THE EFFECTS OF BRIEF-STIMULUS PRESENTATIONS IN FIXED-RATIO SECOND-ORDER SCHEDULES

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Pigeons' responses were reinforced according to a three-component multiple schedule. In Component 1, key pecks produced food according to a fixed-ratio second-order schedule with fixed-ratio units. Here, a fixed number of fixed-ratio units produced food, and the brief stimulus terminating each unit also accompanied food. Responses in Component 2 produced food on an identical schedule except that the brief stimulus was not paired with food. Component 3 contained a simple fixed-ratio schedule whose response requirement equaled that of Components 1 and 2. Across conditions the size of the fixed-ratio unit (five, ten, twenty, forty, and eighty responses) and the total number of responses per reinforcement were parametrically manipulated. The highest response rates and shortest preratio pauses were observed in Component 3 (no brief stimulus). The lowest rates and longest pauses were found in the component with paired brief-stimulus presentations, indicating that the food-paired brief stimulus suppressed responding. The suppressive effects were greatest when the fixed-ratio units were small (e.g., fixed-ratio 5) and the total fixed-ratio requirement was large (e.g., fixed-ratio 160). Under no conditions did the paired brief stimulus facilitate responding. The nonpaired brief stimulus also suppressed responding but to a lesser extent. The suppressive effects of nonpaired brief stimuli were greatest when the fixed-ratio units were small and the total response requirement was large. These data suggest that the suppressive effects of the brief stimuli may have masked the conditioned-reinforcing effects reported in other studies, and that conditions that maximize suppression in second-order schedules involve the use of fixed-ratio schedule units and the presentation of many brief stimuli per reinforcer.

Key words: second-order schedules, brief-stimulus presentations, multiple schedules, conditioned reinforcement, key peck, pigeons

In a second-order schedule of reinforcement, responses maintained by one schedule of reinforcement (the unit schedule) are treated as single responses and reinforced according to another schedule of reinforcement (e.g., Kelleher, 1966b). A brief stimulus presented after each unit maintains the unitary nature of the schedule and engenders response patterns within units similar to those seen with simple schedules of reinforcement. For example, Kelleher (1966b) delivered food after pigeons completed 15 fixed-interval (FI) 4-min schedules. A .7-sec change in key color terminated each FI and maintained response patterns within units that resembled patterns observed under FI schedules of food presentation. In the terminology of second-order schedules (Gollub,

1977; Kelleher, 1966a; Marr, 1969) this schedule may be designated FR 15 (FI 4-min : S).

Many experiments have examined second-order schedules, primarily as a means of studying the conditioned reinforcing functions of brief-stimulus presentations (see Gollub, 1977, for a review). Unfortunately, even though considerable research has been conducted, there have been few parametric examinations of second-order schedules (see Gollub, 1977; Lee & Gollub, 1971). A thorough understanding of the behavior controlled by these schedules and the effects of brief-stimulus presentations requires systematic manipulation of many variables including unit schedules, overall reinforcement schedules, and brief-stimulus presentations. Consequently, the present study was a parametric examination of fixed ratio (FR) second-order schedules containing FR units.

This particular schedule was chosen for examination because (1) compared to other types of second-order schedules relatively lim-

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ited attention has been focused on FR second-order schedules with FR units; (2) this schedule appears to be a sensitive device for detecting the conditioned-reinforcing effects of brief-stimulus presentations (e.g., Findley & Brady, 1965); and (3) while paired and non-paired brief-stimulus presentations have been compared with other second-order schedules, this comparison has generally not been made with FR second-order schedules (see Stubbs, 1971, for an exception). With this type of schedule, a simple FR schedule is divided into smaller FR unit schedules, and a fixed number of units is required for food. For example, Findley and Brady (1965) delivered food after a chimpanzee pressed a button 4,000 times in the presence of a red light. In the presence of a green light, every 400 presses produced a .5-sec illumination of the food hopper, and food was delivered after 10 FR 400 units. Thus, a simple FR 4,000 schedule was compared to a second-order schedule requiring the same number of responses per reinforcement but with the addition of brief-stimulus presentations. The brief-stimulus presentations facilitated responding: the postreinforcement pause was much shorter in the green component and the 4,000 responses were completed in less time.

