DISCRIMINATIVE PROPERTIES OF BRIEFLY PRESENTED STIMULI

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In Experiment I, pigeons' responses produced food according to a fixed-interval schedule while responses on the key also produced brief stimuli according to a variable-interval schedule. Each brief stimulus reset the fixed interval. Thus, a brief stimulus occurred irregularly but a fixed minimum time separated the occurrence of food from a brief stimulus. Pauses followed brief stimuli and were followed by an accelerated response rate until another brief stimulus or food occurred. In Experiment II, four control procedures were examined. (1) Brief-stimulus presentations were omitted, producing a loss of response patterning. (2) A second-order schedule was studied with fixed-interval components. This schedule produced patterning following brief stimuli similar in kind and degree to that found in Experiment I. (3) A conjoint schedule was arranged in which food was no longer separated from the stimulus by a fixed time; pauses following the stimulus no longer resulted. (4) A brief food reinforcer replaced the brief visual stimulus, resulting in a constant response rate with no pausing following the brief food stimulus. The results suggest that the brief-stimulus effects were due to discriminative functions produced by the fixed temporal relation separating the stimulus from food.

Key words: brief-stimulus schedule, discriminative stimulus, conditioned reinforcement, second-order schedule, fixed interval, variable interval, Index of Curvature, pigeons

Brief-stimulus presentations have striking effects on schedule performance. If, for example, a pigeon has to complete a sequence of 15 fixed-interval schedules before food is presented and completion of each interval ends in a brief stimulus (*e.g.*, 1-sec white keylight), a fixed-interval pattern of responding typically results within each component (Kelleher, 1966a). Performance within each fixed interval would be characterized by a pause followed by a positively accelerated rate. The pattern of performance within components is like that observed under simple fixed-interval schedules where each interval ends with a reinforcer such as food (Ferster and Skinner, 1957).

This sample schedule is but one of a wide

variety of situations in which brief-stimulus presentations have affected rates and patterns of responding. A commonality among much of the brief-stimulus research has been the use of second-order schedules (for other procedures see Clark and Sherman, 1970; J. Zimmerman, 1969). Under second-order schedules, behavior maintained under one schedule (the component schedule) is treated as a unitary response that is reinforced according to another schedule. In the case above, the fixed-interval schedule would be the component schedule reinforced according to a fixed-ratio schedule. Brief-stimulus effects are not restricted to fixed-interval components; analogous results have been obtained with fixed-ratio (*e.g.*, Lee and Gollub, 1971), variable-interval (*e.g.*, McMillan, 1971), and differential-reinforcement-of-low-rate (*e.g.*, Thomas and Stubbs, 1967) component schedules. A general finding of second-order schedules is that brief stimuli engender response patterns within components like those seen under simple schedules.

While there are various explanations for brief-stimulus effects (Kelleher, 1966a; Neuringer and Chung, 1967; Staddon, 1972; Stubbs, 1971), most explanations have emphasized the

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reinforcing effects of the stimuli. The similarity between component response patterns and those found on simple schedules suggests that the stimuli might act like food, water, or some other reinforcer. Other evidence for a reinforcement interpretation derives from the conditioned-reinforcement literature and has led to a distinction between two types of brief stimuli, paired and nonpaired. Paired stimuli occur at the end of each component and also when food is presented. Nonpaired stimuli occur at the end of all components except those ending with food. A prevalent view of conditioned reinforcement is that a stimulus paired with a reinforcer will develop reinforcing properties. Paired stimuli presumably would be more reinforcing than nonpaired.

In contrast to explanations emphasizing reinforcing functions, several explanations have placed more emphasis on other factors (Neuringer and Chung, 1967; Staddon, 1972, 1974; Stubbs, 1971). Stubbs suggested that performance is primarily controlled by the discriminative rather than reinforcing functions of stimuli, at least when there is a fixed relationship between presentation of a stimulus and presentation of a reinforcer. When, for example, fixed-interval schedules are the component schedules, there is a fixed temporal relation between presentation of the stimulus and presentation of the reinforcer. The presentation of a brief stimulus is not followed by food (or another brief stimulus) until a fixed period of time has passed. The brief stimulus is followed by a period of nonreinforcement and could acquire discriminative or S^A properties.

