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*DISCRIMINATIVE FUNCTIONS OF SCHEDULE
STIMULI AND MEMORY: A COMBINATION OF
SCHEDULE AND CHOICE PROCEDURES*

D. ALAN STUBBS,¹ SUSAN J. VAUTIN, HOWARD M. REID,
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Pigeons responded under a combination brief-stimulus schedule and choice procedure. Normally, a fixed-interval schedule was in effect, where completion randomly produced either a brief stimulus or food. Intermittently, this schedule was interrupted by a choice arrangement. Two choice keys were lit, either a short or a long time since a prior event (food or stimulus). One choice response produced food if the time had been short, and the alternate response produced food if the time had been long. Across conditions, the duration of the fixed-interval schedule was varied, the stimuli that comprised the brief-stimulus operation were changed, and the stimuli were presented as paired and nonpaired with food. The focus of the study was the control of both schedule performance and choice responding across conditions. The results showed that choice accuracy was correlated with the degree of fixed-interval curvature, the response pattern of a pause followed by a gradually accelerated rate. As fixed-interval schedule duration was increased, both the degree of fixed-interval curvature and choice accuracy decreased. The particular brief stimulus used affected schedule and choice performance, with a more salient stimulus producing a greater degree of curvature and higher accuracy. Pairing and nonpairing operations produced striking differences in performance with the less salient brief stimulus, but not with the more salient stimulus. The results suggest that brief-stimulus schedule performance may be conceptualized in the context of memory research.

Key words: temporal control, memory, conditioned reinforcement, choice, second-order schedule, brief stimulus, pigeons

A number of experiments have studied procedures in which a brief stimulus intermittently replaces a reinforcer at the completion of a schedule requirement. These brief-stimulus procedures have clarified the ways in which reinforcers control behavior, as well as provided information about the reinforcing and discriminative functions of the stimuli that intermittently substitute for reinforcers (Gollub, 1977; Kelleher, 1966; Marr, 1969; Staddon, 1972*b*; Stubbs, 1971).

Two major research areas that have used brief-stimulus procedures are the topic areas involving second-order schedules and reinforcement-omission procedures. Second-order schedule procedures have evolved from conditioned reinforcement research and have tended to emphasize the reinforcing functions of brief stimuli (Gollub, 1977; Kelleher, 1966; Marr, 1969). Reinforcement-omission proce-

dures have evolved from "frustration" research and have emphasized the ways in which reinforcers and brief stimuli substituted for reinforcers differ in their effects on performance (Staddon, 1972*b*, 1974; Staddon and Innis, 1969). The evidence indicates that the stimuli (including reinforcers) have multifaceted and complex effects on behavior. Accordingly, different experiments have emphasized different aspects (*e.g.*, Ferster and Skinner, 1957; Kelleher, 1966; Neuringer and Chung, 1967; Staddon, 1972*b*, 1974; Stubbs, 1971). The present experiment stems from recent suggestions concerning the discriminative functions of stimuli, in particular the ways these functions may be related to memory research (Staddon, 1974).

In a recent review, Staddon (1974) provided evidence relating memory and the control of schedule performance by reinforcers and brief stimuli (see also Starr and Staddon, 1974). If completion of a fixed-interval requirement sometimes produces food and sometimes a brief stimulus, both events will occasion the "typical" fixed-interval response pattern, a pause followed by a gradually accelerated rate

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(*e.g.*, Staddon and Innis, 1969). While food and the stimulus both occasion a pause, typically the pause following the stimulus is not as great as that following food (*e.g.*, Staddon, 1972*a*; Staddon and Innis, 1969). Staddon has interpreted the pause following the stimulus or food as due to inhibitory temporal control, since both events signal a period of nonreinforcement (see also Cohen and Stubbs, 1976). Staddon has suggested that the shorter pause following a stimulus indicates that "neutral" stimuli are not as memorable as reinforcers in controlling performance. Further, Starr and Staddon (1974) found that the degree of pausing depends on the fixed-interval schedule: with short fixed intervals, the degree of pausing is similar following food or a brief stimulus; with longer fixed intervals, however, the pause following a stimulus becomes relatively shorter than that following food. Staddon has interpreted these results in the context of memory; the less memorable stimulus might be expected to exert less temporal control on longer fixed intervals, since the time from the prior event has been lengthened.

If one conceptualizes brief-stimulus research and memory research within the same framework, interesting possibilities arise and new research suggests itself. The memory concept often has been used in explanatory and hypothetical ways. Yet, a basic descriptive definition—one that simply unifies different sets of data—is that memory refers to the control of behavior by prior stimuli. Similarly, discussions of brief-stimulus effects often refer to the control of behavior by prior stimuli (*e.g.*, the pause in responding produced by a prior brief stimulus). So both sets of research are concerned with the effects of prior stimuli on behavior. There are, of course, differences. Memory research, as exemplified by the delayed-matching-to-sample procedure, typically uses choice procedures in which a subject responds differentially, depending on which of two stimuli had previously been present (*e.g.*, D'Amato, 1973; Roberts and Grant, 1974; Shimp, 1976*b*). For example, a pigeon's pecks might be differentially reinforced on red and green choice keys, depending on whether a prior stimulus had been red or green. In contrast, the brief-stimulus research uses a single operant in a free-operant procedure, studying the rate and pattern of responding at different times following a stimulus. There may be sev-