The facilitative effects of brief stimuli in FR second-order schedules have also been reported by Findley (1962) and Thomas and Stubbs (1966). In general, these studies have espoused a conditioned reinforcement interpretation of brief stimuli in second-order schedules. In these experiments the brief stimulus that terminated FR units also accompanied food presentations. This food-pairing operation may be viewed as a means of creating a conditioned reinforcer whose presence increases response rate (Kelleher & Gollub, 1962). These data support other second-order schedule research showing that a brief stimulus must be paired with food for it to enhance response rate or generate response patterns within unit schedules (e.g., Kelleher, 1966a, 1966b; Marr, 1969).

Other studies, however, suggest that a conditioned reinforcement interpretation may be too simple to account for the rate-enhancing effect of brief stimuli in FR second-order schedules. Brief-stimulus presentations may not only contain reinforcing properties but also discriminative and eliciting properties. For example, Stubbs (1971) and others (e.g.,

Cohen, Calisto, & Lentz, 1979; Cohen & Stubbs, 1976; Stubbs, Vautin, Reid, & Delehanty, 1978) have shown that a brief stimulus does not have to be paired with food for it to affect responding in second-order schedules. Their data illustrate how the discriminative properties of a brief stimulus may affect response rates and patterns and how they may mask or interact with the reinforcing properties of the stimulus. A conditioned reinforcement interpretation may stem from the fact that studies reporting rate-enhancing effects of brief stimuli under FR second-order schedules have examined only the effects of food-paired brief stimuli (Findley, 1962; Findley & Brady, 1965; Lee & Gollub, 1971; Thomas & Stubbs, 1966). An examination of nonpaired brief-stimulus presentations might result in alternative interpretations of the data.

In addition, a simple interpretation of the data in terms of conditioned reinforcement is made more complex by Lee and Gollub's (1971) findings that the facilitative effects of food-paired brief stimuli depend on the size of the unit schedule and the number of units required for food. Lee and Gollub (1971) initially examined pigeons' responding under an FR 256 schedule. In subsequent conditions responding was studied under FR second-order schedules that also required 256 responses per reinforcement. Response rate was an inverted U-shaped function of the FR unit size. Thus, the rate-enhancing effects of paired brief stimuli may depend on the size of the FR unit, the number of units per food presentation, or an interaction of these variables. Since these two variables were manipulated simultaneously, it is difficult to attribute changes in responding to either one. Lee and Gollub's (1971) findings clearly illustrate the importance of performing parametric research in order to gain a clearer understanding of behavior under second-order schedules.

In light of these problems, we performed an extensive parametric examination of FR second-order schedules with FR units. In each series of conditions the size of the FR unit was held constant, and the number of units per reinforcement was varied. In the next series of conditions, the size of the FR unit was changed, and the number of units was varied once again. In addition, responding was examined under both paired and non-paired brief-stimulus presentations.

METHOD

Subjects

Four experimentally naive male White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

A Coulbourn Instruments modular pigeon chamber was housed within a sound-attenuated cubicle. The chamber contained one clear plastic key centered on the work panel. A IEE one-plane readout transilluminated the key with blue, red, white, green, yellow, a white vertical line on a dark ground, and a white circle on a dark ground. Mixed grain was presented by a feeder located below the key, and grain delivery was accompanied by a white feeder light. White noise was used to mask extraneous sounds. Solid-state circuitry controlled the experimental sessions.

Procedure

Pigeons were trained to peck a white key for mixed grain reinforcement. In the second session, 60 reinforcers were delivered under a continuous reinforcement schedule for pecking the white key. During the third session reinforcement was delivered for pecks to a red, blue, and white key. Key colors alternated randomly after each food presentation. During the fourth session the number of responses required to produce food was increased to five (i.e., an FR 5 schedule).

Experimental sessions. Beginning with the fifth session, responding was reinforced according to a three-component multiple schedule. The first component contained an FR second-order schedule with paired brief-stimulus presentations [i.e., FR $X(\text{FR } Y:S^P)$], the second contained an FR second-order schedule with nonpaired brief-stimulus presentations [i.e., FR $X(\text{FR } Y:S^M)$], and the third contained a simple FR schedule that equaled the number of responses required for food in Components 1 and 2 (i.e., FR $X \cdot Y$).

Responding in the first component of the multiple schedule produced 6-sec access to grain after a fixed number of FR units were completed, and each FR terminated with a .5-sec brief stimulus that also accompanied food. For example, in Condition 1 (Pigeon #40) five pecks on a blue key produced a .5-sec

change in key color from blue to yellow. Five more pecks on the blue key produced food. The yellow key preceded food by .5 sec and remained on during the food cycle (i.e., a preceding overlapping pairing operation, c.f. Stubbs & Cohen, 1972). Responding under FR 5 units was therefore reinforced according to an FR 2 schedule [i.e., FR 2 (FR 5 : S^P)].

