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RESPONDING IN THE PIGEON UNDER CHAINED SCHEDULES OF FOOD PRESENTATION: THE REPETITION OF A STIMULUS DURING ALTERNATE COMPONENTS[1]

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Key pecking in the pigeon was maintained under chained schedules in which the completion of one schedule component initiated the next component, and food was presented upon completion of a sequence of components. Under the chained schedules studied, a particular key color appeared during more than one component, and different key colors appeared during the other components. When seven 1-min fixed-interval components comprised a chained schedule and the response key was the same color during the first, third, fifth, and terminal components, patterns of positively accelerated responding were maintained during all but the first two components of each sequence. In general, response rates were always lowest during the first one or two components and highest during the terminal component when as few as three and as many as eight components comprised a schedule. Increasing the number of components from three to eight showed that response rate during a component increased when it was no longer one of the initial two components of the schedule, even though its temporal relation to food presentation had not changed. Finally, when seven components comprised a schedule and the response key was one color during the first, third, and fifth and a different color during the last component, response rates were low during the first five components and high during the last two components preceding food presentation.

Under a chained schedule of food presentation, the completion of one schedule component initiates the next component, and food is presented upon completion of a sequence of components (Skinner, 1938; Ferster and Skinner, 1957). Typically, a different stimulus is present during each component and each stimulus appears only once during a sequence.

Responding under chained schedules can be described in terms of the discriminative and reinforcing effects of the stimuli appearing during the components, the schedules comprising the components, and the schedule under which sequences of components are terminated (Gollub, 1958; Findley, 1962; Kelleher and Gollub, 1962; Kelleher, 1966). For example, the stimulus present during the terminal component of a sequence can become a conditioned reinforcer due to its temporal relation to food presentation, and the appearance of that stimulus can enhance responding during the preceding component. In addition, a stimulus can discriminatively control a rate and pattern of responding representative of the component with which it is associated.

When fixed-interval components comprise a chained schedule and the number of components and the order of component stimuli do not change during consecutive sequences, performance is distinguished by very low response rates during the initial components and moderate response rates during the last two or three components only (Gollub, 1958; Findley, 1962). The analysis of responding under chained schedules might proceed more effectively if responding could be maintained by schedules of more than a few fixed-interval components. This paper describes a procedure that can engender increased responding under chained schedules and provide a more detailed analysis of performance during the initial components.

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METHOD

Subjects

Two male White Carneaux pigeons (P40 and P42), previously trained to peck a key, were maintained at 80% of their free-feeding body weights. Between experimental sessions, the pigeons were housed individually in wire-mesh cages where water and grit were always available.

Apparatus

The experimental chamber was a picnic chest modified as described by Ferster and Skinner (1957). One wall of the chamber supported a translucent Plexiglas response key (R. Gerbrands Co.) that could be transilluminated by 28 v dc lamps (#1820). A rectangular opening 4.25 in. (11 cm) below the response key permitted access to a food tray containing a mixture of grain. A 10-w lamp illuminated the tray during food presentation. A second 10-w lamp (houselight) mounted near the corner to the right of the response key provided general illumination of the chamber. Continuous white noise masked extraneous sounds. Relay equipment in an adjacent room arranged the experiments and recorded key pecks having a minimum force of approximately 15 g (0.15N). Each key peck produced an audible click of a relay.

Procedure

Sessions were conducted daily, seven days a week. Each session was limited to 12 hr or to a maximum number of food presentations, whichever occurred first. Initially, the maximum number of food presentations was 50; later the number was reduced to 25, then to 20.

Phase I. At the beginning of the experiment, food was presented under a three-component chained schedule with each component a 1-min fixed-interval schedule. The first response (key peck) occurring after 1 min completed a component and initiated the next component of the chained schedule, and food was presented upon completion of the third component. During the initial component (C3) and during the terminal component (C1), the response key was white; during the second component (C2), the response key was red. The houselight and keylights were off and the food tray was illuminated during each 6-sec presentation of food. The procedure of numbering the components in reverse order has been described previously by Gollub (1958). In the present experiment, C1 identified the component immediately preceding food presentation, C2 identified the component preceding C1 *etc.*, regardless of the number of components comprising the schedule.