eral prior stimuli (*e.g.*, food and a brief stimulus) but the response following both is similar (*e.g.*, key pecks under a fixed-interval schedule). Since both research approaches deal with the effects of prior stimuli, it seems reasonable to combine the brief-stimulus procedures with the more usual memory procedures. Such a combination has merit for several reasons. First, a combination of brief-stimulus and memory procedures provides one step toward unifying two sets of data that largely have been kept separate. Second, the use of a choice procedure in combination with the typical brief-stimulus procedure may provide information to suggest relations between brief-stimulus schedule performance and other results cast in a memory context (Staddon, 1974). The present experiment was designed to study such a combination.

In the experiment, pigeons performed under a fixed-interval schedule ending randomly with food or a brief stimulus. Intermittently, the fixed-interval schedule was interrupted by the illumination of two choice keys. These interruptions occurred either at a relatively short time since a prior food or stimulus or at a long time. Responses to the choice keys were reinforced depending on whether the prior duration had been short or long (*i.e.*, right-key responses were reinforced given a short time since the prior event; left-key responses were reinforced given a long time). Choice responses served as a measure of the control exerted by food and brief stimuli over behavior; and, this measure was correlated with the other, more usual, brief-stimulus measures. We expected that those conditions that produced a strong degree of characteristic fixed-interval patterning (*e.g.*, a relatively long pause followed by a gradually accelerated rate) would also produce a high level of choice accuracy; those conditions that produced a small degree of patterning (*e.g.*, a short pause) might produce a lower degree of choice accuracy. Several conditions, derived from the results of previous brief-stimulus studies, were investigated with specific results expected regarding both response patterning and choice behavior: (1) previous research has shown that the fixed-interval pause is not as great following a brief stimulus as that following food (*e.g.*, Staddon and Innis, 1969). The results suggest that in the combination procedure, choice accuracy would be lower when the prior event was a

brief stimulus than when it was food. (2) Starr and Staddon (1974) demonstrated that the degree of response patterning following a brief stimulus decreased as fixed-interval schedule duration was increased. Their results suggest that choice accuracy might also decrease as fixed-interval duration is increased. (3) Longer-duration, "more-salient" stimuli produce a higher degree of fixed-interval curvature than do briefer, "less-salient" stimuli (*e.g.*, Stubbs, 1971). More-salient stimuli would be expected to produce higher choice accuracy scores. (4) Food-paired brief-stimulus operations sometimes produce a higher degree of patterning than nonpaired (see Gollub, 1977, for a review). Paired brief stimuli might be expected to produce a higher degree of choice accuracy.

METHOD

Subjects

Four White Carneaux male pigeons were maintained at approximately 80% of their free-feeding weights. The pigeons all had experimental histories, although no history with brief-stimulus procedures.

Apparatus

The experimental chamber was a Lehigh Valley Electronics model 1519 three-key pigeon chamber. Sessions were controlled by solid-state electronic circuitry.

Procedure

Sessions, conducted six days a week, lasted until a subject obtained 80 food presentations.

Figure 1 shows an outline of the procedure. The procedure basically involved a fixed-interval schedule intermittently interrupted by a choice trial. Initially, the center key was lit by red light and a fixed-interval schedule was in effect. (The side keylights were off and responses on these keys had no scheduled consequence). The response that ended an interval randomly produced either food or a brief stimulus, each event being scheduled to occur with a probability of 0.5. When food was presented, the red keylight went off, the food magazine was operated and lit by green light for 2.5 sec. When the brief stimulus was presented, the red keylight went off and the stimulus was turned on. The brief stimulus used differed over conditions, as described below.

Following presentation of food or the stimulus, either the fixed-interval schedule or a choice trial began, both conditions scheduled randomly and with equal probability. When the fixed interval was in effect, the procedure was the same as that described above. When a choice trial was arranged, the center key was red, as if a fixed interval were in effect. However, part way into the interval the center keylight went off and both side keys were lit by green light, this change being independent of the bird's behavior. The side keys came on at either of two times, short or long, timed from the onset of the interval. In the initial condition, for example, which involved an FI 10-sec schedule, the side keys came on either 2 sec (short) or 10 sec (long) following the prior presentation of food or the stimulus. Figure 1