The second component of the multiple schedule resembled the first in that food was presented after an equal number of FR units were completed. However, the .5-sec brief stimulus that terminated each FR unit was not paired with food. Instead a different stimulus preceded food for .5 sec and remained on during the food cycle. For example, in Condition 1 (Pigeon #40) five responses on the red key produced a .5-sec change in key color from red to green. Five additional responses on the red key produced food. A white vertical line preceded food by .5 sec and remained on during the food cycle. This schedule may be designated as FR 2 (FR 5 : S^M).

In the third component of the multiple schedule, responding produced food according to a simple FR schedule. While responding did not produce a brief stimulus during the FR schedule, each food presentation was preceded by a .5-sec stimulus that accompanied the food cycle. For example, in the first condition of the experiment, 10 pecks on a white key produced food, and food was preceded and accompanied by a white circle projected on the key.

Thus, all three components required the same number of responses for reinforcement, and all reinforcers were preceded by a .5-sec stimulus that remained on during food presentations. Component key colors, .5-sec brief-stimulus colors, and food-paired stimuli differed for each pigeon and are presented in Table 1. Responses during brief-stimulus and food presentations had no scheduled effects. The three components alternated randomly following each food presentation. A 5-sec timeout occurred between components where key-lights were extinguished and responding had no effects. Sessions terminated after 60 reinforcers or 3 hr, whichever came first. Sessions were conducted Monday through Friday.

Throughout the experiment the size of the FR unit (FR 5, 10, 20, 40, and 80) and the number of FR units needed to produce food were varied systematically. Table 2 presents the sequence of conditions and the number of

Table 1

Key color, brief-stimulus color, and food-paired stimulus within the paired-stimulus component (S^P), non-paired-stimulus component (S^N), and the component without a brief stimulus (S^O) of the multiple schedule. Colors were blue (B), red (R), white (W), yellow (Y), and green (G). The colors in parentheses are component key colors used in the last condition of the experiment.

Component	Component Key Color	Brief-Stimulus	Food-Paired Stimulus
Pigeon #40			
S^P	B (B)	Y	Y
S^N	R (W)	G	Vertical Line
S^O	W (R)	—	Circle
Pigeon #41			
S^P	B (B)	G	G
S^N	R (W)	Y	Circle
S^O	W (R)	—	Vertical Line
Pigeon #42			
S^P	R (W)	G	G
S^N	B (B)	Y	Vertical Line
S^O	W (R)	—	Circle
Pigeon #43			
S^P	R (W)	Y	Y
S^N	B (B)	G	Circle
S^O	W (R)	—	Vertical Line

sessions under each. Each condition was conducted for a minimum of 15 sessions and until overall response rate and preratio pause within each component showed no increasing or decreasing trends for at least five consecutive sessions. Under some conditions the preratio pause was so long that as few as one or two particular components were completed during a session. In these cases the condition was conducted for 30 sessions and terminated.

Control conditions. An analysis of the first five conditions of the experiment revealed that overall response rate was highest in the third (no brief stimulus) component. A possible explanation for the lower rates in Components 1 and 2 is that the .5-sec brief stimuli added a delay to reinforcement that was not present in the third component. For example, in the FR 32 (FR 5) condition 31 brief stimuli or 15.5 additional seconds intervened between the first response and food during Components 1 and 2 but not Component 3. To determine if brief-stimulus time affected responding, control conditions were conducted. In control conditions the simple FR schedule in Component 3 was divided into FR unit schedules and the completion of each FR unit initiated a .5-sec brief-stimulus timer; however, the key remained white during the .5-sec periods.

Thus, during the FR 16 (FR 5) control condition five pecks on the white key started the .5-sec timer but the key remained white, five more pecks started the .5-sec timer again, and this continued until 16 FR 5 units were completed. Responses during operation of the .5-sec "brief-stimulus" timer had no scheduled effects and, as in Components 1 and 2, did not count toward completion of an FR unit. Paired and nonpaired brief-stimulus presentations continued to occur in Components 1 and 2 respectively.

