SEQUENCE SCHEDULES OF REINFORCEMENT¹

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The performance of pigeons was studied under a second-order schedule composed of fixed-interval components, each of which was associated with a different discriminative stimulus, the stimuli occurring in a fixed order. In one condition, food presentation followed the completion of the fourth component. This was designated a fixed-ratio sequence schedule. In another condition, responses in the first component completed after a fixed time were reinforced. This was designated a fixed-interval sequence schedule. Although the stimulus order and maximum reinforcement frequency were identical under the two schedules, considerably more responding occurred under the fixed-interval sequence schedule in all components. Relatively few food presentations occurred after responding during any but the terminal components of the fixed-interval sequence schedule, a feature independent of the parameter values investigated. In addition, while a pattern of increased responding between food presentations prevailed under both schedules, under the fixed-interval sequence schedule the rate in the terminal component was frequently less than in the penultimate component. The fixed-interval sequence schedule appeared to have several properties of simple fixed-interval schedules.

A second-order schedule is one in which the behavior engendered by a schedule is treated as a unitary response that is itself reinforced according to some schedule of reinforcement (Kelleher, 1966a; Marr, 1969). Relevant stimulus conditions in second-order schedules are specified by additional terms. In brief-stimulus procedures, a brief stimulus is presented according to a schedule and this component performance is treated as a unitary response that is reinforced according to some schedule of food presentation. The stimulus may or may not be temporally paired with reinforcement and responses in its presence have no scheduled consequences. Another class of second-order schedules may be termed sequence procedures, under which a different discriminative stimulus (S^D) is associated with each schedule component. The component responding, usually under a fixed-interval or fixed-ratio schedule, is treated as a unitary response that is reinforced according to some schedule of food

presentation. If that schedule is a fixed ratio, then the procedure is identical with that of a chained schedule. For example, a chained schedule with three components, each comprising a fixed-interval of 5 min (FI 5-min) is a second-order schedule under which the performance during the FI 5-min component schedule is treated as a unitary response that is reinforced according to a FR 3 schedule of food presentation. This schedule can be shown schematically as

In the presence of S^D_3 a response after 5 min produces S^D_2 ; in the presence of S^D_2 a response after 5 min produces S^D_1 ; and in the presence of S^D_1 , a response after 5 min produces food, S^R . This schedule is more precisely designated a fixed-ratio (FR) sequence schedule and can be denoted Seq FR 3 (FI 5-min). Thus, a chained schedule composed of n fixed-interval of t -min components represents a fixed-ratio sequence schedule that can be denoted Seq FR n (FI t).

Schedule components associated with different discriminative stimuli can provide reinforcement according to other than a ratio

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schedule. The present experiment describes the performance of pigeons under a sequence schedule in which food presentation followed the first schedule component completed after a fixed minimum time (T -min), rather than after completion of a predetermined number of components. The component schedule (FI t -min) responding was thus treated as a unitary response that was reinforced according to a fixed-interval schedule of food presentation. This schedule can be denoted Seq FI- T (FI- t). Comparisons were made between the performance of pigeons under schedules of the form Seq FR n (FI- t) with that under schedules of the form Seq FI- nt (FI- t). Under these conditions, the minimum interreinforcement time (nt), and component schedule (FI- t) were identical, but the schedule of components terminating in food presentation differed.

METHOD

Subjects

Three White Carneaux pigeons, with no previous training, were maintained at 80% of their free-feeding weights. Water and grit were available at all times in their home cages.

Apparatus

The experimental chamber was similar to that described by Ferster and Skinner (1957). It contained a single response key that could be transilluminated by white, red, green, or orange 6-w lamps; the key required a minimum force of 0.01 N to operate. White noise was present at all times. The experiment was scheduled by relay switching circuitry and data were recorded by impulse counters, elapsed time meters, a print-out counter, and a cumulative recorder. Reinforcement was 4-sec access to mixed grain.

