristics of the

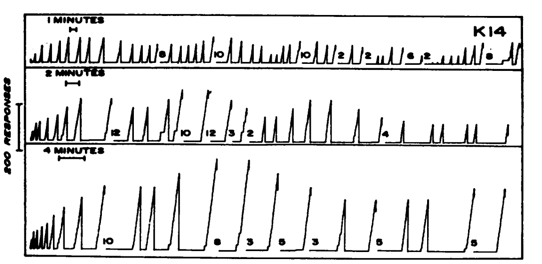

Fig. 3. Representative performances of Monkey K14 at required pause times ranging from 1 to 4 min.

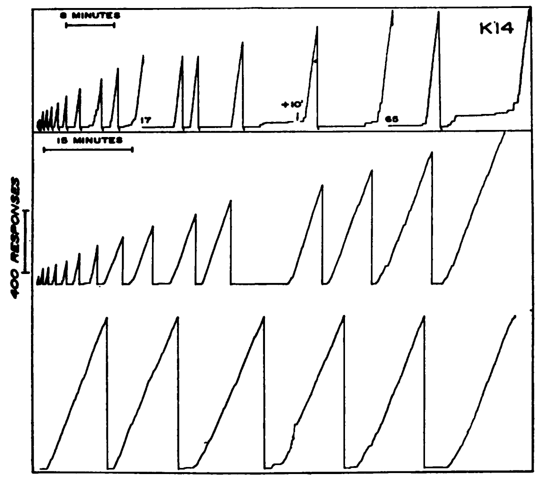

Fig. 4. Representative performances of Monkey K14 at required pause times of 8 and 15 min.

schedule would favor the development of continuous responding. On the other hand, if *S* responded continuously, FR 1,000 was in effect for most of each session. On any simple FR schedule, continuous responding results in the highest frequency of reinforcement; however, ratio strain usually begins to occur as FR values are increased beyond FR 100. Thus, the characteristics of the FR schedule alone opposed the development of continuous responding.

If maximum possible frequency of reinforcement at required initial pauses of 1, 2, or 4 min is considered, the schedule that varies the FR is similar to a DRL schedule (Ferster and Skinner, 1957)[3]. On a DRL schedule a response is reinforced only when a specified period of time has elapsed since the preceding response. On the adjusting FR, as on the DRL, the maximum frequency of reinforcement occurs when the animal adopts a particular pattern of pausing and responding. In Exp. I, however, the high frequency of reinforcement for continuous responding at the start of each session and the possible development of ratio strain make it difficult to analyze the similarities between a DRL schedule and the schedule that varies the FR.

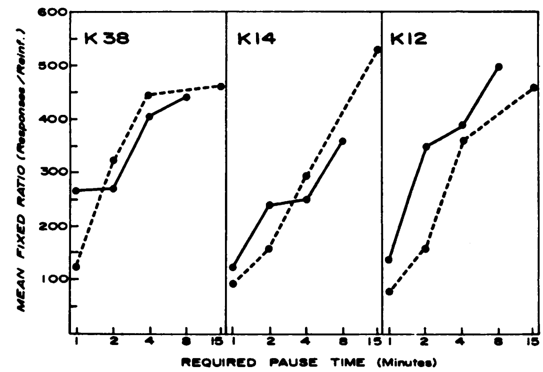

Fig. 5. Mean FR values at each required pause time for each monkey. Each point is the median of the mean ratios from the last five sessions at a required pause time. The points connected by solid lines are from Sessions 1-41; those connected by dashed lines are from Sessions 42-127.

Experiment II

In this experiment, the relationship between the FR schedule and the schedule that adjusts it was simplified by adjusting reinforcement rather than the FR value. The purpose was to study the durations of initial pauses as a function of both required pause and ratio value, and to study the effects of meprobamate (Miltown®) on this adjusting schedule.

Procedure. The ratio value was held constant in each session. When the initial pause was longer than a required pause, the ratio terminated with reinforcement. When the initial pause was shorter than the required pause, the ratio terminated with a 0.5 sec time-out (dark experimental chamber). Required pauses of 1 min and 2 min were studied at FR 200; ratio values of FR 100, FR 200, and FR 300 were studied at a 2 min required pause. The procedure is summarized in Table 3.

Table 3

Sessions in which different required pause times and FR values were in effect in Experiment II.

