STIMULUS FUNCTIONS IN CHAINED FIXED-INTERVAL SCHEDULES

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Pigeons were required to complete three successive fixed-interval components to obtain food. When the same exteroceptive stimulus was correlated with the three components, responding was positively accelerated between food deliveries. When different exteroceptive stimuli were correlated with each component in a fixed sequence, prolonged pauses developed in the first component; low response rates developed in the second component; and responding was positively accelerated in the second and third components. When different exteroceptive stimuli were correlated with each component in a variable sequence, responding was positively accelerated in each component. Because the response and reinforcement contingencies were the same in all three procedures, the differences in performances must be due to the changes in the sequence of stimuli.

In a three-component, chained fixed-interval schedule of reinforcement, the completion of a fixed-interval schedule in the presence of one stimulus produces a second stimulus; the completion of a fixed-interval schedule in the second stimulus produces a third stimulus; and the completion of a fixed-interval schedule in the third stimulus produces food. Of the various functions that a stimulus may have (Skinner, 1938), two are emphasized in chained schedules. First, the presence of a stimulus can control a specific rate and pattern of responding; this is the discriminative function of the stimulus. Of course, the rate of responding and the pattern of responding that occur in the presence of a discriminative stimulus are a function of the schedule of reinforcement that is in effect. Second, a stimulus can reinforce a specific rate and pattern of responding that preceded its appearance; this is the conditioned reinforcing function of the stimulus. Gollub (1958) has demonstrated that each of the component stimuli in a chained fixed-interval schedule may have one or both of these functions. The present paper reports a further experimental analysis of the functions of the stimuli in three-component, chained fixed-interval schedules.

METHOD

Subjects

The two subjects were adult male White Carneaux pigeons maintained at about 75%

of their free-feeding body weights. These birds had long experimental histories on various schedules of reinforcement; and just before the present experiment, both had brief training on a 3-min fixed-interval schedule.

Apparatus

The experimental chamber was a ventilated aluminum picnic icebox similar to that described by Ferster and Skinner (1957). This icebox was enclosed in a large ventilated chamber that almost completely attenuated extraneous sounds. A standard response key, which could be operated by a force of 15 g or more, was mounted in one wall of the chamber. The key could be illuminated by white, green, or red lamps located behind it. A food magazine located below the response key occasionally provided access to grain. The programming and recording equipment has been generally described (Ferster & Skinner, 1957).

Procedure

Experimental sessions were conducted daily from Monday through Friday. Each session ended when 5 hr had elapsed or 50 reinforcements had occurred. Each reinforcement consisted of 4-sec access to grain. On weekends the birds were weighed daily and fed enough grain to maintain appropriate body weights.

In all of the present experiments, the birds had to complete three successive fixed-interval

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schedules to obtain food. That is, the first response after a fixed interval of time in the first component started the second component; the first response after a fixed interval of time in the second component started the third component; and the first response after a fixed interval of time in the third component produced food. The main experimental manipulations involved changes in the stimulus conditions that were correlated with the component fixed-interval (FI) schedules. These experimental procedures are summarized in Table 1. In Sessions 1 to 70 the fixed-interval value in each component was 1 min; in Sessions 71 to 450, it was 1.5 min. Except for

chained fixed-interval schedule (*var chain FI FI FI*).

RESULTS

Figure 1 shows representative records for Bird P 11 from sessions on *tand FI 1 FI 1 FI 1* with the white stimulus present throughout

Fig. 1. Representative cumulative-response records from sessions on *tand FI 1 FI 1 FI 1*. Frames A, B, C, and D, respectively, show records from Sessions 1, 10, 15, and 25. Pips indicate the completion of the first and second components. The pen reset to the base line at the completion of the third component. The recorder did not drive during reinforcement cycles.

Table 1
Summary of Procedures

Session	Stimulus Sequence	Component Schedules
1-30	W-W-W	FI 1 FI 1 FI 1
31-70	Fixed W-G-R	
71-150	Fixed W-G-R	
151-175	Variable W, G, R	
176	W-W-W	FI 1.5 FI 1.5 FI 1.5
177-210	R-R-R	
211-450	Fixed R-G-W	

W = white G = green R = red

this change in fixed-interval values, the response and reinforcement contingencies remained constant throughout the present experiments.