Many, if not all, stimuli have multiple functions: food, electric shock, various drugs, *etc.*, may all have reinforcing, eliciting, and discriminative effects (Catania, 1971). Most likely, brief-stimulus presentations also serve multiple functions, making analysis more difficult. The relative contribution of reinforcing and discriminative functions is not clear from the second-order schedule research. As a result of the difficulties interpreting second-order schedule results, the present procedure was devised as an attempt to clarify the possible discriminative functions of brief-stimulus presentations.

In the basic procedure, pigeons' responses were reinforced according to a modified fixed-interval schedule of 120 sec. Responses on the key also produced a brief stimulus irregularly

according to a variable-interval schedule. Each brief-stimulus presentation reset the fixed-interval requirement, thus setting a minimum time (120 sec) between the occurrence of the stimulus and food. Thus, the stimulus was presented irregularly, and only if 120 sec had passed without a stimulus would food be delivered. Since each stimulus "signalled" that food would not occur for at least 120 sec, a pause would be expected following the stimulus if the stimulus developed a discriminative function. The stimuli were scheduled irregularly according to a variable-interval schedule; if the stimuli primarily served a reinforcing function, a constant rate would be expected because the variable-interval scheduling of a reinforcer typically produces a constant response rate (de Lorge, 1971).

EXPERIMENT I

METHOD

Subjects

Three male, adult Silver King pigeons were maintained at 80% of their free-feeding weights. The pigeons previously served in discrimination experiments.

Apparatus

The experimental space was a two-key Lehigh Valley Electronics pigeon chamber (model 143-04). Only the right response key was used. The key was lit by red or white light. A minimum force of 12 g (0.12 N) operated the key. White noise was continuously present. Relay and timing circuitry located in an adjacent room controlled sessions.

Procedure

Sessions were conducted daily. Each session terminated after thirty-five 4-sec presentations of food. The food magazine was illuminated by green light during each food cycle. The response key normally was transilluminated by red light.

The schedule was a complex schedule under which responses on the same key produced both food and brief stimuli; responses produced food according to a modified fixed-interval (FI) 120-sec schedule and concurrently a brief stimulus according to a variable-interval (VI) 120-sec schedule. When the variable-

interval requirement was met, a response produced the brief stimulus, a 2-sec change of key color from red to white; at the end of the brief stimulus, the fixed-interval requirement was reset. If, for example, 100 sec of the FI 120-sec schedule had elapsed when the variable-interval requirement was met, the response-produced brief stimulus reset the fixed interval. If another brief stimulus occurred 40 sec later, the fixed interval was again reset; another brief stimulus 5 sec later would reset the fixed interval again, and so on. Food could be produced only if 120 sec elapsed without a brief stimulus. If the fixed-interval and variable-interval requirements were met simultaneously, the response produced food but not the stimulus. Following food, the next response produced the brief stimulus. This aspect of the procedure was instituted to avoid unwanted pairing of the brief stimulus and food. In summary, the brief stimulus was produced at varying intervals averaging 120 sec and the stimulus was intermittently followed by food, but only after a fixed minimum time of 120 sec. The variable-interval schedule contained 26 intervals and was constructed from the Catania and Reynolds formula (1968, Pp. 380 to 381).