Session	*Required Pause (Min.)*	*FR*
1-7	1	200
8-17	2	200
18-23	2	300
24-42	2	100

Meprobamate was orally administered to Monkeys K38 and K14 just before Session 34 and to Monkey K12 just before Session 42. Previous results had shown that a dose of 50 mg/kg would increase the response rates of

[3]Following the notation of Skinner and Morse (1958), DRL is used here as equivalent to *crf drl* as used by Ferster and Skinner (1957).

monkeys on simple DRL schedules. The drug was suspended in a 0.5 per cent gum tragacanth solution. The volume of solution administered was always less than 1 ml. Comparable volumes of gum tragacanth solution were administered just before the preceding session (control).

Results. The results for Monkey K38 are presented in detail to show both transitional effects and final performances. Figure 6 shows performance on FR 200 with required pauses of 1 min and 2 min. The recording pen reset to the bottom of the record at the completion of each ratio. The small solid circles at the top of some record segments indicate reinforcements. Beginning in Session 4, the duration of the initial pause in each ratio was recorded, and pause time distributions were computed for each session.

The relative frequencies of different pause times are shown in the histograms at the left of each cumulative response record. In the upper frame of Fig. 6, the first 10 bars of the histogram represent 6-sec class intervals (6″ CI). The eleventh bar indicates the relative frequency of initial pauses of more than 1-min and corresponds to the relative frequency of reinforced ratios. In Session 4, only about 35 per cent of the ratios have initial pauses of more than 1 min. By Session 7, however, more than 80 per cent of the initial pauses were longer than 1 min. Although the histogram does not indicate the actual durations of the pauses of more than 1 min, inspection of cumulative response records from Session 7 indicated that they ranged up to 2 min.

In Sessions 8 to 17, FR 200 was still in effect but the required pause was increased to 2 min. In the lower frame of Fig. 6 each of the first 10 bars of the histogram represent 12-sec class intervals; the eleventh bar shows the relative frequency of pauses of more than 2 min. The relative frequency distribution for Session 8 is bi-modal. The mode between 1 and 2 min suggests persistence of the response pattern that had developed at the 1-min required pause. The mode at more than 2 min indicates that the response pattern was chang-