Procedure

The birds were first magazine trained and then shaped by successive approximations to peck the key. The next 50 responses in the presence of a white keylight were each followed by presentations of grain. The keylight was off during the reinforcement period. The schedule was then changed to a fixed-ratio (FR) sequence schedule, Seq FR 4 (FI 1-min), under which grain followed the fourth FI 1-min component completed. Associated with each FI 1-min component was a different colored keylight. The keylights occurred in the

following order: white (S_4), red (S_3), green (S_2), and orange (S_1). Presentation of grain followed the first response after 1 min in the presence of S_1 (orange). This FR sequence schedule is identical with a chained schedule composed of four fixed-interval components.

After 10 sessions under the Seq FR 4 (FI 1-min) schedule, the birds were changed to a fixed-interval (FI) sequence schedule, Seq FI 4-min (FI 1-min), under which food followed the terminal response in the first FI 1-min component completed after 4 min. The stimulus order remained the same as in the Seq FR 4 (FI 1-min) schedule. The component stimulus that terminated in reinforcement did not depend upon the completion of a predetermined number of components (four), but upon the subject's responding in time. For example, to consider the extremes, if the pigeon did not pause for more than 1 min in any component, food presentation would always follow the first response after 1 min in the presence of S_1 (orange). However, if the pigeon paused more than 4 min in the initial component, S_4 (white), then reinforcement would follow a response in that component. The maximum frequency of reinforcement under this schedule was equal to that under Seq FR 4 (FI 1-min). Examination of the cumulative records indicated stability of performance when the birds had been under this schedule for 25 sessions. The parameter values of the FI sequence schedule were then increased such that food followed the terminal response in the first FI 2-min component completed after 8 min, *i.e.*, Seq FI 8-min (FI 2-min). The performance of all birds appeared stable after 10 sessions and the schedule was changed to Seq FR 4 (FI 2-min) and continued for 15 sessions, after which the birds were re-subjected to Seq FI 8-min (FI 2-min) for 26 sessions. The parameter value was then increased so that food followed the terminal response in the first FI 4-min component completed after 16 min, *i.e.*, Seq FI 16-min (FI 4-min). After 55 sessions under this schedule, it was changed to Seq FR 4 (FI 4-min) for 17 sessions. Finally, Seq FI 16-min (FI 4-min) was reinstated and continued for 37 sessions. The procedure is summarized in Table 1.

RESULTS

Figure 1 shows the mean response rate in each successive stimulus of the FI and FR se-

Table 1

The Order of Experimental Conditions for all Subjects

Schedule	Number of Sessions	Session Length (Food Presentations)
Seq FR 4 (FI 1-min)	10	16
Seq FI 4-min (FI 1-min)	25	16
Seq FI 8-min (FI 2-min)	10	12
Seq FR 4 (FI 2-min)	15	15
Seq FI 8-min (FI 2-min)	26	15
Seq FI 16-min (FI 4-min)	55	8
Seq FR 4 (FI 4-min)	17	8
Seq FI 16-min (FI 4-min)	37	8

quence schedules at all the parameter values studied. With few exceptions, the rate in the presence of each stimulus of the FI sequence schedule was higher than that during the

corresponding stimulus in the FR sequence schedule at all parameter values. In the FR sequence schedule, responding was positively accelerated throughout successive components. The distribution of response rates in the FI sequence schedule was more complex. Although, at all parameter values of the FI sequence schedule response rates increased rapidly from S_4 through S_2 , under the schedules Seq FI 4-min (FI 1-min) and Seq FI 8-min (FI 2-min) the rate in S_1 was lower than that in S_2 . Under Seq FI 16-min (FI 4-min), the rate was slightly higher in S_1 than in S_2 . However, in common with the lower parameter values of the FI sequence schedule the percentage difference between the rate in S_1 and S_2 was much less than that between S_1 and S_2 in the comparable FR sequence schedule.

Fig. 1. A comparison of the mean response rates in each component of the FI and FR sequence schedules at each parameter value. Each point is a mean of the mean rate for each bird. At least three sessions were used to determine the means for each bird. Schedules in each frame represented by the same symbol have the same maximum frequency of reinforcement.

Record A of Fig. 2 shows the performance of Bird 51 under Seq FI 8-min (FI 2-min). The rate difference between S_2 and S_1 noted above is seen to be the result of the pattern of responding in the presence of S_2 and S_1 . Responding during S_2 tended to be at a high and relatively constant rate, with only a brief pause at the beginning of the interval. In the presence of S_1 , responding was positively accelerated.