New key colors. Throughout the experiment the key colors of Components 1 and 2 (red and blue) were counterbalanced across subjects. However, the third component was white for all subjects. To test the possibility that higher response rates in Component 3 were controlled by the white key color, the final condition examined responding under an FR 8 (FR 10) schedule where the key color was white in Components 1 or 2 (see Table 1).

Table 2

Sequence of conditions in order of occurrence, and the number of sessions in each condition for Pigeons #40, #41, #42, and #43.

Condition	Sessions			
	#40	#41	#42	#43
FR 2 (FR 5)	24	20	20	20
FR 4 (FR 5)	15	18	18	18
FR 8 (FR 5)	21	22	22	26
FR 16 (FR 5)	32	46	28	34
FR 32 (FR 5)	30*	30*	16	30*
FR 16 (FR 5) Control	19	31	16	39
FR 32 (FR 5) Control	16	—	26	—
FR 2 (FR 10)	16	15	16	16
FR 4 (FR 10)	15	33	15	19
FR 8 (FR 10)	16	25	20	18
FR 16 (FR 10)	20	15	25	30*
FR 8 (FR 10) Control	—	30*	—	30*
FR 16 (FR 10) Control	23	—	26	—
FR 2 (FR 20)	15	15	15	15
FR 4 (FR 20)	16	15	15	15
FR 8 (FR 20)	17	32	15	30*
FR 8 (FR 20) Control	17	31	16	30*
FR 2 (FR 40)	22	19	15	21
FR 4 (FR 40)	26	26	15	30*
FR 4 (FR 40) Control	32	16	22	30*
FR 2 (FR 80)	29	15	19	23
FR 2 (FR 80) Control	23	15	26	18
FR 8 (FR 10) Changed Key Colors	26	17	15	30

*These conditions were conducted for 30 sessions, and calculations presented in Figures 1 to 5 were derived by summing the data over the last five sessions of the condition (see text for an explanation).

RESULTS

The two main dependent variables were overall response rate and preratio pause within each of the three components of the multiple schedule. Preratio pause was measured from the onset of a component to the first response. To account for warmup effects, responses and time during the first component of a session were not included in any calculations. Overall response rate did not include responses or time

during brief-stimulus or food presentations. In all figures data represent the mean response rate and preratio pause of the last five sessions for each condition. In conditions terminated after 30 sessions due to very few component presentations (see Table 2) responses and time were summed over the last five sessions and treated as a single session in deriving response rate and preratio pause.

Figures 1, 2, 3, and 4 present the overall response rate and preratio pause as a function

Fig. 1. Response rate in each of the three components of the multiple schedule for Pigeons #40 and #41. Component 1 contained paired brief-stimulus presentations (S^P), Component 2 contained nonpaired brief-stimulus presentations (S^N), and Component 3 contained a simple FR schedule without brief-stimulus presentations (no stimulus). Data are presented as a function of the total number of responses required for each food presentation (total FR responses). The values across the top of the figure represent the size of the FR unit (FR 5, 10, 20, 40, and 80). Filled points not connected by lines represent control conditions. The "C" next to the data points at the right of the figure are control conditions when the unit was FR 80. Unfilled points represent the last condition of the experiment where component key colors were changed.

Fig. 2. Response rate in each of the three components of the multiple schedule for Pigeons #42 and #43. Other aspects of the figure are identical to Figure 1.

of the total number of responses per reinforcement on the FR second-order schedule with FR unit schedule (FR 5, 10, 20, 40, and 80) as a parameter. The figures show a family of functions illustrating performance in the paired-stimulus components, nonpaired-stimulus components, and components without brief-stimulus presentations. Several salient points are evident: (1) response rate decreased and preratio pause increased as the total FR requirement per reinforcer increased. An exception to this is that response rates increased when conditions were changed from FR 2 (FR 5) to FR 4 (FR 5) before decreasing at FR 8 (FR 5). (2) There was an inverse relationship between overall response rate and preratio pause. This relationship indicates that the major effects of our independent variables were on preratio pause and not on local response rates. (3) The highest response rates and shortest pauses were generally observed in the component without brief-stimulus presen-

tations. There were a few exceptions to this finding. With FR 20 and FR 40 units Pigeons #42 and #43 had highest response rates and longest pauses in the component with nonpaired brief stimuli. (4) The lowest response rates and longest pauses were consistently observed in the component with paired brief-stimulus presentations. No facilitative effects of paired brief-stimulus presentations were found under any conditions. (5) Differences in response rate and pause time between components with paired brief-stimuli and components without brief stimuli appear to be greatest when the FR unit was small and the total FR response requirement was large. For example, large differences were observed under the FR 32 (FR 5) condition, but not under the FR 2 (FR 80) condition. This relationship is made clearer in Figure 5, and indicates that under these conditions the paired brief stimulus acts to suppress responding. (6) The effects of nonpaired brief-stimulus presentations were