At the end of 42 sessions, the three-component chained schedule was changed to a five-component schedule by adding two 1-min fixed-interval components (C5 and C4) at the beginning of each sequence. The response key was white during C5, C3, and C1, blue during C4, and red during C2.

After 47 sessions under the five-component chained schedule, the number of fixed-interval components was increased to seven. The response key was white during C7, C5, C3, and C1, green during C6, blue during C4, and red during C2. The seven-component schedule was studied during Sessions 90 to 115.

Phase II. During Sessions 116 to 140, key color during C7, C5, and C3 was changed to amber in order to evaluate the effect of presenting the same stimulus during C7, C5, C3, and C1. In every other respect, the procedure was as described in Phase I.

Phase III. Beginning with Session 141, food was again presented under the seven-component schedule studied in Phase I. During the 98 sessions that this schedule was in effect, drugs were occasionally administered to the pigeons. The drug data are not reported here.

During Sessions 239 to 288, the number of FI 1-min components comprising the chained schedule was increased to eight by the addition of a component (C8) at the beginning of each sequence. The response key was amber during C8, green during C6, blue during C4, red during C2, and white during C7, C5, C3, and C1.

A 30-sec timeout was added during Sessions 289-299. The timeout followed the 6-sec presentation of food, and terminated with the beginning of C8. All lights in the chamber were off during the timeout, and responses had no scheduled consequences. The experiment ended after the two hundred ninety-ninth session.

RESULTS

Phase I. When food was presented under a chained schedule of three FI 1-min components and the response key was the same color

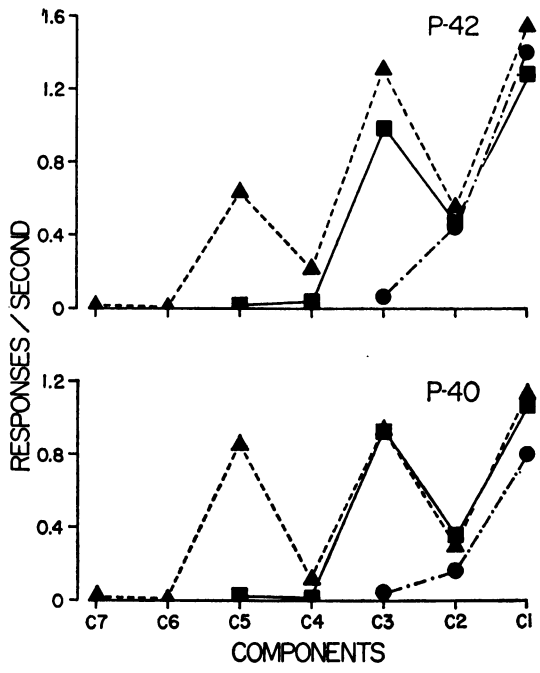

Fig. 1. Mean rates of responding for Pigeons P42 and P40 during individual 1-min fixed-interval components of three-component (closed circles), five-component (closed squares), and seven-component (closed triangles) chained schedules. Each point is the mean of the last four sessions. The response key was white during C7, C5, C3, and C1, green during C6, blue during C4, and red during C2. Food presentation followed completion of C1.

during both the initial (C3) and terminal (C1) components, mean response rates were lowest during C3, intermediate during C2, and highest during C1 (Fig. 1, circles). P40, and to a lesser extent P42, typically showed patterns of positively accelerated responding during each of the last two components of the chained schedule (Fig. 2A). During C3, response rates approached zero for both pigeons and patterns of positively accelerated responding were absent.

When the chained schedule was increased to five components, response rates during C3 increased ten-fold and exceeded response rates during C2. Rates of responding during C3 were approximately 0.9 (P40) and 1.0 (P42) response per second (Fig. 1, squares), and the patterns of responding during C3 were similar to those during C1 (Fig. 2B). Rates and patterns of responding during C2 and C1 of the five-component schedule were nearly identical to those during the same components of the three-component schedule. Response rates during the initial components (C5 and C4) approached zero.

