STIMULUS CONTROL OF TEMPORALLY SPACED RESPONDING IN SECOND-ORDER SCHEDULES¹

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Second-order schedules consisting of sequences of component differential-reinforcement-of-low-rate schedules were used to investigate two different methods of introducing exteroceptive stimuli. When different exteroceptive stimuli were associated with each component (chained schedule), periods of pausing and lower response rates developed in the early components compared to the early components of the same sequence in the presence of a single exteroceptive stimulus (tandem schedule). When a brief stimulus change occurred at the completion of each component, response rates were higher in the early components compared to the tandem schedule. Changes in response rates in the early components were directly related to changes in reinforcement frequency in the terminal components produced by the two methods of presenting the exteroceptive stimuli.

A second-order schedule of reinforcement is one in which a particular schedule is treated as a component that is itself reinforced on a schedule of primary reinforcement (Kelleher, 1966). The manner of presenting exteroceptive stimuli in a second-order schedule has marked effects on the maintenance of behavior. Two methods of presenting exteroceptive stimuli in second-order schedules have been studied under fixed-ratio schedules of primary reinforcement. With sequences of fixed-interval components (Gollub, 1958, 1965; Kelleher and Fry, 1962; Findley, 1962) and fixed-ratio components (Ferster and Skinner, 1957; Findley, 1962; Thomas, 1964), longer periods of pausing and lower response rates developed in the early components when different exteroceptive stimuli were associated with each component than when a single exteroceptive stimulus was associated with each component. Under similar second-order schedules of fixed-interval components (deLonge, 1964; Kelleher, 1966) and fixed-ratio components (Findley and Brady, 1965; Thomas and Stubbs, 1966), in which a brief exteroceptive stimulus change occurred at the completion of each component, overall response rates were well maintained and behavioral patterns appropriate to the schedule developed in each component.

With fixed-ratio components, response rates are usually higher in the early components, when a brief stimulus change occurs at the completion of each component, than they are on the same second-order schedule with a single exteroceptive stimulus present throughout the schedule.

In the present study, second-order schedules consisting of sequences of component differential-reinforcement-of-low-rate (DRL) schedules were used to evaluate the two different methods of presenting exteroceptive stimuli. A DRL schedule specifies that only those responses which terminate interresponse times (IRTs) longer than some particular value (the DRL value) will be reinforced. In previous studies of second-order schedules consisting of component fixed-interval and fixed-ratio schedules, it was generally true that changes in response rates were positively correlated with changes in reinforcement frequency. Under a simple DRL schedule, however, changes in response rates are usually negatively correlated with changes in reinforcement frequency. The present investigation was concerned with whether or not the two methods of presenting exteroceptive stimuli in second-order schedules would have effects on behavior in DRL schedule components similar to their effects on behavior in other types of schedule components. Such a result would add generality to the behavioral effects produced by the two different methods of presenting stimuli in second-order schedules.

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METHOD

Subjects

Two adult male homing pigeons (B1 and B2) and one adult male White Carneaux pigeon (B4) were maintained at approximately 80% of their free-feeding weights. Birds B1 and B2 had a history of 20 sessions on a fixed-interval schedule of reinforcement. Bird B4 had an extended history on various fixed-ratio and fixed-interval schedules.

Apparatus

The experimental space was a Lehigh Valley Electronics pigeon chamber containing two response keys. All procedures were programmed on the left response key which could be operated by a force of 15 g or more. A response feed-back relay was located behind the panel on which the key was mounted. The experimental chamber was enclosed in a larger ventilated chamber which attenuated most extraneous sounds and a continuous masking noise was provided by a white-noise generator. Programming was accomplished automatically by a system of switching relays and timers. Data were recorded on magnetic impulse counters and a cumulative recorder.

Procedure

Experimental sessions were given daily, five days a week. Each session terminated after 50 reinforcements. A reinforcement consisted of a 4-sec access to mixed grain. The key light and house light went off simultaneously with the 4-sec operation of the grain magazine and illumination of the grain by the magazine light. Each session was preceded and followed by a "blackout" condition, variable in duration, during which all lights in the experimental chamber were off and responses had no programmed consequences.