Fig. 3. Preratio pause in each of the three components of the multiple schedule for Pigeons #40 and #41. Other aspects of the figure are identical to Figure 1.

variable. Under some conditions the non-paired stimulus controlled response rates and preratio pauses that resembled rates and pauses in components with paired stimuli. Under other conditions they resembled performance in components without brief stimuli. Yet in other conditions an intermediate level of response rates and preratio pauses was observed. Figures 1 through 4 show that, as with paired brief stimuli, nonpaired brief stimuli were more likely to suppress responding when

the FR unit was small and the total FR response requirement was large. For example, response rates were lower and pauses longer in the nonpaired brief-stimulus component compared to the component without brief stimuli under FR 16 (FR 5) and FR 32 (FR 5) conditions, but not under FR 4 (FR 5), FR 2 (FR 40), and FR 4 (FR 40) conditions (see Figure 5). (7) Performance under control conditions resembled performance under experimental conditions: the preratio pause, for ex-

Fig. 4. Preratio pause in each of the three components of the multiple schedule for Pigeons #42 and #43. Other aspects of the figure are identical to Figure 1.

ample, was still shortest in Component 3 and longest in Component 1. In several cases, however, the differences among components were attenuated under control conditions. For example, with FR 16 (FR 5), FR 32 (FR 5), FR 8 (FR 10), and FR 16 (FR 10) schedules, the differences among the three components under control conditions were clearly smaller than under experimental conditions. Thus, the addition of brief-stimulus time in Component 3 may have had an effect on responding, but it did not eliminate the differences among components. (8) In the last condition of the experiment, the FR 8 (FR 10) schedule

was redetermined with different component key colors. The highest response rates and shortest preratio pauses were still observed in Component 3. Therefore, the white key color was not responsible for the higher rates and shorter pauses observed in that component.

Figure 5 is a plot derived from Figures 1 through 4 and is intended to illustrate the relationship between response suppression and the number of FR units per reinforcer suggested in those figures. Figure 5 presents the ratio of response rate in the components with brief stimuli to the response rate in the com-

Fig. 5. The ratio of response rate in the paired brief-stimulus component (filled points) and nonpaired brief-stimulus component (unfilled points) to response rate in the component without brief-stimulus presentations as a function of the number of unit schedules per reinforcer. Solid and dashed lines connect the median values of noncontrol conditions for paired and nonpaired components respectively. The "C" next to data points represents control conditions. A "KC" next to data points represents the condition where key colors were changed in the last condition of the experiment. The legend at the top right of the figure indicates the size of the FR unit.

ponent without brief stimuli as a function of the number of unit schedules per reinforcer. Ratios for both paired and nonpaired brief-stimulus components are presented. A value of 1.0 indicates that the response rate during the brief-stimulus component equaled response rate during the component without brief stimuli. Values less than 1.0 indicate response suppression and values greater than

1.0 indicate response facilitation. Solid and dashed lines are drawn through the median ratios of noncontrol conditions. A considerable degree of variability around the median values is evident, especially for Pigeon #40. However, several trends in the data are apparent from this figure. First, most of the points fall below the 1.0 value, indicating general response suppression from the brief stimuli. Second, re-

Fig. 6. Representative cumulative records of Pigeon #41 when the total FR response requirement equaled 160 responses. The numbers at the right of the records indicate the size of the FR unit. Each response stepped the pen once, and the pen reset to the baseline after each food presentation. Deflections of the response pen represent brief-stimulus presentations. The brief stimulus that accompanied food is not shown on the record. The event pen was down during Component 1 (paired brief stimulus) and up during Components 2 and 3.

sponse suppression with both paired and non-paired brief stimuli increased as the number of brief stimuli per reinforcer increased. For example, response suppression was greatest under FR 32 (FR 5), FR 16 (FR 5), and FR 16 (FR 10) conditions and least under FR 2 (FR 5) and FR 2 (FR 80) conditions. Finally, although it is clear that the nonpaired brief stimulus suppressed responding (especially with 16 and 32 FR units per reinforcer), the paired brief stimulus generated greater suppression. For example, for all subjects in Figure 5 there are 37 unfilled (nonpaired)

points compared to only 8 filled (paired) points falling on or above the 1.0 ratio value.