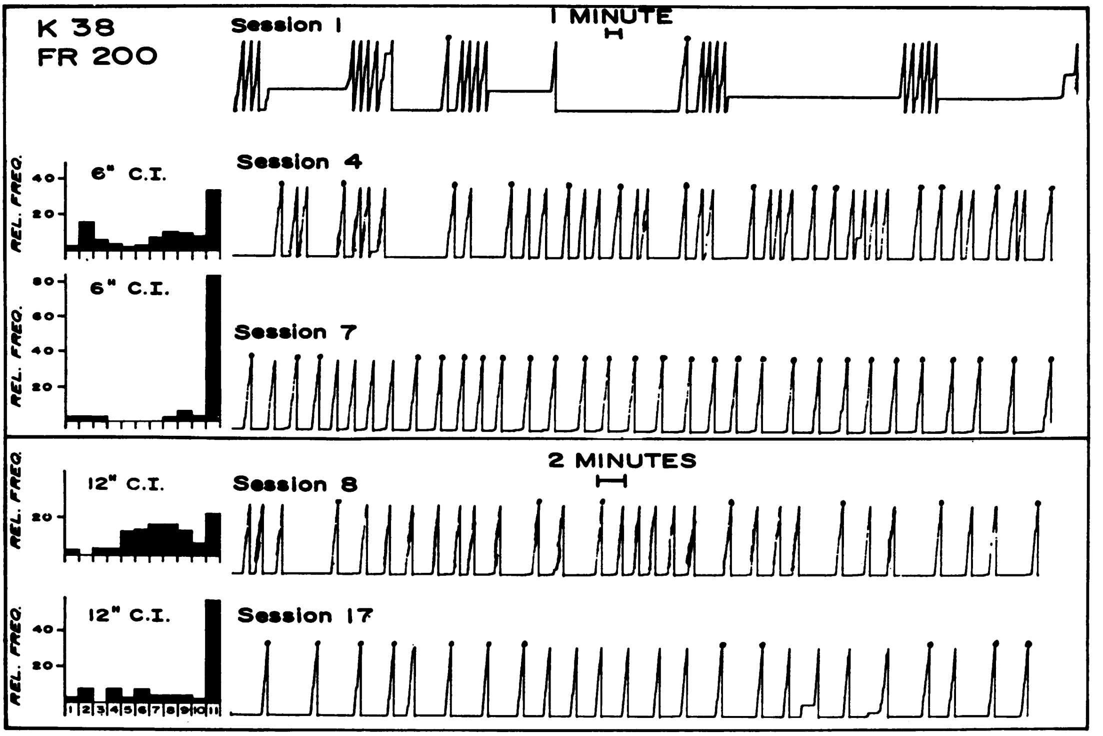

Fig. 6. Development of performance of Monkey K38 at FR 200 with required pauses of 1 min (upper frame) and 2 min (lower frame). The solid circles indicate ratios that were reinforced; the other ratios were terminated by a 0.5-sec time-out. The recorder did not run during time-outs or reinforcements. The relative frequencies of different initial pause times are shown in the histogram at left. The class intervals are shown above each histogram.

ing, probably because the frequency of reinforcement in Session 8 was lower than in Session 7. In Session 17 about 58 per cent of the pauses were longer than 2 min; inspection of the cumulative response records indicated that pauses ranged up to 2.5 min.

In Sessions 18 to 23 the required pause was held at 2 min; however, the response requirement was increased to FR 300. Results from Sessions 18 and 23 are shown in the upper frame of Fig. 7. An increase in the relative frequency of pauses longer than 2 min occurred in Session 18. By Session 23 almost all initial pauses exceeded 2 min; inspection of the cumulative response records indicated that these pauses actually ranged up to 3 min.

In Sessions 24 to 42 the required pause was held at 2 min, and the response requirement was decreased to FR 100. The results are shown in the lower frame of Fig. 7. In Sessions 24 and 25 the *S* frequently completed two or three ratios in rapid succession. By Session 40, the ratios were more evenly spaced; however, many initial pauses ranged from 72 sec to 119 sec. The relative frequency of reinforced ratios ranged from 25 to 60 per cent in different sessions. Results obtained with Monkeys K12 and K14 were generally comparable; however, Monkey K14 occasionally responded at intermediate rates (see control records in Fig. 9 and 10).

Figures 8, 9, and 10 show the effects of meprobamate on the performance of each *S*. In each figure, a comparison of the cumulative response records and pause time distributions in the upper and lower frames shows that meprobamate increased average response rates by decreasing the durations of initial pauses.

Discussion. On DRL schedules there is a required pause between single responses; the relative frequency of pauses longer than the required pause is inversely related to the