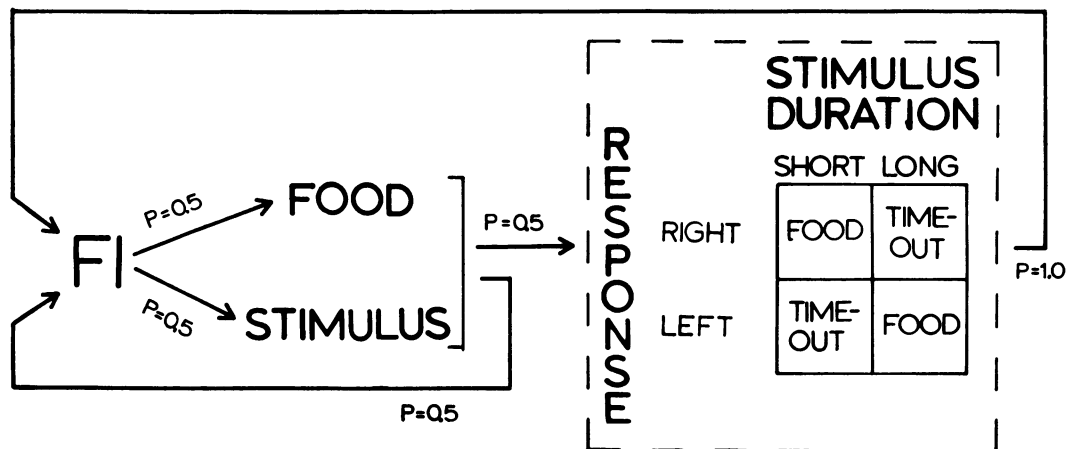


Fig. 1. Diagram of the basic experimental procedure; see text for additional details.

shows the consequences of different stimulus-response combinations. If the side keys were lit after the short duration, a right-key response produced food and a left-key response produced a timeout. If the keys were lit after the long duration, a left-key response produced food and a right-key response produced a timeout. The duration of the food cycle was 2.5 sec, the duration of timeout 5 sec. Short and long durations occurred equally often. During food or timeout periods, the keylights were off. The green magazine light was on during food; no lights were on during timeout periods.

Following food or timeout, the fixed-interval schedule was in effect (a choice trial could not be followed by a choice trial), then the series of fixed intervals and choice trials began anew. A correction procedure was used: if the animal responded incorrectly (*i.e.*, produced a timeout) given the short or the long duration, that same duration was presented the next time a choice trial was given.

The following procedures were adopted to train the pigeons on the task. First, the pigeons were exposed to a simple FI 10-sec schedule for several days; the response that ended each interval produced food. Second, the choice procedure was added. The fixed-interval schedule was occasionally interrupted by a choice trial. On choice trials, only the appropriate side key was lit; this procedure was in effect for one session and was used simply to establish responding on both side keys. Third, both side keys were lit on choice trials. At this point the procedure was like that described above, except that the fixed-interval schedule ended with food only. This phase of training was in effect for almost two months. During this phase, several modifications took place: the duration of the reinforcer was changed; the feeder light, originally white, was changed to green (see Stubbs, 1971 for rationale); the correction procedure was instituted when several pigeons developed a position bias. Finally, the brief stimulus was added, making the procedure the same as that described above.

Three main variables were manipulated in the study: (1) size of the fixed-interval schedule, (2) the stimulus used for the brief-stimulus operation, (3) the pairing or nonpairing of the brief stimulus with food. Table 1 shows the different conditions for each pigeon and the order of occurrence.

Fixed-interval duration. Three fixed-interval schedules were studied: FI 10-sec, FI 20-sec, and FI 100-sec. The pigeons were exposed to different fixed-interval schedules in different orders (see Table 1). The times at which the side keys were lit for choices differed according to the size of the fixed-interval schedule. For the FI 10-sec schedule, the times were 2 and 10 sec; for FI 20-sec, 4 and 20 sec; for FI 100-sec, 20 and 100 sec. These times were chosen to be equal on a relative scale with the short time at 20% of the fixed-interval value and the long time at 100% of the value. Across conditions, two birds were given one brief-stimulus operation and the remaining two birds were given a second brief-stimulus operation. Pigeons C2 and C3 received a 2.5-sec presentation of a white keylight plus houselight as the brief-stimulus operation; Pigeons C5 and C6 received a 0.5-sec presentation of the white keylight, but no houselight.

Different brief-stimulus operations. A within-subjects comparison of the two different brief-stimulus operations was made. All four subjects were exposed to both brief-stimulus operations: the 2.5-sec white keylight plus houselight stimulus, and the 0.5-sec white keylight stimulus. A comparison was made when the fixed interval was 20 sec (FI 20-sec) and 100 sec (FI 100-sec). Different subjects received these conditions in different orders (Table 1).

Pairing and nonpairing of the brief stimulus. In all conditions described so far, the brief stimulus was not paired with food. The last comparison concerned the pairing and nonpairing of the stimulus with food. When the fixed-interval schedule was 100 sec, the pigeons

Table 1

Experimental conditions in order of occurrence. (S^N = nonpaired stimulus, S^P = paired stimulus.)

Schedule	Stimulus	Pigeons			
		C2	C3	C5	C6
FI 10-sec	0.5-sec S ^N			1	1
FI 10-sec	2.5-sec S ^N	1	1		
FI 20-sec	0.5-sec S ^N	3	7	2	7
FI 20-sec	2.5-sec S ^N	2	6, 8*	3	6, 8*
FI 100-sec	0.5-sec S ^N	5	3	5	2
FI 100-sec	2.5-sec S ^N	4	2	4	3
FI 100-sec	0.5-sec S ^P	6	4	6	4
FI 100-sec	2.5-sec S ^P	7	5	7	5

*This condition was in effect twice; scores shown in the results represent the average for the two determinations.

received the 0.5- and 2.5-sec stimuli, both non-paired and then paired with food. When the stimuli were nonpaired, the conditions were the same as described above: completion of an interval produced either the stimulus or food, never both. When, however, the stimuli were paired, completion of an interval produced either the stimulus or the stimulus plus food. When food was produced, the key peck that completed the interval produced a 0.5-sec presentation of the stimulus, followed by a 2.5-sec presentation of food and the green feeder light. Different subjects received the conditions in different orders, with the restriction that both brief stimuli were not paired first.