Three types of stimulus sequence were used. First, in Sessions 1 to 30 and Sessions 176 to 210, no exteroceptive stimulus change occurred until the bird completed the third component, and food was delivered; a single stimulus occurred throughout each sequence. Technically, this is a three-component tandem fixed-interval schedule of reinforcement (*tand FI FI FI*) (Ferster & Skinner, 1957). Second, in Sessions 31 to 150 and Sessions 211 to 450, a different exteroceptive stimulus was correlated with each component; these stimuli appeared in a fixed sequence. Technically, this is a three-component, chained fixed-interval schedule (*chain FI FI FI*). Third, in Sessions 151 to 175, a different exteroceptive stimulus was correlated with each component; however, these stimuli appeared in a variable sequence. We will refer to this as a variable,

each sequence. Pips indicate the completion of the first and second components; at the completion of the third component, food was delivered and the recording pen reset to the bottom of the record. Occasionally, the bird paused throughout the first component (as at a, c, and e). Segments in which these pauses occurred were usually followed by segments in which high response rates occurred in the first component (as at b, d, and f).

Figure 2 shows the transition from *tand FI 1 FI 1 FI 1* to *chain FI 1 FI 1 FI 1*. In the first session on the chained schedule (frame B), the introduction of the novel stimuli in the second and third components did not disrupt performance. One of the first effects of the chained schedule appears at a, where the bird emitted only one response in each of the first two components. In the second session of the chained schedule (frame C) the bird occasionally paused for as long as 2.5 min in the first component (as at b), and low response rates prevailed in the second component (as at c, d, and e). In the third session on the chained schedule (frame D), prolonged pauses occurred in the first component (as at g, h, and i), and response rates in all components were lower than they had been on the tandem schedule (as at f). Figure 3 shows the

Fig. 2. Transition from *tand* FI 1 FI 1 FI 1 to *chain* FI 1 FI 1 FI 1 for P 11. Frame A shows records from Session 30 on the tandem schedules; frames B, C, and D show records from the first three sessions on the chained schedule.

transition from the tandem to the chained schedule for P 12. Prolonged pausing in the first two components of the chained schedule developed rapidly.

Figure 4 shows the performance of P 11 during further exposure to *chain* FI 1 FI 1

Fig. 3. Transition from tandem to chained schedule for Bird P 12. Frame A shows records from Session 30 on the tandem schedule; frames B, C, and D show records from the first three sessions on the chained schedule.

FI 1. This performance was characterized by the frequent occurrence of prolonged pauses in the first component (frames C and D), and by the development of positively accelerated responding in the second and third components of the chain (as at *a*, *b*, and *c*). Except for more frequent prolonged pauses in the

Fig. 4. Later development of performance on *chain* FI 1 FI 1 FI 1. Frames A, B, C, D, and E, respectively, show records from Sessions 35, 40, 55, 60, and 70. Periods of pausing have been omitted from the records, as indicated by the arrows.

first component, the performance of P 12 confirmed the results obtained with P 11.

In Session 71 the birds were shifted to *chain* FI 1.5 FI 1.5 FI 1.5, and were maintained on this schedule over Sessions 71 to 150. Performance on *chain* FI 1.5 FI 1.5 FI 1.5 (Fig. 5)

Fig. 5. Representative performances on *chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, and C, respectively, show records from Sessions 80, 90, and 100.

is qualitatively similar to performance on *chain* FI 1 FI 1 FI 1.