The basic schedule of reinforcement was such that the subject was reinforced when three consecutive DRL requirements had been completed. No exteroceptive stimulus changes occurred between the beginning of the schedule and grain reinforcement. The schedule was a tandem schedule (tand DRL DRL DRL) (Dews and Morse, 1959; Ferster and Skinner, 1957) or a second-order schedule in which the DRL requirement was reinforced on a fixed-ratio schedule, FR 3 (DRL) (Kelleher, 1966).

One method of presenting exteroceptive stimuli in the second-order schedule was to associate a different stimulus with each of the three component DRL schedules. When stimuli are presented in this manner, the second-order schedule is a chained schedule (chain DRL DRL DRL) (Ferster and Skinner, 1957). The other method was to present a brief exteroceptive stimulus change at the completion of each DRL component. The schedule will be referred to as the brief-stimulus schedule, following the terminology of Kelleher (1966).

All three subjects performed on the tandem schedule. B1 was exposed to both methods of presenting the exteroceptive stimuli in the second-order schedule. B2 was exposed to only the chained schedule. B3 was exposed to only the brief-stimulus schedule. The sequence and number of sessions for each schedule are presented in Table 1 for the three birds. The DRL value for B1 and B4 was 8 sec, and for B2, 12 sec.

Table 1
Sequence and number of sessions for each schedule for three subjects.

<i>Schedule</i>	<i>B1</i>	<i>B2</i>	<i>B4</i>
Tandem	20	52	—
Chain	38	19	—
Tandem	16	—	—
Brief-stimulus	31	—	32
Tandem	30	—	13

On the tandem schedule, the response key was transilluminated with green light during the completion of the three consecutive DRL schedules. On the chained schedule, the response key was transilluminated with red light during the first DRL component, white light during the second component and blue light during the third component. On the brief-stimulus schedule, the response key was transilluminated with green light during each component and the magazine light was presented for 0.3 sec after each of the first two DRL components was completed. The key light and the house light were turned off for the 0.3 sec the magazine light was illuminated.

Interresponse times were recorded separately for each of the three DRL components in eight class intervals with a class interval duration of $0.25x$, where x is the DRL value. Responses occurring in class intervals 5 through 8 terminated a component, and all

IRTs longer than $7x$ were recorded in class interval 8. The definition of an IRT in the present study follows the extended definition of Morse (1966) in that the initiation of an IRT is allowed to begin with events other than a previous response, such as the end of a reinforcement period or the presentation of an exteroceptive stimulus.

RESULTS

Figure 1 presents the response rates in each of the three components of the tandem, chained, and brief-stimulus schedules for B1. Each point is based on the median of the last five sessions under each experimental condition. The vertical line through each point shows the range of rates over the five sessions. When a different exteroceptive stimulus was associated with each of the three component DRL schedules (chained schedule), the response rates in all three components were lower than those in the three components

Fig. 1. Response rates of Subject B1 in each of the three components of the tandem, chained, and brief-stimulus schedules. The schedules are presented in the order of exposure to the subject. The first, second, and third components of each of the schedules are indicated by numerals on the abscissa. Each point is based on the median of the last five sessions under each schedule and the vertical line through each point shows the range of response rates over the last five sessions.

Fig. 2. Cumulative response records of B1 on the three component tandem and chained schedules. Pips of the recording pen indicate the completion of each DRL component; the pen resets to baseline with the occurrence of primary reinforcement. The records are from the last session of the first exposure to the tandem schedule and the last session on the chained schedule.

under the first tandem schedule exposure. Response rates obtained in the first two components of the chained schedule were lower than rates in the first two components of the tandem schedule on the second and third replication of the tandem schedule. The rate in the third component during the chained schedule was the same as the rates in the third component during the second and third replication of the tandem schedule. Cumulative response records of performances of B1 on the tandem and chained schedules are presented in Fig. 2. The records are from the last session of the first exposure to the tandem schedule and the last session on the chained schedule. The differences between the performances on the tandem and the chained schedules obtained for B1 were generally replicated with B2. The response rates of B2 on the two schedules are presented in Fig. 3a. Response rates of both subjects in the first component of the chained schedule were much lower than the rates required to obtain maximum frequency of component termination. Pauses in the first component of the chained schedule were often longer than the required DRL value.