Experimental conditions were in effect until no systematic changes in the data were observed for at least five sessions. The criterion for stability was based on visual inspection of patterning measures and choice accuracy measures. Conditions were in effect for an average of 26 sessions, with a range between 17

and 55 sessions. These numbers do not include the first condition, which was in effect several months, with various modifications. The numbers also do not include transitional sessions (two weeks) where the schedule was gradually changed from FI 10-sec or FI 20-sec to FI 100-sec (e.g., FI 30-sec to FI 50-sec to FI 70-sec, etc.).

RESULTS

Fixed-interval duration. One manipulation in the study involved the size of the fixed-interval schedule. Figures 2 and 3 show the results. Figure 2 shows response rates across fixed-interval quarters for the different schedules. Points represent means of the last five sessions under each condition. Rate data are shown separately when each of four events preceded intervals. A response ending a fixed interval produced food or a stimulus. Hence, some intervals were preceded by food and some by the stimulus. Also, choice trials interrupted

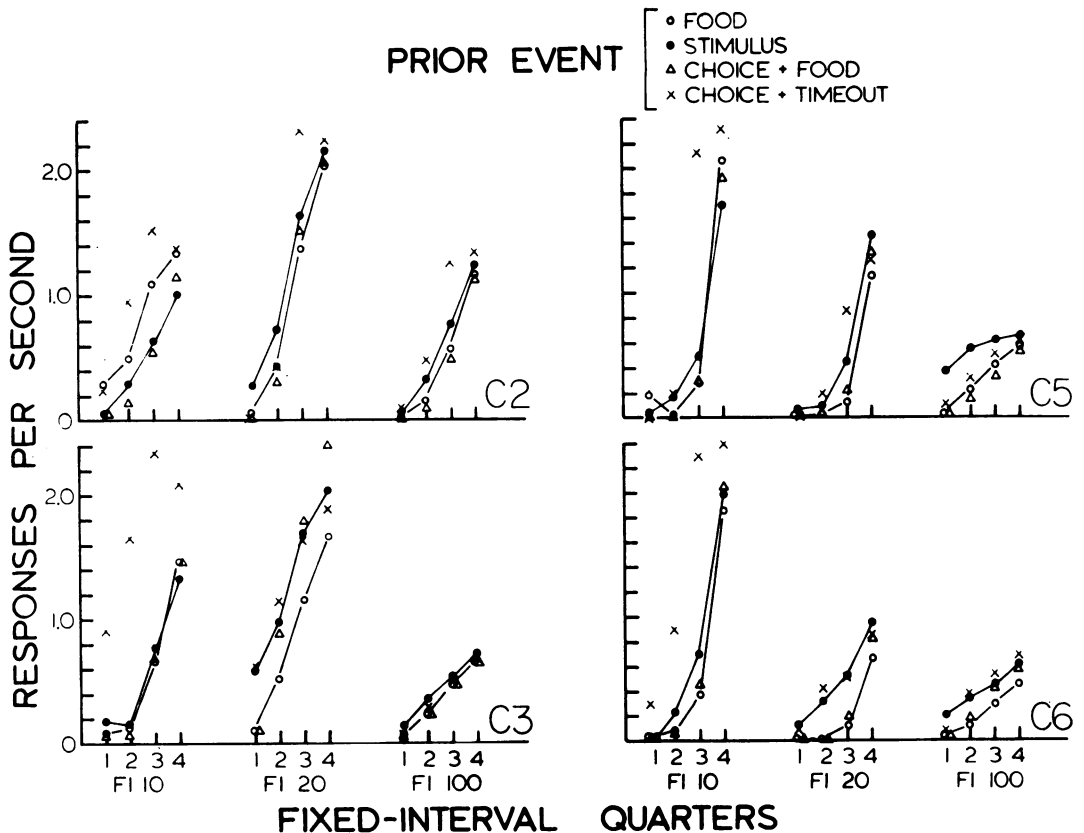


Fig. 2. Response rates across quarters of fixed intervals. Data are shown for each pigeon under the three fixed-interval schedules and separated depending on which of four events preceded the fixed intervals. The stimulus was a 2.5-sec keylight plus houselight for C2 and C3 and a 0.5-sec keylight for C5 and C6.

some intervals. These trials ended with food (correct) or a timeout (incorrect), and as a result, some intervals were preceded by a choice plus food and some by a choice plus timeout. Responses during the first interval of a session were not recorded because only the red keylight began the interval, not one of the four events described. Similarly, responses were not recorded in intervals where the choice situations interrupted the fixed-interval schedule.