Figure 6 shows the transition from *chain* FI 1.5 FI 1.5 FI 1.5 to *var chain* FI 1.5 FI 1.5 FI 1.5. Frames A and B show the final performance (Sessions 149 and 150) on *chain* FI 1.5 FI 1.5 FI 1.5. The numbers at the left of some segments indicate the number of minutes of pausing that have been omitted from the first component of that segment. The letters *W-G-R* indicate that the fixed sequence of stimuli was white-green-red throughout these two

sessions. Frame C shows the first session (Session 151) in which the stimuli were presented in a variable sequence; the letters above each segment indicate the sequence in which the component stimuli appeared in that segment. The results in frame C show that the response pattern and response rate in each component were still under the discriminative control that had prevailed with the fixed sequence of stimuli. In the third segment shown in frame C, for example, the sequence

Fig. 6. Transition from *chain* FI 1.5 FI 1.5 FI 1.5 to *var chain* FI 1.5 FI 1.5 FI 1.5. Frames A and B show records from Sessions 149 and 150; frames C and D show records from Sessions 151 and 156. The letters indicate the sequence in which the component stimuli appeared. The numbers at the left of some segments indicate the number of minutes of pausing that preceded that segment.

was red-green-white. Responding occurred at a high rate in the first component (red); responding was negatively accelerated in the second component (green); and responding ceased for more than 30 min in the third component (white). Thus, when the stimuli appeared in the reverse of the order in which they had appeared in the previous session, the response pattern was inverted. These effects were transient, and by the fifth session on the variable sequence (frame D), response rates were usually high in all three components.

Figure 7 shows a later performance of P 11 on *var chain* FI 1.5 FI 1.5 FI 1.5. Responding was maintained in all components, and pausing seldom exceeded 1 min, even in the first component. In each of the components, posi-

Fig. 7. Later development of the performance of P 11 on *var chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, and C, respectively, show records from Sessions 165, 170, and 175.

tively accelerated responding developed (as at *a*, *b*, *c*, and *d*).

Figure 8 shows the performance of P 12 on *var chain* FI 1.5 FI 1.5 FI 1.5. The results are similar to those obtained with P 11. Examples of the early development of positively accelerated responding in each compo-

Fig. 8. Performance of P 12 on *var chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, and C, respectively, show records from Sessions 151, 156, and 175.

nent are shown at *a* and *b*, and an example of final development appears at *c*.

In Session 176, both birds were shifted to *tand* FI 1.5 FI 1.5 FI 1.5, with the white stimulus occurring in each component. Over Sessions 177 to 210, the tandem schedule remained in effect, but the red stimulus appeared in each component. The results

Fig. 9. Performance on *tand* FI 1.5 FI 1.5 FI 1.5. Frame A shows records from Session 176 in which the white stimulus appeared in each component. Frames B and C show records from Sessions 177 and 210 in which the red stimulus appeared in each sequence.

shown in Fig. 9 indicate that the performance of P 11 on *tand* FI 1.5 FI 1.5 FI 1.5 was similar to this bird's performance on *tand* FI 1 FI 1 FI 1. (See Fig. 1.) These results were confirmed with P 12.

Over Sessions 211 to 450, both birds were on *chain* FI 1.5 FI 1.5 FI 1.5, with the stimuli appearing in a fixed sequence of red-green-

Fig. 10. Performance of P 11 on *chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, C, and D, respectively, show records from Sessions 221, 250, 275, and 325.

white. Figure 10 shows the performance of P 11 on this procedure. The numbers at the left of each sequence indicate the number of minutes of pausing that have been omitted from the first component of that sequence. These performances, which are comparable with those in Fig. 5 for P 11, show that the earlier performance on *chain* FI 1.5 FI 1.5

Fig. 11. Performance of P 12 on *chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, and C, respectively, show records from Sessions 300, 303, and 330. Following the arrow in frames A and B, extinction was in effect.

FI 1.5 could be recovered with the component stimuli appearing in the reverse order.

Figure 11 shows the performance of P 12 on *chain* FI 1.5 FI 1.5 FI 1.5. The four sequences before the arrow in frame A show the type of performance of this bird over Sessions 211 to 300. The red and green stimuli in the first two components of each sequence controlled consistently high response rates, whereas the white stimulus controlled a brief pause followed by positively accelerated responding. At the arrow, the bird was put on extinction with the red stimulus present. At *a* and *b*, respectively, 110 min and 160 min of responding at continuous high response rates were omitted from the record. This procedure was repeated in Session 303, shown in frame B, with similar results. The extinction periods had no apparent effects. By

Session 330 (frame C), response rates had decreased, and positively accelerated responding occasionally occurred in individual components.