Figure 6 presents representative cumulative records under conditions where 160 responses were required for food. These records show that performance under the FR second-order schedule was characterized by a pause at the start of a component followed by an abrupt change to a high response rate, typical of responding under simple FR schedules. Whereas there were some breaks in the records in early FR units, there were usually no perceptible pauses after brief-stimulus presentations. The

records also show that the preratio pause in Component 3 was usually much shorter than in Components 1 and 2. This effect is particularly evident with FR 5, FR 10, and FR 20 unit schedules.

DISCUSSION

In the present study a three-component multiple schedule was used to assess the effects of brief-stimulus presentations on responding under FR second-order schedules of reinforcement. A significant finding was the failure of a parametric examination to reveal any rate-enhancing effects of food-paired brief-stimulus presentations. These findings agree with data reported by Stubbs (1971) who examined pigeons' responding under FR second-order schedules and failed to find consistent differences in overall response rate with paired brief stimuli, nonpaired brief stimuli, and FR schedules without brief stimuli. However, these data contradict other studies (Findley, 1962; Findley & Brady, 1965; Lee & Gollub, 1971; Thomas & Stubbs, 1966) showing that paired brief-stimulus presentations facilitate responding in FR second-order schedules.

The present study differed from these studies in several ways, and it is difficult to identify the variables responsible for the discrepant results. As in the present study, Findley and Brady (1965) and Thomas and Stubbs (1966) used multiple schedules of reinforcement to compare a simple FR schedule with an FR second-order schedule. However, their studies used the illumination of the food hopper as a brief stimulus, whereas we used keylight illumination. The food hopper stimulus may have served as a more potent conditioned reinforcer because of its similarity to primary reinforcement (Kello, 1972). Perhaps the strong conditioned-reinforcing properties of the feeder light masked the suppressive effects of the brief stimuli observed in this experiment. Findley (1962) and Lee and Gollub (1971) did use keylight illumination as a paired brief stimulus. However, they did not use multiple schedules, and this could have accounted for the different results.

Not only was there a failure to obtain a facilitory effect, but the lowest response rates and longest preratio pauses were consistently observed in the component containing paired brief-stimulus presentations. Control condi-

tions revealed that the suppressive effects of paired brief stimuli were not a result of the delay to reinforcement imposed by the .5-sec brief-stimulus presentations or by component key colors. Figure 5 indicates that the greatest suppression from paired brief stimuli occurred when the FR unit was small and the total response requirement was large. For example, greater suppression occurred under FR 32 (FR 5) and FR 16 (FR 10) conditions than under FR 2 (FR 5) and FR 2 (FR 80) conditions. Large FR schedules typically generate longer preratio pauses than smaller FR schedules. The addition of many paired brief-stimulus presentations during the FR sequence lengthened the pauses inherent within the simple FR schedule. When only two, four, or eight brief stimuli were presented, suppression was reduced or inconsistent. Interestingly, in prior studies reporting response-rate enhancement (Findley, 1962; Findley & Brady, 1965; Lee & Gollub, 1971; Thomas & Stubbs, 1966) 10 or less FR units were required for food. When Lee and Gollub (1971) required 32 or 128 units for food they failed to get response facilitation and even observed response suppression.

The long preratio pause in paired stimulus components is reminiscent of the pause observed in chained fixed-ratio schedules of reinforcement and fixed-ratio schedules with added counter. A common finding in comparisons of chained and tandem schedules is that the pause in the initial component of a chained schedule is longer than the pause in a comparable tandem schedule without different component stimuli (e.g., Jwaideh, 1973; Thomas, 1967), a finding consistent with the present data.

Crossman (1969) compared the effects of chained stimuli and brief stimuli in FR schedules of reinforcement. In the first phase of his experiment Crossman used a multiple schedule to compare responding under a simple FR 75 schedule with a chain FR 5 FR 70 schedule. In the chained schedule the fifth peck on a white key turned the key green, and 70 pecks on a green key produced food. As expected, the pause in the initial component of the chained schedule was longer than the pause under the FR 75 schedule. In later phases of the experiment, the chained schedule was altered so that five responses on a white key produced a 2-sec paired or nonpaired brief-stimulus presentation; then 70 responses on

the white key produced food. The preratio pause under the paired and nonpaired brief-stimulus schedules was consistently longer than under the simple FR 75 schedule and comparable to that under the chained schedule.