The pigeons were exposed to four experimental conditions. Under the first (86 sessions) and third (18 sessions), the brief stimulus was not paired with food. The red key darkened during each food presentation; thus, the white-key stimulus was never paired with food. Under the second and fourth conditions, the white stimulus was paired with food. There are several ways to pair a stimulus (Stubbs and Cohen, 1972); two were used. For the second condition, the red key turned white at the onset of each food cycle and remained on (simultaneous pairing). This condition was in effect for 22 sessions. For the fourth condition, the stimulus was also paired, but here when food was to be presented, the white-key stimulus preceded each food presentation by 0.5 sec and remained on for the duration of the food cycle (preceding overlapping pairing). This condition was in effect for 28 sessions for Pigeons 31 and 33 and for 46 sessions for Pigeon 34. This last condition was imposed after the procedures of Experiment II; thus, numerous conditions and nine months intervened between the third and fourth conditions. Conditions were changed only when there were

no systematic changes in performance for at least five consecutive sessions.

RESULTS

Figure 1 shows cumulative records taken from the last session of the second condition (paired brief stimulus) and the last session of the third (nonpaired brief stimulus) for each pigeon. The records indicate that the brief stimulus (represented by downward pen deflections) occurred at varying time intervals; food presentations (represented by the reset of the response pen) were separated from prior brief-stimulus presentations by a fixed time period. Behavior generally was characterized by pausing after a brief stimulus followed by positively accelerated responding. Once responding began, it continued until another brief stimulus or food occurred; then another pause would occur. Responding was characteristic of fixed-interval schedule control. Not all brief-stimulus presentations produced pauses, however. Pigeon 31 exhibited pauses after approximately 85% of the brief-stimulus presentations; Pigeons 33 and 34 showed pauses following approximately 70%. No differences were observed between the paired condition (S^P) and the nonpaired condition (S^N). The records are similar to those from the other two conditions.

Figure 2 shows response rates across four 30-sec class intervals following brief-stimulus presentations; responses and time were recorded separately for the first 30-sec interval following a brief stimulus, second 30-sec, third 30-sec, and fourth 30-sec intervals. Total responses for each interval were divided by the total time spent in each interval over the entire session. Since each brief stimulus reset the fixed-interval requirement to the first 30-sec class interval, a greater proportion of session time was spent in earlier intervals. Responses following the fourth 30-sec period, which produced food, were not included in the calculations. Responses and time following a reinforcer were not counted until a brief stimulus had occurred. Responses and time before a brief stimulus were omitted because pausing might occur following food due to the fixed-interval requirement (Stubbs, 1971). The data are medians of the last five sessions of each condition.

Figure 2 shows that response rates were low during the first 30-sec period following a brief

Fig. 1. Cumulative response records for three pigeons. Brief-stimulus presentations were scheduled according to a VI 120-sec schedule; food was scheduled according to a modified FI 120-sec schedule. The records are from the last sessions each from the second and third conditions. The label S^P indicates that the brief stimulus was intermittently paired with food; the label S^N indicates that the stimulus was not paired. Each response stepped the pen, and downward deflections of the pen indicate brief-stimulus presentations. Each reset of the pen indicates food delivery. The recorder motor ran except during food cycles.

Fig. 2. Response rate as a function of time since a brief-stimulus presentation. Data are medians of the last five sessions. The conditions go from left to right in order of occurrence. The label S^N (and filled circles) indicate non-paired brief-stimulus conditions; the label S^P (and unfilled circles) indicate paired brief-stimulus conditions.

stimulus and increased across the four 30-sec class intervals. The increase in response rate is like that observed on simple fixed-interval schedules and second-order schedules with fixed-interval components (Kelleher, 1966b). Although behavior was somewhat variable across conditions, there were no consistent

differences between the paired and nonpaired conditions.

Figure 3 shows a variation of the Index-of-Curvature measure. The Index of Curvature is a statistic that describes the degree of response patterning under fixed-interval schedules (Fry, Kelleher, and Cook, 1960; Gollub,

Fig. 3. Index of Curvature measures, the medians and ranges of the last five sessions of each condition. Filled circles indicate nonpaired brief-stimulus conditions, unfilled circles indicate paired conditions. The vertical lines show the ranges. The points are arranged from left to right in order of occurrence.