When the number of components comprising the chained schedule was increased to seven, rates of responding increased markedly during C5 and increased to a lesser extent during C4 (Fig. 1, triangles). Rates and patterns of responding during C2 and C1 did not differ significantly from those maintained during C2 and C1 of the three- and five-component schedules (Fig. 2C). A comparison of response rates during C7, C5, C3, and C1 under each of the three schedules showed that response rates were highest during C1, then decreased systematically the greater the temporal separation of a component from food presentation. Consistent with the very low response rates engendered during the initial components of both the three- and five-component schedules, response rates approached zero during the initial components (C7 and C6) of the seven-component schedule.

Phase II. When the response key was amber during C7, C5, and C3, response rates during the first five components were generally lower than those maintained during the same components in Phase I (Fig. 3, circles). Extended periods of no responding were frequent during the initial components (C7 and C6) of the schedule, and briefer periods of no responding occurred occasionally during C5 and C3. Response rates during C4 changed little, but response rates during C5 and C3 decreased and were lower than the rates during C4. Response rates during both C2 and C1 increased above the highest rate previously maintained during any component. The patterns of positively accelerated responding engendered during individual components of the chained schedule when the response key was white during C7, C5, C3, and C1 were absent when the response key was amber during C7, C5, and C3 and white during C1. Instead, a high, steady rate of responding was typical during C2 and C1. To show clearly the effect upon responding when the amber key replaced the white key, response rates under the seven-component schedule studied in Phase 1 are included in Fig. 3 (triangles) for comparison.

Phase III. A return to the seven-component chained schedule in which the response key was white during C7, C5, C3, and C1 in-

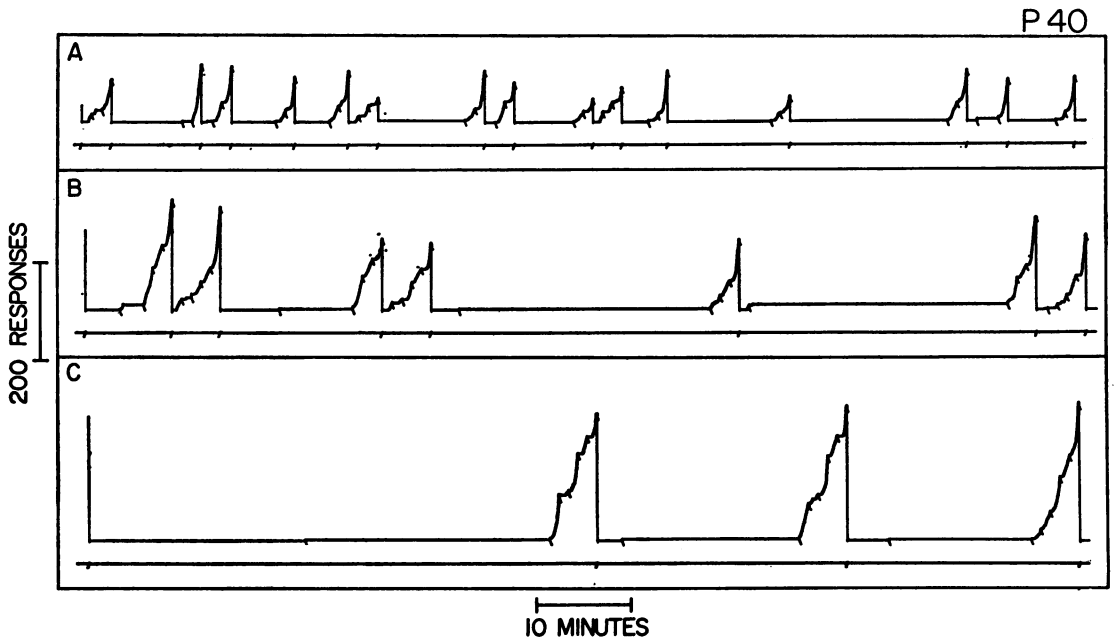

Fig. 2. Cumulative records of responding for Pigeon P40 under three-component (A), five-component (B), and seven-component (C) chained schedules in which the response key was white during C7, C5, C3, and C1, green during C6, blue during C4, and red during C2. A 1-min fixed-interval schedule comprised each component of the chained schedules, and food presentation followed completion of C1. A diagonal mark of the response pen indicates completion of a component; a mark of the event pen indicates food presentation. The response pen reset upon cumulation of 550 responses or upon food presentation.

creased response rates during C5 and C3 and decreased them during C2 and C1. In general, the rates and patterns of responding were like those maintained during Phase I, with response rates during C7 and C6 approaching zero (Fig. 4, triangles).