Record B of Fig. 2 shows the first session under Seq FR 4 (FI 2-min), the session following that shown in Record A. Rapid changes took place in this session so that at d , the response rate during S_2 became substantially less than that during S_1 , and the distinct acceleration

pattern seen in the FI sequence schedule in the presence of S_1 disappeared. The record marked C shows the tenth session under the FR sequence schedule. Long pauses developed during S_4 and S_3 and although the response rate in the presence of S_2 increased over that seen in the terminal portion of Record B, it was still considerably lower than that during S_1 .

Figure 3 shows representative cumulative records of the three birds, comparing their performances under Seq FI 16-min (FI 4-min) and Seq FR 4 (FI 4-min). The three birds showed similar patterns of responding under the respective schedule conditions. Bird 276 had the lowest rate in both the FI and FR sequence schedules. Bird 51 had the highest rate under

Fig. 2 A. Representative cumulative response records showing the tenth session of Bird 51 under Seq FI 8-min (FI 2-min). The small diagonal pips mark the change from one component to the next. The pen reset at food presentation. At a , b , and c pausing was of sufficient duration in the initial components so that reinforcement occurred in the presence of S_2 , i.e., only the first three components were completed. It can be seen, however, that most reinforcements occurred after responding during S_1 . B. Cumulative records showing the session following that in A in which the schedule was changed to Seq FR 4 (FI 2-min). C. Cumulative records showing the tenth session under Seq FR 4 (FI 2-min). The numbers denote minutes during which no responding occurred that have been omitted from the record.

Fig. 3. Representative cumulative records comparing performances under Seq FI 16-min (FI 4-min) and Seq FR 4 (FI 4-min) for each bird. The numbers appearing in the records of the FR sequence schedule are the durations in minutes of no responding that have been omitted from the record.

the FI sequence schedule and Bird 52 had a slightly higher rate than Bird 51 under the FR sequence schedule. Considerably more responding occurred under the FI sequence schedule than under the FR sequence schedule, although the maximum frequency of reinforcement and stimulus order were identical in the two schedules. Generally, only a single response per food presentation occurred during S_4 in both the FI and FR sequence schedules; however, there was considerably less pausing during S_4 under the FI sequence schedule. In the presence of S_3 under the FR sequence schedule, usually only a single response occurred but substantially more responding occurred during S_3 under the FI sequence schedule, particularly by Birds 51 and 52. The most obvious difference in the amount of responding occurred during S_2 , where the rate was up to 30 times greater in the FI sequence than in the FR sequence schedule. In contrast, there was little difference between the response rate during S_1 in the FI and FR sequence schedules. At these parameter values of the FI sequence schedule, the rates during S_1 averaged higher than those during S_2 (see Fig. 1), although occasionally a sustained high rate during S_2 occurred and was followed by a distinct pattern of positively accelerated responding, as seen frequently at the lower parameter values.

Figure 4 shows the percentage of food presentations that occurred in the presence of each stimulus of the FI sequence schedule at

Fig. 4. The percentage of food presentations that occurred after a response in each component at each parameter value. Each point represents the mean of means of the three birds. At least 20 sessions at each parameter value were used to determine the mean for each bird.

Table 2

The percentage of food presentations following responding in the presence of each stimulus of the FI sequence schedule at three component parameter values. The percentage values are means over at least 20 sessions at each parameter value.

Bird	Seq FI 4-min (FI 1-min)				Seq FI 8-min (FI 2-min)				Seq FI 16-min (FI 4-min)			
	S ₄	S ₃	S ₂	S ₁	S ₄	S ₃	S ₂	S ₁	S ₄	S ₃	S ₂	S ₁
51	0.58	7.56	40.70	51.16	0	0.38	9.54	90.08	0	1.50	24.00	74.00
52	1.44	5.75	18.75	74.03	0.75	2.25	12.03	84.96	0	1.25	18.75	80.00
276	1.33	1.33	10.66	86.66	0	2.23	11.94	85.82	1.25	1.25	11.25	86.25

each set of parameter values. Increasing the parameter values had relatively little effect on this function. Most food presentations occurred after responding during S₁; very few reinforcements occurred in the presence of S₄. Table 2 shows data for the individual birds at each schedule value. For all birds at all parameter values, the range during S₄ was from 0 to 1.44%. During S₃ the range was from 0.38 to 7.56%; during S₂ from 10.66 to 40.70% and, during S₁ from 51.16 to 86.66%. The 40.70 and 51.16% values are from Bird 51 under the Seq FI 4 (FI 1-min) schedule and were much larger in the case of S₂ and much smaller in the case of S₁ than the percentages for the other birds.