1964). A value of 0.0 indicates a constant response rate across quarters of a fixed interval, while larger numbers (reaching a maximum of 0.75 when the fixed interval is divided into quarters) indicate greater curvature. The data are medians and ranges of the last five sessions of each condition. The Index was calculated from daily response-rate measures across the four 30-sec class intervals (the data shown in Figure 2). Figure 3 shows no consistent differences in the degree of response patterning across conditions; both paired and nonpaired stimuli engendered similar performances. Pigeon 33 showed a low curvature measure under the first condition, but curvature measures increased over the second and third conditions.

EXPERIMENT II: CONTROL PROCEDURES

Experiment I demonstrated that maintaining a fixed minimum time between brief-stimulus and food presentations resulted in fixed-interval-like patterning, even though the brief stimulus was produced according to a variable-interval schedule. In Experiment II, four control procedures were studied to clarify the conditions responsible for patterning.

METHOD

Subjects and Apparatus

Same as in Experiment I.

Procedure

Conditions were similar to those described in Experiment I, in that each session was terminated after thirty-five 4-sec food presentations; the hopper was illuminated by green light; the key stimulus was red; and each brief stimulus was a 2-sec change in key color to white unless otherwise indicated. All variable-interval interreinforcement distributions were derived from the Catania and Reynolds formulation. Conditions were conducted according to the order outlined in Table 1.

Brief stimulus omitted. The procedure was identical to that of Experiment I, except that brief-stimulus presentations were omitted. The VI 120-sec schedule and the FI 120-sec schedule timed concurrently. Once the variable-interval requirement had been met, the fixed-interval requirement was reset. Completion of the variable interval was not accompanied by any stimulus change; the response key remained red rather than turning white as in Experiment I.

Table 1

The order of conditions and the number of sessions under each in Experiment II.

Condition	Number of Sessions
1. Brief Stimulus Omitted	10
2. Second-Order Schedule	74
3. Conjoint Schedule	9
4. Food as Brief Stimulus	*

*Pigeon 31 was exposed to this condition for 10 sessions; the duration of the food brief stimulus was 2 sec. Pigeon 33 was exposed for nine sessions with a 2-sec food stimulus, then seven sessions with a 4-sec food stimulus. Pigeon 34 was not exposed to this condition.

Second-order schedule. During this condition, pigeons responded under a second-order schedule where FI 120-sec components were maintained under a VI 200-sec schedule. If an FI 120-sec component was completed before an interval of the VI 200-sec schedule had elapsed, a brief stimulus was presented. If the variable-interval requirement was met, completion of a fixed-interval component produced food. Only nonpaired brief stimuli terminated components (see Experiment I). The variable-interval interreinforcement distribution contained 18 intervals.

The particular value of the second-order schedule was chosen because (1) it maintained the same relationship (120 sec) between brief-stimulus and food presentations as in Experiment I; and (2) it approximated the mean reinforcement rate observed in Experiment I for all three pigeons (260 sec per reinforcement).

Conjoint schedule. Performance was then examined under a conjoint schedule (Catania, Deegan, and Cook, 1966), in which the brief stimulus was presented according to an FI 120-sec schedule and food was presented according to a simultaneous, independent VI 260-sec schedule. The variable-interval distribution contained 18 intervals. This schedule differed from the second-order and complex brief-stimulus schedules in that food could follow the presentation of a brief stimulus at any time. If fixed- and variable-interval requirements were met simultaneously, the first response produced the brief stimulus and the next produced food. Thus, although only non-paired brief stimuli were used there could have been opportunities for the brief stimulus to be closely followed by food.