Figure 12 shows the later performance of P 12 on *chain* FI 1.5 FI 1.5 FI 1.5. The numbers at the left of each sequence indicate the number of minutes of pausing that have been omitted from the first component of that sequence; other omitted periods of pausing are also indicated. By Session 415, prolonged pauses developed in the first component, and performance was comparable with that on *chain* FI 1.5 FI 1.5 FI 1.5 when the stimuli had appeared in the reverse order.

Fig. 12. Later performance of P 12 on *chain* FI 1.5 FI 1.5 FI 1.5. Frames A, B, and C, respectively, show records from Sessions 335, 400, and 415.

In summary, performance on *tand* FI FI FI is characterized by positively accelerated responding between reinforcements. Performance on *chain* FI FI FI is characterized by prolonged pausing in the first component, and positively accelerated responding in the second and third components. Performance on *var chain* FI FI FI is characterized by positively accelerated responding in each component. Because the tandem schedule, the chained schedule, and the variable chained schedule have identical response and reinforcement contingencies, the marked differences in performance among these schedules must be a function of the different sequences of exteroceptive stimuli.

DISCUSSION

The comparison of performances on *tand* FI FI FI and *chain* FI FI FI indicates that each of the component stimuli in the chained schedule is a discriminative stimulus; that is, different response rates and response patterns occur in each of the component stimuli. In

the first component of the chained schedule, prolonged pauses developed. Thus, neither the rate nor pattern of responding in the first component indicated that the appearance of the second-component stimulus is a conditioned reinforcer. In the second component of the chained schedule, response rates were lower than in the second component of the tandem schedule; however, the positively accelerated responding, which is a characteristic of simple FI schedules of food reinforcement, indicates that the appearance of the third-component stimulus was a conditioned reinforcer.

A comparison of performances on *tand* FI FI FI and *var chain* FI FI FI indicates that each of the component stimuli in the variable chained schedule also becomes a discriminative stimulus controlling a specific response rate and pattern of responding. On the variable chain, response rates in the individual components were not consistently higher than response rates in the comparable components of the tandem schedule; however, positively accelerated responding developed in each component of the variable chain. The patterns of responding indicate that the second- and third- component stimuli of the variable chain were conditioned reinforcers.

A comparison of performances on *chain* FI FI FI and *var chain* FI FI FI indicates that the prolonged pauses and low response rates in the first two components of the chained schedule occur not because different exteroceptive stimuli are associated with each component, but because these stimuli occur in a fixed sequence. The sustained performance in the first two components of the variable chain might be due to changes in either the discriminative function or the conditioned reinforcing function of the component stimuli. Although each component stimulus of the variable chain becomes a discriminative stimulus for positively accelerated responding, no stimulus is in the unfavorable position of consistently following reinforcement. Also, each component stimulus of the variable chain is associated with food delivery in one out of three sequences, on the average, and this intermittent association might maintain each stimulus as a conditioned reinforcer.

We have no explanation for the remarkable performance of Bird P 12 in Sessions 211 to 320 on *chain* FI 1.5 FI 1.5 FI 1.5 with the

red-green-white sequence. (See Fig. 11.) Frequent observations of this bird working in the chamber did not reveal anything unusual. Neither the previous performance nor the subsequent performance of P 12 indicated that this bird had an unusually high disposition to peck at a red response key.

The results obtained when the birds in the present experiments were shifted from the tandem to the chained schedules confirm previous experiments by Gollub (1958). Also, prolonged pauses in the early components of chained FI schedules with three or more components have been reported by Gollub (1958) and by Findley (1962). On fixed-interval schedules of token reinforcement, in which chimpanzees had to obtain several tokens before the tokens could be exchanged for food, prolonged pauses occurred before the animals obtained the first few tokens (Kelleher, 1957). In these experiments, as in the chained schedule in the present experiment, the prolonged

pauses occurred in the presence of some exteroceptive stimulus that was correlated with nonreinforcement. By using the variable chained schedule, we eliminated prolonged pauses and developed positively accelerated responding in each of the three components.

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Received August 8, 1961