Cumulative response records for B1, showing the transition from tandem to chain performances, are presented in Fig. 4. As early as

Fig. 3. (a) Response rates of Subject B2 in each of three components of the tandem and the chained schedules. (b) Response rates of Subject B4 in each of the three components of the tandem and the brief-stimulus schedules. The first, second, and third components of each of the schedules are indicated by numerals on the abscissa. Each point is based on the median of the last five sessions under each schedule and the vertical line through each point shows the range of the response rates over the last five sessions.

Fig. 4. Cumulative response records of B1 showing selected aspects of the transition from tandem to chain performance. Pips of the recording pen indicate the completion of each DRL component; the pen resets to baseline with the occurrence of primary reinforcement.

the third session on the chained schedule, many of the characteristics of the final chain performance were apparent. The highest response rates occurred in the terminal component, and pausing began to occur in the first component. During the fifth session, response rates in the terminal component were lower than in previous sessions, and increased pausing was apparent in the first component. By the eleventh session, the first component consisted mainly of long periods without responding. Response rates increased in the third component above the levels of previous sessions, and pausing in the first component was less extreme in the seventeenth session. By the twenty-seventh session, the performances were characteristic of the stable chain performances. The transition from tandem performance to chain performance was replicated with B2.

When B1 was exposed to the brief-stimulus schedule, during which the magazine light was presented for 0.3 sec after each of the first two DRL components was completed, response rates were higher in the first component than in the tandem schedule (Fig. 1). The increase in response rates in the initial component under the brief-stimulus schedule also occurred for B4 (Fig. 2b). B1 had lower response rates in the second and third components of the brief-stimulus schedule than in the second and third tandem components; B4 had higher response rates in the second and third brief-stimulus components than in the second and third tandem components. Cumulative response records of both subjects on the brief-stimulus schedule are presented in Fig. 5. The tandem schedule records are from the last session of the second exposure to the tandem schedule for B1 and from the last tandem schedule session for B4. The brief-stimulus records of both subjects are from the last session on that schedule.

The behavioral effects of the two methods of presenting the exteroceptive stimuli in the second-order schedule were also differentiated by the IRT distributions of each of the three components. Figure 6 presents the IRT distributions of B1 and B2 on the tandem and the chained schedules. The IRT distributions are based upon the median values of the last five sessions under each condition. The tandem IRT distribution of B1 is based on the last five sessions of the first exposure to the

tandem schedule. The IRT distributions indicate that the major difference between the tandem and the chained schedules was in the larger percentage of responses terminating with long IRTs in the first component of the chained schedule. The largest percentage of responses in the first chain component (Fig. 6a and b) occurred in class interval 8. The second and third chain components were characterized by a higher percentage of responses terminating with shorter IRTs and relatively few responses terminating with longer IRTs. The pattern of responding in the second and third tandem components was almost identical to that in the second and third chain components.

The IRT distributions of B1 and B4 on the tandem and the brief-stimulus schedules are presented in Fig. 7. The distributions are based upon the median values of the last five sessions of the second exposure to the tandem schedule and the last five sessions of the brief-stimulus schedule for B1. The distributions of

Fig. 5. Cumulative response records of Subjects B1 and B4 on the three component tandem and brief-stimulus schedules. On the brief-stimulus schedule the completion of each of the first two components produced a 0.3-sec presentation of the magazine light. Pips of the recording pen indicate the completion of each DRL component; the pen resets to baseline with the occurrence of primary reinforcement. The tandem schedule records are from the last session of the second exposure to that schedule for B1 and from the last tandem schedule for B4. The brief-stimulus records of both subjects are from the last session on that schedule.

B4 are based on the last five sessions under both conditions. For both subjects the major difference between the two schedules was in the distribution of the first components. The

response distribution of the first component of the brief-stimulus schedule had a larger percentage of responses terminating with short IRTs and a smaller percentage of responses terminating with long IRTs than the distribution of the first component of the tandem schedule. The second and third component distributions of both schedules were very similar. The modal IRT of B4 was near the DRL value for all three components of the brief-stimulus schedule. The modal IRT was at or near the DRL value for B4 for the second and third components of the tandem schedule. The nearness of the modal IRT to the DRL value of B4 is similar to data reported by Stadon (1965) for birds on simple DRL schedules with similar DRL values. For the other two subjects, under all schedule conditions, the modal IRT of the components occurred either before or after the DRL value.