Figure 2 shows that response rates increased across quarters in all conditions. Response rates were low in the first quarter and gradually increased across quarters. Differences in responding occurred depending on the schedule and the prior event. In a general way, overall response rates tended to become lower as the duration of the fixed-interval schedule was increased. This effect was not consistent when the FI 10-sec and FI 20-sec schedules are compared, but both of these schedules generated higher rates than the FI 100-sec schedule. Under each schedule, the pattern of responding was quite similar whether the prior event was food or choice plus food. When, however, the brief stimulus was the prior event, rates were occasionally higher in the first two quarters of the fixed-interval schedule. This effect was not apparent under the FI 10-sec schedule, but occurred under the other schedules. When the prior event was a choice plus timeout, the data were irregular. Statements about effects of choice plus timeout are difficult to make because this event occurred only infrequently. Particularly under the shorter two schedules, choice accuracy was high; as a result, few timeouts occurred and the data shown are probably irregular due to few instances entering into recording.

Figure 3 shows summary data on response patterning and choice accuracy. All points represent means of the last five sessions.² The top portions show the Index of Curvature, which is a measure of the degree of curvature

under a fixed-interval schedule (Fry, Kelleher, and Cook, 1960; Gollub, 1964). With the interval divided into four quarters, the measure can vary from -0.75 to $+0.75$. A measure of 0 would mean that response rates were equal in all quarters. Values above 0 would mean that relatively more responses occurred in the fourth quarter. Bottom portions show choice accuracy. The measure is the total number of correct responses divided by the total of correct plus incorrect responses.

Figure 3 shows that for all subjects except C2, there was a general trend for response measures—both Index and accuracy—to decline as the fixed-interval schedule increased. This declining trend characterized the three subjects in every comparison involving accuracy measures, and in most cases involving Index measures with food and the brief stimulus as prior events. Some exceptions may be seen for C5 and C6 when FI 10-sec and FI 20-sec schedules are compared. However, both of these schedules generated higher Index measures than did the FI 100-sec schedule. The exceptions, together with those seen in Figure 2, show that the two shortest schedules did not produce reliably different effects.

Different brief-stimulus operations. All pigeons were trained under FI 20-sec and FI 100-sec schedules with both brief stimuli, the 0.5-sec white keylight and the 2.5-sec keylight plus houselight. Figure 4 shows the results. Points represent means of the last five sessions. Figure 4 is like Figure 3 in form, except that bars replace the closed circles of Figure 3 to represent performance when a stimulus was the prior event. The change emphasizes the effects of the stimulus, the major focus of this part of the study. Some of the data are the same as those shown in Figure 3 (C2 and C3 for the 2.5-sec stimulus and C5 and C6 for the 0.5-sec stimulus).

Figure 4 shows four main findings. First, the 2.5-sec stimulus produced higher Index and choice measures than did the 0.5-sec stimulus at both schedule values, with one exception (C5) when the FI 20-sec schedule was in effect. Second, there was a decrement in both Index and choice measures when the schedule was changed from FI 20-sec to FI 100-sec. When the 0.5-sec stimulus was used, there was a lowering in all cases. When the 2.5-sec stimulus was used, there was minimal decrement in accuracy for all four pigeons and a lowering

²Standard deviations also were calculated for the last five sessions of each condition, but these data are not present in Figure 3 (or the following figures) since presentation would make the figures too cumbersome. The average standard deviations were 0.06, 0.05, 0.04, and 0.05 for Pigeons C2, C3, C5, and C6 for Index of Curvature measures and 0.06, 0.08, 0.07, and 0.05 for accuracy measures.

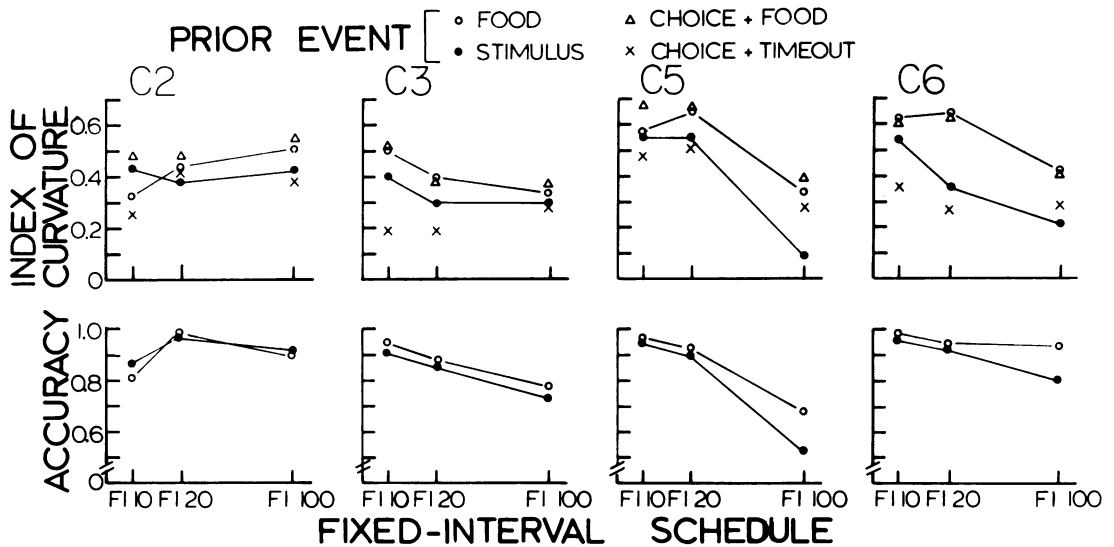


Fig. 3. Index of Curvature (top) and choice accuracy (bottom) measures for the pigeons at different fixed-interval values. Index measures are shown separately, depending on which of four events preceded the fixed intervals. Accuracy is shown separately when food or the brief stimulus was the event preceding a choice. Pigeons C2 and C3 received a 2.5-sec stimulus while C5 and C6 received a 0.5-sec stimulus.