Food as the "brief stimulus". For the final condition, the schedule of Experiment I was re-instated for two subjects with one major change. As before, food was presented according to the modified FI 120-sec schedule. But food, rather than a white stimulus, was presented as the brief stimulus according to the VI 120-sec schedule. Each presentation of food under the VI 120-sec schedule reset the fixed-interval requirement. When food followed completion of a fixed interval, the red-key light went off and food was available for 4 sec. When food followed completion of a variable-interval requirement, the keylight remained red and food was available for only 2 sec. The

reinforcers following completion of a fixed-interval or variable-interval requirement differed in duration and with regard to the accompanying stimuli. This condition was in effect for 10 sessions for Pigeon 31 and nine sessions for Pigeon 33. Observation of Pigeon 33 revealed that this pigeon did not eat any grain during 2-sec food presentations. Accordingly, the duration of the "brief-stimulus" food cycle was increased to 4 sec; during these food cycles, the key remained red (the key turned dark only for food presentation after completion of a fixed-interval requirement).

RESULTS

Figure 4 shows response rates across the various conditions. The data are medians of the last five sessions under the complex brief-stimulus schedule (Experiment I, Condition 3) and the four control schedules. Data from the complex brief-stimulus schedule are the same as in Figure 2 and are presented again simply for comparative purposes. Figure 4 is analogous to Figure 2 and the data were gathered in a similar way. Responses and times were recorded for 30-sec time classes following a brief stimulus and response rates were calculated for each class. For all brief-stimulus schedules, except the conjoint, responses and time following food were not counted until a brief stimulus (white light or food) had occurred. Under the one condition where brief stimuli were omitted, responses and time were not counted during the first variable-interval component that followed food.

Under the complex brief-stimulus schedule, redrawn from Experiment I, response rates increased across the four time-class intervals. When, however, brief-stimulus presentations were omitted, an approximately constant rate was observed across the four time classes of the modified fixed interval; pauses characteristic of the brief-stimulus schedule were absent here. Overall response rates were higher when the stimulus was no longer presented than when it had been. Under the second-order schedule, response rates were low during the first 30-sec period following a brief stimulus and increased across the four time classes. Response rates were lower under the second-order schedule than the complex brief-stimulus schedule, even though the reinforcement rate was similar.

Fig. 4. Response rate as a function of time since a brief stimulus. Data are medians of the last five sessions. The labels at the top indicate the various conditions. (See text for additional details.)

Under the conjoint schedule, a constant rate resulted across quarters of the fixed interval. Although the stimulus was presented according to a fixed-interval schedule, fixed-interval-like performance was eliminated when there no longer was a fixed relationship between brief-stimulus and food presentations.

The right-hand portion of Figure 4 shows data when the "brief stimulus" was a 2-sec presentation of food for Pigeon 31, 4-sec for Pigeon 33. Rates were higher in all intervals when food was presented than when the white light had been presented. Response rates tended to increase across intervals when food was used as the brief stimulus. The increase in rates does not, however, indicate pausing following food "brief-stimulus" presentation. For Pigeon 31, the response rate was higher in the

first interval than in any of the four intervals when the white light was presented: for Pigeon 33, the initial interval response rate was higher when food was presented than in all time classes except one when the white light was presented. This schedule approximated a variable-interval schedule of reinforcement with food occurring irregularly. Such schedules typically generate fairly constant response rates. However, depending on the distribution of reinforcers in time, variable-interval schedules may generate a positively increasing response rate as a function of time since reinforcement (Catania and Reynolds, 1968). The increase in rates observed here seemed to result from the fixed-interval requirement being superimposed on the variable-interval schedule.

Figure 5 shows Index-of-Curvature measures for the experimental conditions; the data are medians and ranges of the last five sessions. Data from Experiment I (third condition) are included for comparison. Figure 5 shows that a high degree of positive curvature occurred only under the complex brief-stimulus and second-order schedules. Under the remaining three conditions, the measures were positive but near zero. The degree of curvature was similar when comparing the brief-stimulus and second-order schedules. Pigeon 31 showed a higher median value under the second-order schedule, while Pigeon 34 showed a lower median value. For all three pigeons there was considerable overlap in the ranges. The degree of positive curvature declined when the brief stimulus was omitted, when the fixed relation between the stimulus and food was removed (conjoint schedule), and when food replaced the white-light stimulus.