DISCUSSION

It has been shown in this study, as well as in several previous ones (Gollub, 1958; Findley, 1962; Kelleher and Fry, 1962; Thomas, 1964; Thomas and Stubbs, 1967; Marr, 1969), that under a fixed-ratio sequence (chained) schedule in which a reinforcing stimulus terminates a fixed-ratio of schedule components, little responding occurs during the early components. However, modifications of FR sequence schedules can increase responding in the initial components. Kelleher and Fry (1962) studied responding in the pigeon under a sequence schedule composed of three FI 1.5-min components, in which the stimulus order varied so that no stimulus was consistently correlated with food presentation. Under this schedule, responding was well maintained in all three components. Findley (1962) found in the pigeon that prolonged pauses occurred in the initial components of a sequence schedule in which responding engendered under an FI 15-sec schedule was reinforced according to an FR 5 schedule of food presentation. When this schedule was modified to one in which the FI 15-sec components were reinforced accord-

ing to a variable-ratio (VR 3) schedule so that the number of FI components varied from one to five with the same stimulus order as in the previous schedule, pausing was abolished and responding was positively accelerated in each component. Only when the parameter value of the fixed-interval component was increased to 2 min did pronounced pausing return to the initial components. The results of these studies indicate that a significant factor in determining the low rates in the initial components of an FR sequence schedule is the decreasing conditioned reinforcing effectiveness of the component schedule stimulus the more remote its position in relationship to the terminal reinforcer (Kelleher and Gollub, 1962; Kelleher, 1966a; Marr, 1969). In the experiments of Findley (1962) and Kelleher and Fry (1962), no component stimulus was uniquely associated with food presentation, in that responding in the presence of each stimulus was at some time followed directly by the presentation of food. The effect was to increase responding in the early components. Under the FI sequence schedule, each of the four ordered components stimuli could occasionally be directly associated with food presentation, and this resulted in marked increases in response rates during the first three components as compared with a FR sequence schedule of identical minimum interreinforcement time.

There is a significant difference between the FI sequence schedule and the ratio sequence schedules of Findley (1962) and Kelleher and Fry (1962). Under these latter schedules, the probability of reinforcement in the presence of a given stimulus is predetermined. Under the FI sequence schedule, it is determined by the rate and pattern of responding; the higher the rate the greater the probability that reinforcement will follow a response in the presence of a later component stimulus. This may reduce the rate in the presence of the initial com-

ponent stimuli and therefore increase the probability that reinforcement will occur after a response in their presence. The FI sequence schedule thus has the characteristics of a fixed-ratio adjusting schedule (Ferster and Skinner, 1957; Kelleher, Fry, and Cook, 1964) in that the number of schedule components required to be executed is a function of the animal's performance. The adjusting aspect of the FI sequence schedule allows for the determination of the frequency of reinforcement required in the presence of each stimulus to maintain responding throughout the series of stimuli.

The percentage of reinforcements that occurred in the presence of each FI sequence schedule stimulus remained relatively constant over the four-fold range of parameter values. Perhaps the major factor contributing to this effect was that the schedule components were fixed intervals that themselves produced reinforcement under a fixed-interval schedule. Thus, under the schedule Seq FI 4-min (FI 1-min), an initial pause of slightly less than 2-min during S_4 would still allow the possibility of food presentation following a response during S_1 , provided responding was maintained throughout S_3 and S_2 . Similarly, under the schedules Seq FI 8-min (FI 2-min) and Seq FI 16-min (FI 4-min) initial pauses of just less than 4 and 8 min respectively, would provide the possibility of food presentation following a response during S_1 . Thus, increased tendency for pausing in the initial components of the sequence schedule as the parameter values were increased could have relatively little effect on the percentage of reinforcements occurring in the presence of each component stimulus. By far the greatest percentage of reinforcements occurred in the presence of S_1 . Very infrequently was initial pausing lengthy enough for a reinforced response to occur during S_4 . Although generally only a single response was made in S_4 , the low frequency of reinforcement in its presence, as well as perhaps S_3 and S_2 , may have been adequate to decrease considerably the pause length over that under the comparable FR sequence schedule. This corresponds to the results of Crossman (1968) who found that under a chained FR 10 FR 100 schedule, the latency of the first response of the FR 10 was greater than that of the FR 100. By reinforcing only 1.23% of the FR 10s, this pattern was reversed.