When the number of components comprising the chained schedule was increased to eight, rates of responding during C7 increased markedly, although responding during the other components was not affected significantly (Fig. 4, squares). Response rates approached zero during C8 and C6, but patterns of positively accelerated responding were typical during C5 through C1.

In general, the 30-sec timeout did not significantly affect rates or patterns of responding under the eight-component chained schedule (Fig. 4, circles). Response rates during components C8 and C6 remained near zero, and periods of no responding were typical during these two components. In both pigeons, response rates during C5 through C1 were slightly higher, but the magnitude of the increase was small.

DISCUSSION

Previous experiments have shown that responding in the pigeon can be maintained at moderate response rates only during the last two or three components of each sequence when (1) as few as five fixed-interval components comprise a chained schedule, (2) each stimulus appears only once during a sequence of components, and (3) the order of component stimuli does not change during successive sequences (Gollub, 1958; Findley, 1962). The present data show that the repetition of a stimulus during alternate components can enhance responding under a chained schedule. When as many as eight components comprised a chained schedule of food presentation and the stimulus appearing during the terminal component also appeared during alternate components, moderate response rates were maintained during all but the initial components.

Responding under chained schedules can also be enhanced under certain other conditions. Kelleher and Fry (1962) studied responding under a three-component chained schedule

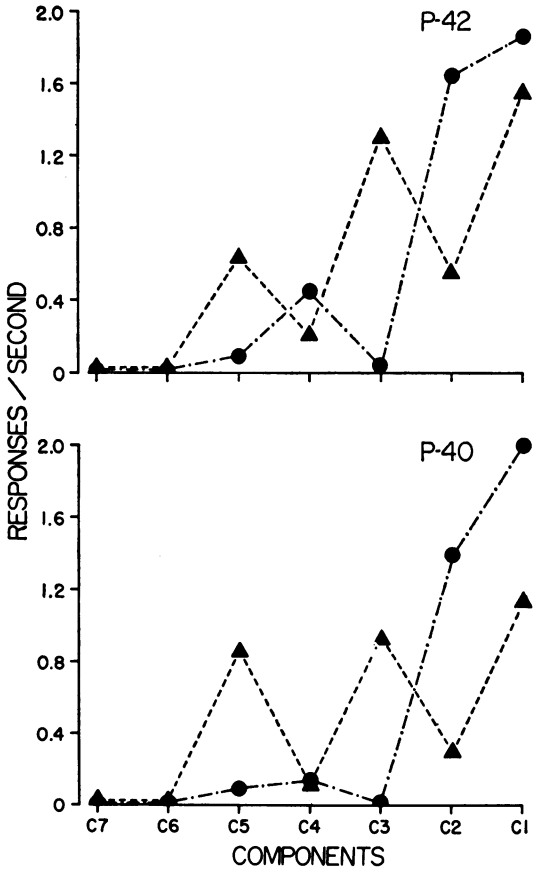

Fig. 3. Mean rates of responding for Pigeons P42 and P40 during individual 1-min fixed-interval components of two seven-component chained schedules. Closed triangles show response rates when the response key was white during C7, C5, C3, and C1; closed circles show response rates when the key was amber during C7, C5, and C3, and white during C1. Under both schedules, the key was green during C6, blue during C4, and red during C2, and food presentation followed completion of C1. Each point is the mean of the last four sessions.