for two of the four subjects in the Index measures. The upper right-hand section of Figure 4 presents average data, and shows a greater decrement for the 0.5-sec stimulus as the schedule was increased. The averaged data are generally representative of the performance of the individual subjects.

A third point concerns the data at the FI 100-sec schedule. With the 0.5-sec stimulus, Index measures were below 0.1 for three subjects (C2, C3, C5) and accuracy measures for these subjects were below 0.6. These results indicate that the 0.5-sec stimulus had minimal control over performance when the schedule was FI 100-sec. In contrast, the 2.5-sec stimulus engendered both higher Index and higher accuracy scores. Fourth, the 2.5-sec stimulus generated similar, though slightly lower, Index and accuracy scores to those produced when food was the prior event. In contrast, the 0.5-sec stimulus led to Index and accuracy scores that were consistently and markedly below those generated when food was the prior event.

The various points, taken together, imply the following summary statement. Under the shorter fixed-interval schedule, both brief stimuli controlled patterning and choice. When fixed-interval duration was increased, the control exerted by the more-salient stim-

ulus showed only a slight decrement; in contrast, the control exerted by the less-salient stimulus was greatly reduced.

Pairing and nonpairing of the brief stimulus. Another manipulation in the study concerned the pairing or nonpairing of the brief stimulus with food. The 0.5-sec and 2.5-sec stimuli were presented as paired and nonpaired stimuli with the FI 100-sec schedule in effect. Figure 5 shows the results. Points are means of the last five sessions. Some points are the same as presented in Figure 4 (the data under the FI 100-sec schedule with the nonpaired conditions).

Figure 5 shows that the 2.5-sec stimulus produced higher Index and accuracy scores than the 0.5-sec stimulus, as was the case in Figure 4. Figure 5 also shows that scores were higher when the stimulus was paired than when it was nonpaired; these results held for both measures for the 0.5-sec and 2.5-sec stimuli. When the 0.5-sec stimulus was changed from nonpaired to paired, there was a marked increase in curvature and accuracy for three of the four pigeons. The one pigeon (C6) that exhibited only a small change in behavior was the one subject with relatively high scores under the nonpaired condition. The remaining three showed Index scores near zero and accuracy scores near chance when the stimulus was