Ferster and Peele (1980) used a multiple schedule to compare responding on a simple FR 220 schedule with an FR 220 with added counter. In the component with added counter, a small visual slit increased in size with each peck on the key until it reached its maximal size at reinforcement. The preratio pause was consistently longer in the FR 220 with added counter, and they suggested that the visual stimulus weakened FR performance because the small slit was negatively correlated with food. The present analysis suggests that the presentation of many brief stimuli in an FR sequence is functionally equivalent to the discriminative stimulus in the initial component of a chained schedule or an added counter stimulus present at the beginning of an FR requirement. The main difference is that in the chained and added counter schedules the stimulus present at the beginning of the ratio is distinctly different from the stimulus present at reinforcement. In the second-order schedule, the key color present at the start of the ratio is the same color present at the end of the ratio, and the brief stimuli that suppress performance are not presented until after responding begins.

In the present study the paired brief stimulus suppressed responding. The nonpaired brief stimulus also suppressed responding but to a lesser extent (see Figure 5). Many studies have compared the effects of paired and nonpaired brief-stimulus presentations in second-order schedules. Some studies (e.g., Kelleher, 1966a, 1966b) have reported that only paired brief stimuli affect response rates and patterns within second-order schedules, and others (e.g., Stubbs, 1971) have reported that both types of brief stimuli affect responding equally. Several studies have identified some of the factors that determine if a nonpaired brief-stimulus will affect responding in second-order schedules. These factors include the complexity of the brief stimulus (e.g., Stubbs, 1971), brief-stimulus duration (e.g., Cohen, Hughes, & Stubbs, 1973), and type of brief stimulus (e.g., Stubbs & Cohen, 1972). For example, in a second-order schedule with FI units, a nonpaired brief stimulus composed of a 2-sec

change in key color plus houselight illumination will produce a greater degree of response curvature within FI units than a 2-sec paired blackout (Stubbs & Cohen, 1972). The present study suggests that the number of times the brief stimulus is presented during an FR sequence is an additional factor that may determine if a nonpaired stimulus will affect responding. Figure 5 indicates that under FR 32 (FR 5), FR 16 (FR 5), and FR 16 (FR 10) schedules the nonpaired stimulus consistently suppressed responding. With larger FR units or with a small FR response requirement, less consistent suppression was observed. The number of nonpaired brief stimuli per reinforcer in a second-order schedule may interact with other aspects of the brief stimulus, such as its duration, to determine if differences are to be found between paired and nonpaired stimuli.

The suppressive effects of brief-stimulus presentations contrast with the rate-enhancing effects of brief-stimulus presentations observed in some FR second-order schedules with interval units (de Lorge, 1971; Malagodi, DeWeese, & Johnston, 1973; Rose & Fantino, 1978). de Lorge (1971) and Rose and Fantino (1978) used multiple schedules to compare the effects of paired and nonpaired brief stimuli in FR second-order schedules with fixed-interval and variable-interval units. Both studies reported shorter postreinforcement pauses and higher response rates with paired brief stimuli compared to nonpaired or no brief stimuli.

Two factors could be responsible for the failure of these studies to observe the suppressive effects of brief stimuli found in the present study. First, pigeons had to complete only four or five unit schedules for food. In the present study consistent suppression was observed when 16 or 32 unit schedules were required. Perhaps suppression would have been observed if, for example, pigeons had to complete 32 FI 10-sec units. A second factor involves differences in the feedback relationships between response rate and reinforcement rate that exist with ratio and interval unit schedules. In FR schedules rate of response and rate of reinforcement are directly proportional. Any condition that lowers rate or probability of reinforcement will lower response rate, which will further reduce reinforcement rate. This condition does not exist with interval schedules where reinforcement rate is relatively insensitive to changes in response rate.

In an FR second-order schedule with FR units, several factors could reduce reinforcement rate in the brief-stimulus component. First, the .5-sec brief-stimulus presentations add a delay to reinforcement that is not present in the component without brief stimuli. Second, pecks made during a brief stimulus do not count toward completion of the ratio requirement. These pecks would lower the probability of reinforcement compared to the component without brief stimuli. Third, in second-order schedules animals often pause after brief-stimulus presentations (e.g., Stubbs, 1971). Pausing after a brief stimulus would reduce reinforcement rate in FR unit (but not FI unit) schedules. Any of these factors that reduce rate or probability of reinforcement in the brief-stimulus component would tend to lower response rate, which would continue to drive down reinforcement rate. This reciprocal relationship does not exist with interval units and would not favor response suppression.