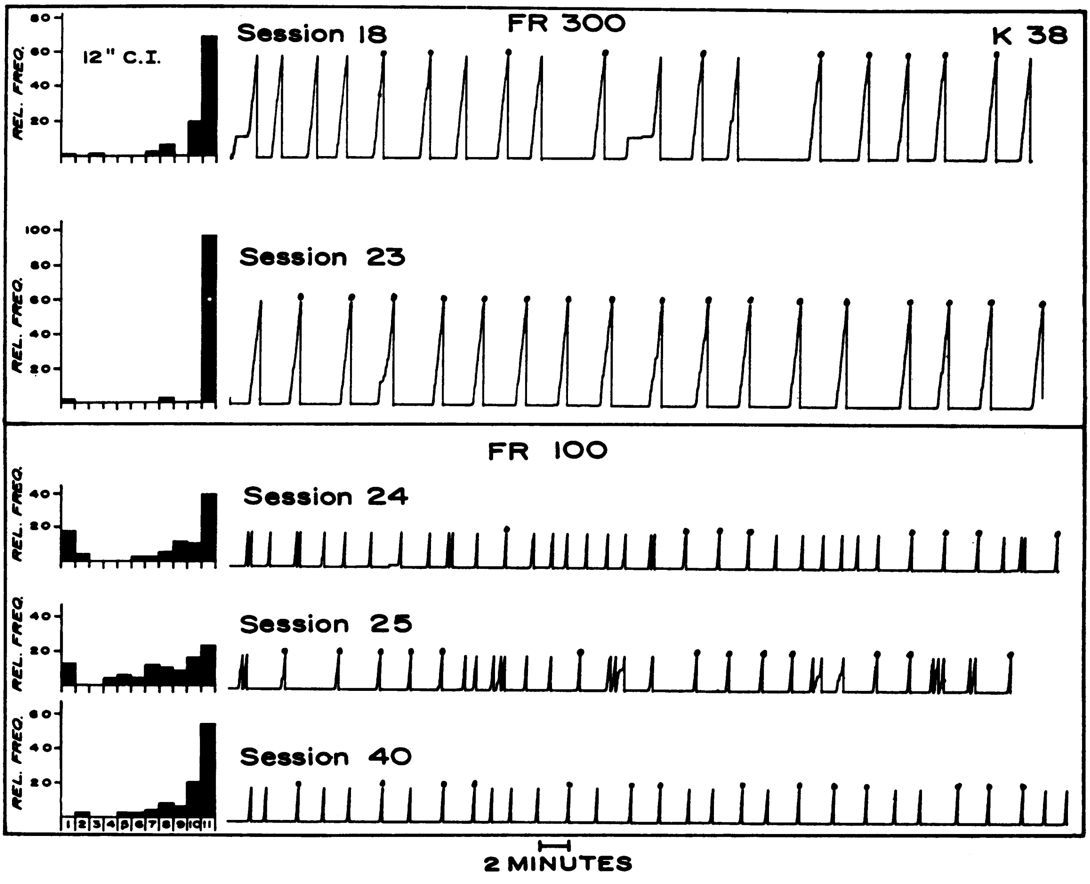

Fig. 7. Development of performance of Monkey K38 with a required pause of 2 min at FR 300 (upper frame) and FR 100 (lower frame).

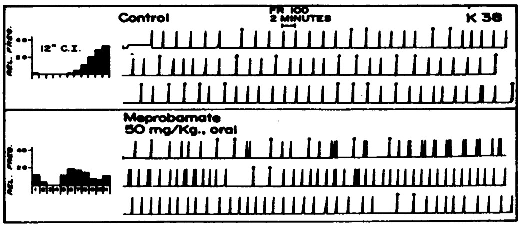

Fig. 8. The effects of meprobamate on the performance of Monkey K38 at FR 100 with a required pause of 2 min.

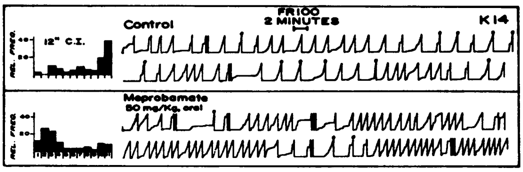

Fig. 9. The effects of meprobamate on the performance of Monkey K14.

length of the required pause. Although there is no required pause on FR schedules, the average durations of initial pauses are directly related to the size of the ratio. On the adjusting FR schedule used in Exp. II there was a required pause between ratios; *i.e.*, the FR was treated as a unit of behavior that was reinforced according to a DRL schedule. When the required pause was increased from 1 min to 2 min at FR 200, and when the ratio was increased from FR 200 to FR 300, the average durations of initial pauses increased. The opposite effect occurred when the ratio was decreased from FR 300 to FR 100.

The results of Exp. II support the notion that the adjusting FR schedule is a type of second-order schedule involving a combination of DRL and FR schedules. The characteristics of FR and DRL schedules suggest that, as the ratio value is increased at a given required pause, performances should be increasingly similar to performances on an FR schedule; as the ratio value is decreased, performances should be increasingly similar to those on a DRL schedule. (Of course, at the extreme value of FR 1, the adjusting FR schedule is identical with the DRL schedule.)

At FR 300 with a 2-min required pause, almost all initial pauses were longer than 2 min; however, at FR 100 with a 2-min required pause, there was a relatively high frequency of initial pauses shorter than 2 min. Presumably, as the ratio is decreased, the results are less influenced by ratio strain and more influenced by the required pause.