An important difference between the schedules as a function of the method by which the stimuli were introduced was in the relative time spent in each of the components. Figure 8 presents the durations per session of the three components of all three schedules for B1. Each point is the median of the last five sessions under each experimental condition. The vertical line through each point shows the range of durations over the five sessions. With the tandem schedule, the duration per session of each component increased from the first to the third component. When the program was changed to the chained schedule, more time was spent in the terminal component than was spent in the terminal component of the tandem schedule. Less time was spent in the second component of the chained schedule than was spent in the second component of the tandem schedule. The difference in the duration of the components on the tandem and chained schedule of B1 may also be seen in a comparison of the cumulative records in Fig. 2. The change in the relative duration of the components for B2 is shown in Fig. 9a. The duration of the terminal component increased and that of the second component decreased when the schedule was changed from tandem to chain. The duration of the first component of B2, however, increased with the chained schedule whereas that of B1 did not. When the program was changed to the brief-stimulus schedule, the duration of the second and third components

Fig. 6. Interresponse time distributions for Subjects B1 and B2 of the three components of the chained (a and b) and tandem (c and d) schedules. The class intervals are 2 sec for B1 and 3 sec for B2. Class interval 5 is the earliest reinforced class interval.

Fig. 7. Interresponse time distributions of Subjects B1 and B4 on the brief-stimulus (a and b) and tandem (c and d) schedules. The class intervals are 2 sec and class interval 5 is the earliest reinforced interval.

Fig. 8. Duration per session of the three components of the tandem, chained, and brief-stimulus schedules for B1: duration per session of the components is indicated on the left ordinate. The points representing the durations of the three components for each schedule are indicated by the numerals on the abscissa. Reinforcement frequency in the terminal component of the three schedules for B1: reinforcement frequency of the terminal components is indicated on the right ordinate. The points representing reinforcement frequency are the isolated points plotted for the terminal component of each schedule. Each point is the median of the last five sessions under each schedule and the vertical line through each point shows the range over the five sessions.

of B1 decreased from what they were on the tandem schedule, and the first component duration increased. The durations of the second and third components of B4 both increased when the schedule was changed from tandem to brief-stimulus (Fig. 9b). There was little change in the duration of the first component of B4 between the two schedules.

The above differences in the durations of the terminal component, resulting from the two different manners of introducing the exteroceptive stimuli, produced differences in the reinforcement frequencies in the terminal components. Figure 8 shows the reinforcement frequency (reinforcements per minute) in the terminal component of all three schedules for B1. Each point is the median of the last five sessions under each experimental condition. The vertical line through each point

indicates the range of reinforcement frequency over the five sessions. When the schedule was changed from tandem to chain, the reinforcement frequency in the terminal component declined. The decline is associated with a decline in response rates in the first two components of the chained schedule (Fig. 1). The reinforcement frequency increased when the schedule was returned to tandem, and response rates in the first two components also increased. The reinforcement frequency in the third component of B2 also decreased when the schedule was changed from tandem to chain (Fig. 9a) and response rates declined in the first two components (Fig. 3a). When the schedule for B1 was changed from tandem to brief-stimulus, the frequency of reinforcement in the terminal component increased markedly (Fig. 8) and the increase in reinforcement

frequency was associated with a marked increase in response rates in the first component (Fig. 1). When the schedule for B4 was changed from tandem to brief-stimulus, however, the reinforcement frequency in the terminal component decreased (Fig. 9b), although the response rate in all three components was higher on the brief-stimulus schedule than on the tandem schedule (Fig. 3b).

DISCUSSION

In general, the behavioral effects of the two methods of presenting exteroceptive stimuli in the second-order schedule consisting of sequences of component DRL schedules, were similar to those effects observed with second-order schedules consisting of sequences of other types of schedule components.