DISCUSSION

The results suggest that the discriminative relation of the brief stimuli and food was a major determinant in affecting behavior. Pausing and the fixed-interval-like pattern resulted only in procedures where a brief stimulus set the occasion for a period of nonreinforcement: the complex brief-stimulus schedule of Experiment I and the second-order schedule of Experiment II. The degree of curvature was similar in both cases despite the two different ways in which brief-stimulus presentations were scheduled. The controlling feature, which was the same in both cases, was the scheduled relation with reinforcement, the fixed temporal relationship. Pausing did not occur under the conjoint schedule when the brief stimulus was no longer followed by a period of nonreinforcement. Thus, it would appear that the brief stimulus produced inhibitory or S_A-like aftereffects only when the stimulus was consistently followed by a period of nonreinforcement.

It is not clear how to explain the results in terms of reinforcing functions of the brief stimulus. The brief stimulus was presented according to a variable-interval schedule in Experiment I. Since variable-interval reinforcement schedules typically engender relatively constant response rates (Catania and Reynolds, 1968), a more constant response rate

Fig. 5. Index of Curvature measures, the medians and ranges of the last five sessions of each condition. The vertical lines show the ranges. The labels at the top indicate the various conditions.

would have been expected here if the brief stimulus had functioned primarily as a reinforcer. Such a variable-interval pattern was not observed. When food, a known reinforcer, replaced the white light as the brief stimulus, pauses following the "brief stimulus" disappeared and the previously observed fixed-interval-like pattern of responding was replaced by a higher, more constant response rate. Thus, a white-light brief stimulus did not produce the same effects as a known reinforcer. Additionally, the presentation of a conditioned reinforcer might be expected to enhance response rates (de Lorge, 1971). However, comparison of the brief-stimulus schedule with the comparable nonbrief-stimulus schedule showed that response rates tended to be higher when the stimulus was omitted. Also, pausing after the brief stimulus occurred whether or not it was paired with food. In short, brief-stimulus presentations produced neither those effects on rate nor those effects on response patterns that would be expected if the stimulus primarily served reinforcing

functions. To the extent that the brief stimulus exerted similar patterning effects under the complex schedule and the second-order schedule, the data suggest that brief-stimulus presentations serve discriminative functions in certain second-order schedules. Under second-order schedules with fixed-interval, fixed-time, fixed-ratio, or differential-reinforcement-of-low-rate schedules as components, the presentation of a brief stimulus and the presentation of a reinforcer are separated by a fixed minimum requirement, either in terms of time or responses. Under these schedules, the brief stimuli probably would acquire discriminative functions that could contribute to the observed effects on patterning.

While the present studies were concerned with the discriminative functions of brief-stimulus presentations, the results do not imply that brief stimuli necessarily lack reinforcing properties. Research from a variety of procedures indicates that brief stimuli (at least paired brief stimuli) do serve reinforcing functions (Clark and Sherman, 1970; Thomas, 1969; D. W. Zimmerman, 1969; J. Zimmerman, 1969). Further, the results do not exclude the possibility that brief stimuli had reinforcing functions in the present experiment, even though such effects were not clearly apparent. A stimulus may serve both reinforcing and discriminative functions simultaneously, but one function might mask the other. For example, Reid (1958) and Cruse, Vitulli, and Dertke (1966) demonstrated that food can have discriminative effects as well as reinforcing effects. Also, Kelleher and Gollub (1962) and Marr (1969) discussed the possibility that the conditioned-reinforcing effects of chained-schedule stimuli often are masked by the discriminative effects. In the present experiment, the discriminative functions of the brief stimuli could have masked possible reinforcing effects. For example, rate-enhancing (reinforcing) effects of the brief stimuli could have been counteracted by the inhibitory (discriminative) effects. (See Stubbs, 1971, for a more complete discussion of this point.)

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