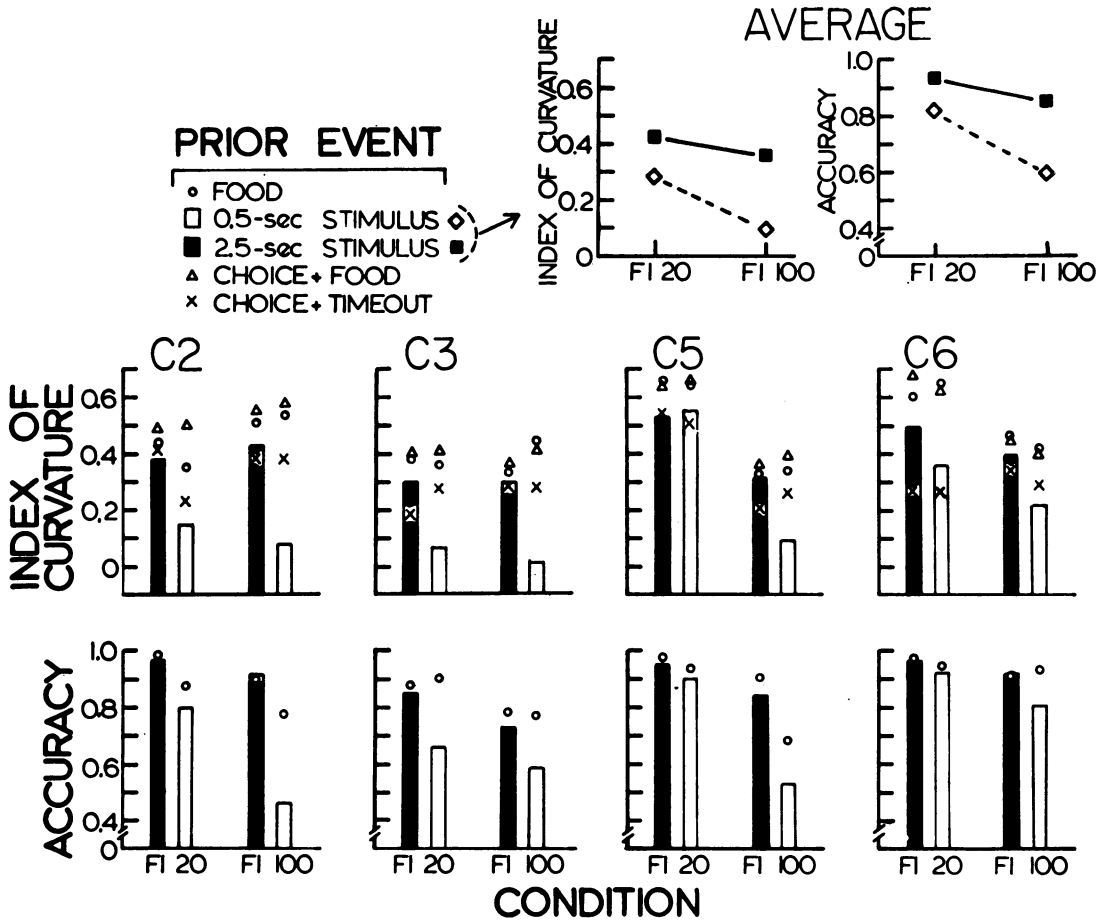


Fig. 4. Index of Curvature and accuracy measures for the pigeons across conditions: each pigeon was exposed to both brief stimuli at each of two fixed-interval schedules. The upper right-hand portion shows the average scores of the four subjects when the brief stimuli were prior events.

nonpaired. In contrast, there was only a slight increase in scores when the 2.5-sec stimulus was changed from nonpaired to paired: an average increase of 0.05 in Index scores and an average increase of 0.01 in accuracy. The upper right-hand section of Figure 5 shows the major effect of pairing *versus* nonpairing averaged for the four subjects: the relatively large difference in effect of pairing and nonpairing for the 0.5-sec stimulus and the slight difference for the 2.5-sec stimulus.

Figure 5 shows other effects similar to those of Figures 3 and 4. Food and choice plus food produced similar effects on patterning, and both of these prior events generally produced higher scores than the brief stimuli. The 2.5-sec stimulus occasioned Index and accuracy measures near the level of those produced by food and by choice plus food. Accuracy and

patterning measures tended to vary together, as was the case in previous figures.

General results. Figures 3, 4, and 5 showed data on choice accuracy. These data represent total accuracy, the combination of choice data given short durations and given long durations. Choice responses were recorded separately to compare accuracy at short and long durations. The data show a tendency for accuracy to be somewhat higher for short duration choices than for long. A comparison was made for each pigeon under each condition. Of the 56 comparisons, mean accuracy was higher at the short duration in 41 cases and lower in 12 cases (with accuracy measures being equal in three cases). A similar result obtained with the session-to-session performance; accuracy scores were higher given short durations on about 70 to 80% of the sessions. There