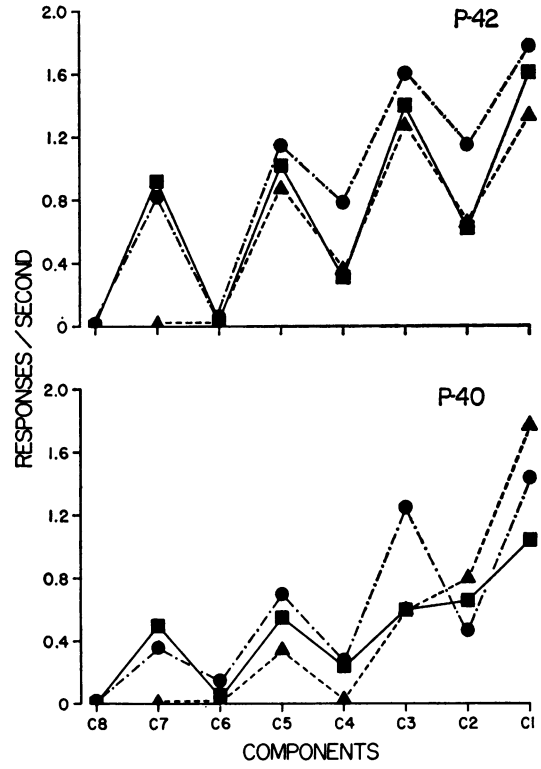

Fig. 4. Mean rates of responding for Pigeons P42 and P40 during individual 1-min fixed-interval components of seven-component (closed triangles) and eight-component (closed squares) chained schedules, and of an eight-component chained schedule with a 30-sec timeout intervening between termination of food presentation and beginning of C8 (closed circles). The response key was white during C7, C5, C3, and C1, amber during C8, green during C6, blue during C4, and red during C2. Food presentation followed completion of C1. Each point is the mean of the last four sessions.

and showed that response rates during the first two components increased when the order of component stimuli changed during successive sequences. Findley (1962) showed that when the number of components comprising consecutive sequences varied, moderate rates of responding were maintained during as many as five fixed-interval components. A recent study (Byrd and Marr, 1969) suggested, however, that the enhancing effects of varying both the number of components and the order of component stimuli may be limited to chained schedules in which a relatively small number of components comprise a sequence. When each component was a 2-min fixed-interval schedule and the number of components comprising a sequence varied between two and 27, responding was not maintained during all components uniformly.

Traditionally, responding under chained schedules has been described in terms of discriminative effects and reinforcing effects of the component stimuli (Skinner, 1938; Gollub, 1958; Kelleher and Gollub, 1962; Kelleher, 1966). The stimulus appearing during a component can discriminatively control a rate and pattern of responding characteristic of that component. Responding during the component may be determined by several factors, including the schedule comprising the component, proximity of the component to food pre-

sentation, and the reinforcing effect of the stimulus appearing during the succeeding component. The present results confirm that discriminative effects of the stimuli are important determinants of the behavior engendered under chained schedules. When the stimulus of the terminal component of a seven-component chained schedule also appeared during alternate components (Phases I and III), response rates were higher than when a different stimulus appeared during alternate components (Phase II). The decreased rates of responding during C7, C5, and C3 in Phase II can be attributed largely to discriminative effects of the stimulus appearing during these components.

While the present results confirm that discriminative effects of the stimuli are important, the results also indicate that the reinforcing effects of the component stimuli are not adequate to account for low response rates during the initial components of chained schedules. Performance under the three-component chained schedule in the present experiment was similar to performance under a three-component chained schedule in which a different stimulus appears during each component (*cf.*, Kelleher and Fry, 1962; Thomas, 1967). Response rates were highest during C1, intermediate during C2, and lowest during C3. Response rate during C3 increased more than eight-fold when the chained schedule was increased from three to five components, and response rate during C5 increased more than six-fold when the five-component schedule was subsequently increased to seven components. The marked increase in response rates during C3 and C5 cannot be described parsimoniously in terms of the conditioned reinforcing effect of the stimuli present during C2 and C4. Under both the three-component and five-component schedules, for example, the response key was red during C2 and white during C3 and C1; yet, response rate during C3 was low under the three-component schedule and high under the five-component schedule. Performance under the eight-component schedule similarly demonstrates that response rate during the initial component is not necessarily a function of the stimulus appearing during the succeeding component. The same stimulus (white key) was present during C7, C5, C3, and C1 (the terminal component), so that responding during C8 was followed by the appearance of a stimulus (white key) that was occasionally associated with food presentation. Gollub (1958), Kelleher and Gollub (1962), Kelleher (1966), and Marr (1969) have reported that the stimulus appearing during the terminal component of a chained schedule can have conditioned reinforcing effects. Indeed, the pattern of positively accelerated responding maintained during C2 and C4 of the eight-component schedule indicates that the white key, the stimulus appearing during alternate components, was a conditioned reinforcer. Therefore, presentation of the white key during C7 might be expected to enhance responding during C8. The data show that response rate during C8 approached zero.