The periods without responding, and with lower response rates that developed in the first and second chain components compared to performances obtained on the analogous tandem DRL schedule, are similar to per-

formances obtained on extended chained schedules containing other schedule requirements (Kelleher, 1966; Kelleher and Gollub, 1962). When the response rates of the first chain component are compared to those of the first tandem component, the results show that the difference in response rates in the early components is due to an attenuation of behavior in the presence of the exteroceptive stimulus associated with the first chain component. The pauses and lower response rates in early chain components have been interpreted as a result of the stimulus associated with the following component not functioning as an effective conditioned reinforcer for responding in the early component (Gollub, 1958; Kelleher, 1966; Kelleher and Fry, 1962; Kelleher and Gollub, 1962). The lower response rates in the early chain components could also be due to the association of the first chain component with exteroceptive stimuli which have an unfavorable position in the overall reinforcement contingency. The first chain component stimuli are associated with periods of nonreinforcement, whereas the stimuli associated with the terminal component are consistently associated with primary reinforcement. The discriminative function of the stimuli associated with the initial chain component, as they are associated with nonreinforcement, may control lower response rates that would obscure any possible rate-enhancing conditioned reinforcing function of stimuli associated with the next component.

The transition from the tandem to the chained schedule was similar in some respects to the transition from two-component tandem fixed-interval schedules to two-component chained fixed-interval schedules reported by Gollub (1958). Gollub showed that response rates first decreased in the initial chain component due to the development of a discrimination between the two components; behavior in the terminal component is reinforced with primary reinforcement while behavior in the first component is not. Response rates in the first component began to increase with further exposure to the chained schedule as the second component stimulus became an effective conditioned reinforcer. The rates eventually increased in the first fixed-interval chain component above their levels in the first fixed-interval tandem component. In the present study, response rates first decreased in the ini-

Fig. 9. Duration of the three components of the tandem and chained schedules for B2 is shown in a. Duration of the three components of the tandem and brief-stimulus schedules for B4 is shown in b. Duration of the components is indicated on the left ordinate. The points representing the durations of the three components for each schedule are connected by solid lines. The first, second, and third components of each schedule are indicated by numerals on the abscissa. Reinforcement frequency in the terminal component of the tandem and chained schedules for B2 is shown in a. Reinforcement frequency in the terminal component of the tandem and brief-stimulus schedules for B4 is shown in b. Reinforcement frequency is indicated on the right ordinate. The points representing reinforcement frequency are the isolated points plotted on the terminal component of each schedule. Each point is the median of the last five sessions under each schedule and the vertical line through each point shows the range over the five sessions.

tial component when the schedule was changed from tandem to chained. The long pauses in the initial component became shorter and response rates increased with further exposure to the chained schedule. Response rates in the first and second chain components never approached the rates that had been maintained in the first and second tandem components. The increase in response rates after the initial decrease in rates, however, does suggest that the stimuli associated with the following components did develop some conditioned reinforcing effectiveness.

The increases in response rate in the first DRL component of B1, and in all three components of B4 when completion of the first two components produced brief presentations of a stimulus intermittently associated with primary reinforcement, are consistent with previous studies involving the presentations of such stimuli following the completion of the components of second-order schedules containing other schedule requirements (deLorge, 1964; Findley and Brady, 1965; Kelleher, 1966; Thomas and Stubbs, 1966). The increase in response rates indicates that the brief stimulus presentations functioned as effective conditioned reinforcing stimuli.

The changes in the response rates in the first and second components of B1 and B2 under the chained schedule and the brief-stimulus schedule when compared to the tandem schedule are apparently related to the changes in the reinforcement frequency in the terminal component of the second-order schedule. Studies concerned with performances on two-component chained schedules of reinforcement have indicated that the conditioned reinforcing effectiveness of the terminal component stimulus is directly related to the frequency of reinforcement in the terminal component (Kelleher, 1966; Kelleher and Gollub, 1962). Presumably, the frequency of reinforcement in the terminal component affects behavior in the early components of extended chained and tandem schedules. However, the increased response rates of B4 with the brief-stimulus schedule show that the rate-enhancing effect of stimuli intermittently associated with pri-

mary reinforcement can occur in a second-order schedule when there is an overall decrease in reinforcement frequency. This indicates that the method of associating stimuli with primary reinforcement and of presenting them in a second-order schedule may be as important as the frequency of primary reinforcement (*cf.* Kelleher, 1966).

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