The results of Exp. II show, that as the ratio was decreased from FR 300 to FR 100, the relative frequency distributions of initial pause times became more similar to the distributions of interresponse times on DRL schedules. Nevertheless, the results suggest that the required pause was having an effect even at FR 300. It is characteristic of FR strain that the durations of the individual initial

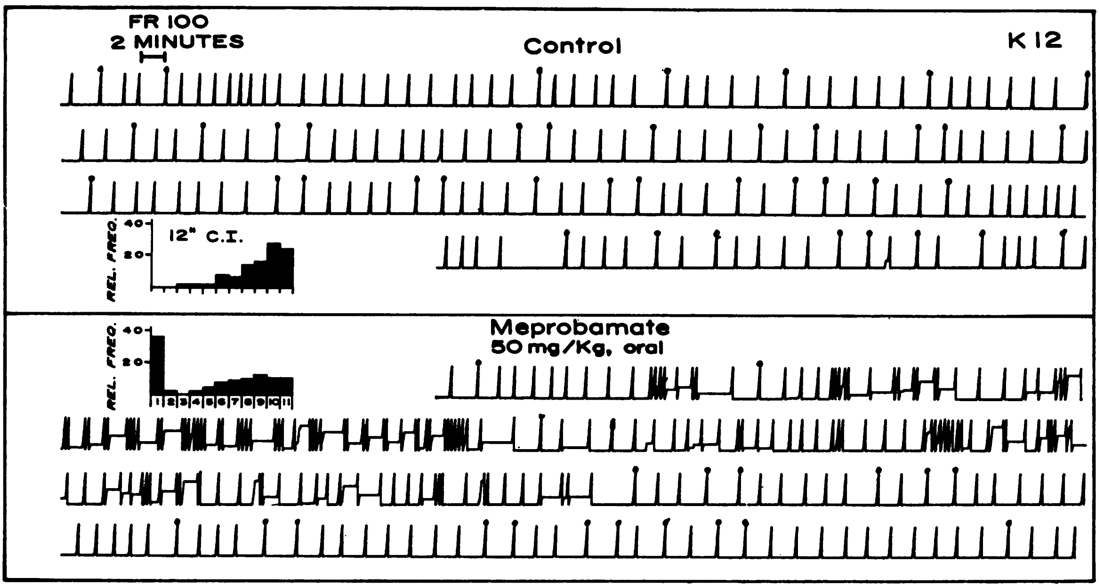

Fig. 10. The effects of meprobamate on the performance of Monkey K12.

pauses are highly variable. In Exp. II, the initial pauses at FR 300 were relatively stable.

Meprobamate consistently decreased the durations of the initial pauses. This effect is qualitatively similar to the effects of meprobamate in increasing the relative frequency of short interresponse times in DRL schedules (Kelleher, Fry, Deegan, and Cook, 1961). The results obtained with meprobamate are consistent with the notion that the adjusting FR schedule is a second-order schedule in which the FR is a unit of behavior that is reinforced according to a DRL; however, there are no reported studies on the effects of meprobamate on initial pauses in ratios as large as FR 100. Thus, meprobamate might decrease pausing on both DRL and FR schedules.

There are many different types of adjusting schedule (*e.g.*, Lindsley, 1957; Weiss and Laties, 1959; Boren and Malis, 1961; Stein and Ray, 1959, 1960); they have the common characteristic that some parameter of a basic schedule of reinforcement is varied as a function of the animal's performance. Although performances on adjusting schedules are sometimes discussed in terms of thresholds, it is usually found that the threshold value depends upon the parameter values of the adjusting schedule. (Weiss and Laties, 1959; Boren and Malis, 1961). Also, most adjusting schedules can be considered as combinations of other schedules. The present results suggest that the characteristics of these component schedules may be critical, especially when the effects of drugs are being studied with an adjusting schedule (*cf.* Boren and Malis, 1961).

The notion that adjusting schedules are combinations of other schedules also suggests new techniques for the analysis of basic schedules of reinforcement. In Exp. II, for example, we can consider the FR schedule as a unit of behavior that is itself on a DRL schedule of reinforcement. The functional relationships obtained with FR 100 as the unit of behavior are similar to those obtained when a single response is the unit of behavior. The size of the ratio does affect the results; this effect may be similar to changing the amount of effort required for a single response. Further studies with the type of second-order schedule used in Exp. II should advance understanding of both DRL and FR schedules.

It is apparent that there are many possible ways in which schedule performances, as units of behavior, can be scheduled. In a recent monograph Findley (1962) describes several experiments on the scheduling of complex sequences of behavior. The results of the present investigation, as well as the experiments by Findley (1962), indicate that these second-order schedules provide a powerful technique for the analysis of behavior.

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Received May 15, 1963