A salient feature of the FI sequence schedule, particularly at the lower parameter values, was that the highest rates often occurred in the presence of S_2 rather than S_1 . This contrasted sharply with the distribution of responding under the FR sequence schedule, where the highest rates always occurred in the presence of S_1 . The unusual response-rate distribution under the FI sequence schedule revealed itself in the cumulative records as a high, relatively constant rate during S_2 followed by a distinct pattern of positively accelerated responding during S_1 . The high rate during S_2 could possibly have resulted from two factors. First, responding during S_2 occasionally terminated in food presentation, thus resulting in a considerably higher rate during S_2 of the FI sequence schedule than that seen during S_2 of the FR sequence schedule. Second, and perhaps more important, the overall fixed-interval dependency of the FI sequence schedule would tend to generate a higher rate during S_2 just as under a simple fixed-interval schedule responding generally begins to accelerate rapidly by the time half the interval has elapsed. This high rate may terminate in food presentation or, more often the onset of S_1 , presumably an effective conditioned reinforcer and thus be sustained.

The pattern of responding in the presence of S_1 was perhaps largely determined by the fixed-interval schedule of food presentation in its presence. But the rate during S_1 may also have been affected by the high rate during S_2 . A high rate in a fixed interval tends to be followed by a low rate in the succeeding fixed interval (Ferster and Skinner, 1957). An additional factor that may have contributed to the relatively low rate during S_1 , compared with that during S_2 , is that under a fixed-interval schedule the maximal rate occasionally occurs some time before the end of the interval (Ferster and Skinner, 1957). As the FI sequence schedule is a fixed-interval schedule of a component performance rather than individual responses, it may amplify certain characteristics of schedules of single responses. This possibility has been discussed in relation to other second-order schedules (Kelleher, 1966b; Byrd and Marr, 1969; Marr, 1969).

The low rates of responding in the presence of S_4 and S_3 of the FI sequence schedule may not only have occurred as a result of the low frequency of reinforcement in their presence

but perhaps also from the over-all fixed-interval dependency of the schedule. In contrast with the FR sequence schedule, rates during S_4 and S_3 of the FI sequence schedule were probably under less stimulus control. Reinforcement could occur quite frequently after a response in their presence provided the bird paused significantly after their presentation. But just as pronounced responding occurs under an ordinary fixed-interval schedule, although only a single response after a specified time is required, so more than a single component was generally completed under the FI sequence schedule. The reinforcement of a component performance under a fixed-interval schedule has produced similar results using brief stimulus procedures, wherein the component stimuli did not differ but a brief stimulus terminated each component. Kelleher (1966a) studied the performance of pigeons under the schedule FI 10-min (FR 20:S) in which a brief stimulus (S) followed every twentieth response (FR 20) and the first FR 20 completed after 10 min produced reinforcement. deLorge (1967) studied the performance of a pigeon under the schedule FI 18-min (FI 3-min:S) wherein the first response after 3 min produced a brief stimulus (S) and the first FI 3-min component completed after 18-min produced reinforcement. Under both these schedules of reinforcement, the completion of many more than a single component per reinforcer presentation was found to be common.

That the completion of only one component of an FI sequence schedule is necessary may be as significant a feature in the maintenance of responding under that schedule as the single response requirement under an ordinary fixed-interval schedule. Herrnstein and Morse (1958), in their analysis of conjunctive FI-FR schedules, argue convincingly that: "A property of fixed-interval reinforcement that contributes to unreinforced responding may be that this schedule makes no requirement about such responding." (p. 23) A similar assertion may be made regarding the FI sequence schedule, wherein no requirements are imposed

upon the number of unreinforced components completed.

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