Analysis of the control conditions gives partial support for the above argument. When brief-stimulus time was added in the third component, differences among the three components of the multiple schedules were attenuated. However, response suppression in the brief-stimulus component was not eliminated. Also, suppression was not eliminated in control conditions even though pigeons made many extra responses during operation of the .5-sec "brief-stimulus" timer and reduced the probability of reinforcement in that component. Finally, casual observation of pigeons' performance and analysis of cumulative records showed that pigeons did not usually pause after brief-stimulus presentations, and thus did not accumulate additional time to reinforcement. Unfortunately, response latencies after brief stimuli were not recorded and no definitive statement can be made on this point.

In second-order schedules brief-stimulus presentations sometime produce response suppression and other times response enhancement. Factors which favor suppression appear to be the use of FR unit schedules and the presentation of many brief stimuli per reinforcer. Factors which favor response enhancement include the use of interval unit schedules and perhaps the use of few brief stimuli per reinforcer and potent conditioned reinforcers such as brief operations of the feeder mechanism.

REFERENCES

- Cohen, S. L., Calisto, G., & Lentz, B. E. Separating the reinforcing and discriminative properties of brief-stimulus presentations in second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1979, 32, 149-156.
- Cohen, S. L., Hughes, J. E., & Stubbs, D. A. Second-order schedules: Manipulation of brief-stimulus duration at component completion. *Animal Learning and Behavior*, 1973, 1, 121-124.
- Cohen, S. L., & Stubbs, D. A. Discriminative properties of briefly presented stimuli. *Journal of the Experimental Analysis of Behavior*, 1976, 25, 15-25.
- Crossman, E. K. A comparison of various types of stimulus-change in two alternating fixed-ratio components. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Ill.: Dorsey Press, 1969.
- de Lorge, J. The effects of brief stimuli presented under a multiple schedule of second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 19-25.
- Ferster, C. B., & Peele, D. B. The contribution of an added counter to a fixed-ratio schedule. *Journal of the Experimental Analysis of Behavior*, 1980, 34, 93-105.
- Findley, J. D. An experimental outline for building and exploring multi-operant behavior repertoires. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 113-166.
- Findley, J. D., & Brady, J. V. Facilitation of large ratio performance by use of conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 125-129.
- Gollub, L. Conditioned reinforcement: Schedule effects. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Jwaideh, A. R. Responding under chained and tandem fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 259-267.
- Kelleher, R. T. Chaining and conditioned reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application*. New York: Appleton-Century-Crofts, 1966. (a)
- Kelleher, R. T. Conditioned reinforcement in second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 475-485. (b)
- Kelleher, R. T., & Gollub, L. R. A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 543-597.
- Kello, J. E. The reinforcement-omission effect on fixed-interval schedules: Frustration or inhibition? *Learning and Motivation*, 1972, 3, 138-147.
- Lee, J. K., & Gollub, L. R. Second-order schedules with fixed-ratio components: Variation of component size. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 303-310.
- Malagodi, E. F., DeWeese, J., & Johnston, J. M. Second-order schedules: A comparison of chained, brief-stimulus, and tandem procedures. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 447-460.
- Marr, M. J. Second-order schedules. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Ill.: Dorsey Press, 1969.

- Rose, J. E., & Fantino, E. Conditioned reinforcement and discrimination in second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 393-418.
- Stubbs, D. A. Second-order schedules and the problem of conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 289-313.
- Stubbs, D. A., & Cohen, S. L. Second-order schedules: Comparison of different procedures for scheduling paired and nonpaired brief stimuli. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 403-413.
- Stubbs, D. A., Vautin, S. J., Reid, H. M., & Delehanty, D. L. Discriminative functions of schedule stimuli and memory: A combination of schedule and choice procedures. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 167-180.
- Thomas, J. R. Chained and tandem fixed-interval schedule performance and frequency of primary reinforcement. *Psychological Reports*, 1967, **20**, 471-480.
- Thomas, J. R., & Stubbs, D. A. Enhancement of fixed-ratio performance by briefly presented conditioned reinforcing stimuli. *Psychonomic Science*, 1966, **5**, 329-330.

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