Clearly, these results suggest that when the number of components and the order of component stimuli remain constant during successive sequences, response rate during the initial component of a chained schedule will be low regardless of (1) the number of components comprising a sequence, (2) whether the stimulus present during the succeeding component is a conditioned reinforcer, and (3) whether the stimulus present during the initial component discriminatively controls a high rate of responding when presented during other components. Under the three-component, five-component, and seven-component chained schedules studied, response rates were low during C3, C5, and C7, respectively. Response rates during these three components increased, however, when they were no longer the initial components.

One interpretation of these results is that low response rates are engendered during the initial components of certain chained schedules, just as low response rates are engendered during the initial period of a fixed-interval schedule. Under a fixed-interval schedule, there is a period of little responding at the beginning of the interval followed by an orderly increase in responding during the interval (Skinner, 1938; Ferster and Skinner, 1957). Dews (1962, 1965, 1966) described performance under a fixed-interval schedule in terms of the retroactive enhancing effect of food presentation upon individual responses. According to his analysis, " . . . the progressive increase in rate of responding through the fixed interval would be based on a declining retroactive rate-enhancing effect of the reinforcing stimuli as the delay between response and reinforcement is increased" (Dews, 1962, p. 373). Not only has

Dews shown this adequately to describe performance under fixed-interval schedules when a stimulus is continuously present for the duration of the interval, but he has shown that it can be applied to fixed-interval schedules when there are interruptions of the stimulus conditions (houselight on) prevailing at food presentation (Dews, 1962, 1965). When an interval was divided into 10 segments by the repeated interruption of the houselight condition, response rates were low during the initial segments and increased in an orderly manner during succeeding segments of the interval.

Under a chained schedule, food presentation can be assumed to have similar retroactive enhancing effects upon responding. The effect of food presentation is greatest during the terminal component and is less during each preceding component. When the number of components and the order of component stimuli do not change during successive sequences and each component stimulus is unique, the stimulus of the terminal component discriminatively controls the highest response rate and the stimulus of each preceding component controls a response rate that is lower the further the component is removed from food presentation (*cf.*, Gollub, 1958; Findley 1962). Response rate is always low during the initial component, however, because it is the first component of the sequence. As Dews has stated with respect to fixed-interval schedules, " . . . in any particular interval the fixed reference point for the organism must be the start of the interval rather than the future reinforcement" (Dews, 1962, p. 373). Similarly, the initial component of a chained schedule is the reference point for the beginning of the interreinforcement interval, and response rate during the initial component is low, just as response rate during the initial period of a fixed-interval schedule is low. That the low response rate during the initial component is not a function of the termination of food presentation *per se* was evidenced in the present experiment by the low response rates that prevailed when a 30-sec timeout intervened between food termination and the beginning of the sequence of components. The timeout did not enhance responding during the initial component.

While the present experiment did not specifically study conditioned reinforcing effects of the stimuli appearing during the later components of each sequence, the patterns of positively accelerated responding during individual components implied enhancement by the stimuli appearing during succeeding components. The data show unequivocally, however, that conditioned reinforcement cannot account for low response rates during the initial components.

Chained schedules are complex schedules, and although the present experiment implicates the retroactive rate-enhancing effect of food presentation, the relatively fixed temporal relation of a component to food presentation, and the discriminative and reinforcing effects of the component stimuli, only additional data will contribute to a greater understanding of performance under these schedules. The repetition of a stimulus during alternate components demonstrated more clearly the extent to which (1) response rate during a component is low because it references the beginning of the sequence, and (2) component stimuli discriminatively control responding under a chained schedule. The enhancement of responding during alternate components permitted a quantitative analysis of responding when a particular component was and was not the initial component of a sequence, and when the number of components comprising a sequence was increased systematically.

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