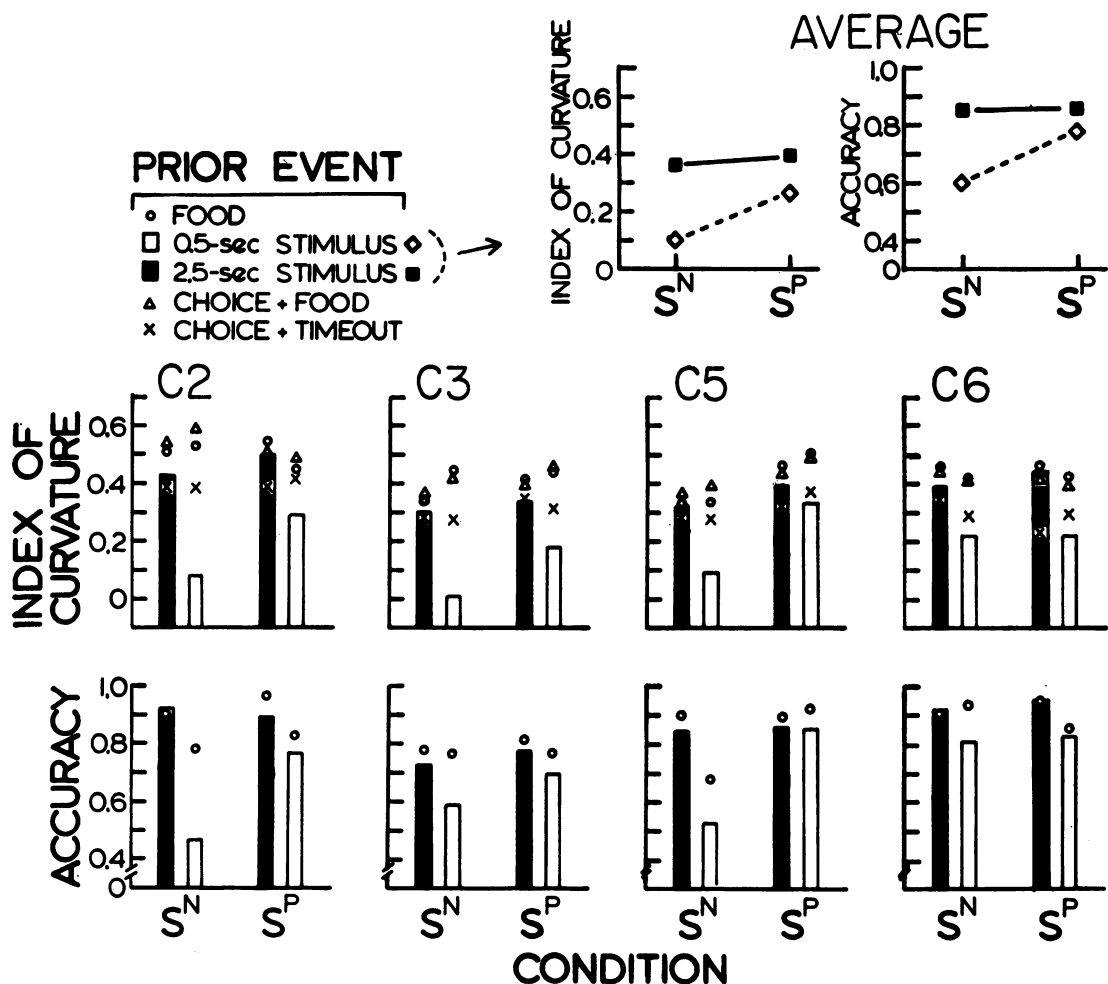


Fig. 5. Index and accuracy scores for the pigeons across conditions: each pigeon was exposed to both brief stimuli both as a nonpaired (S^N) and a paired (S^P) stimulus when the value of the fixed interval was 100 sec. The upper right-hand portion shows the average scores of the pigeons when the brief stimuli were the prior events.

was no tendency for the pattern of errors to change (e.g., greater proportion of "long errors") as a function of changes in the fixed-interval schedule, changes in the brief stimulus, changes in the pairing operation, or changes in accuracy level.

The previous figures demonstrated a correlation between Index of Curvature and accuracy measures. Figure 6 clarifies and suggests some limitations on the nature of the correlation. Figure 6 presents accuracy scores as a function of Index of Curvature across all conditions of the study. The points represent five-session means.

Figure 6 shows that patterning and accuracy were correlated: in general, the higher the In-

dex score the higher was accuracy (more so for C5 and C6 than for C2 and C3). The points approximate the curved lines. These functions were fit visually to approximate the obtained points. The functions originate at 0 for Index measures and 0.5 for accuracy (under an assumption that the functions originate where curvature was absent and accuracy was at the chance level). The points and curved lines suggest something about the nature of the relation. When Index measures were low (0 to 0.3) increases in patterning were accompanied by relatively large increases in choice accuracy; when, however, Index measures were high (0.4 to 0.7), increases in patterning were accompanied by only slight changes in accuracy.

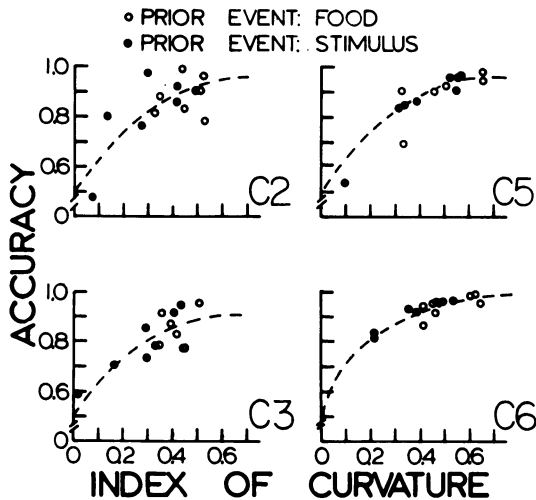


Fig. 6. Correlational data showing accuracy scores as a function of Index scores across all conditions of the experiment. Points are shown separately when preceding events were food and the brief stimulus. The curved lines were visually fit.

When, for example, Index measures were 0.4 or above, virtually all of the points show accuracy scores of 0.9 or higher for Pigeons C5 and C6. For these birds, changes in Index measures of nearly 0.30 were accompanied by a change of only 0.05 in accuracy. The results imply that accuracy is correlated with patterning, but that accuracy may approach a maximum while patterning still increases. Further, the results imply that the correlation would be most obvious when the degree of patterning is low.

The data of C2 and C3 are not as regular as those of the other subjects. While the earlier correlational statements and the general findings of Figure 7 hold for these subjects, their results indicate that statements about correlations should be made with some caution.

DISCUSSION

The present experiment involved a combination of brief-stimulus schedule and choice procedures. The experiment produced three main findings. First, both patterning and choice measures decreased as the fixed-interval schedule increased. The decrease occurred whether food or stimuli were the prior events controlling schedule performance or choice responding. Second, the degree of control differed for the two brief stimuli, with higher Index and accuracy measures being produced by

the more-salient stimulus. There was an interaction between brief-stimulus effects and schedule size: the decrease in control by the 2.5-sec stimulus was relatively small as fixed-interval schedule increased, while the decrease was relatively large for the 0.5-sec stimulus. Third, the pairing operation increased both patterning and choice accuracy for the 0.5-sec stimulus, but had little effect on these measures with the 2.5-sec stimulus.

The results bear on previous brief-stimulus research. In addition, the combination of schedule and choice procedures provides implications for animal memory research. Both aspects of the results will be discussed in turn.

Several reinforcement-omission studies have found that the degree of response patterning is higher following food than following a brief stimulus (Staddon, 1972*b*, 1974; Staddon and Innis, 1969; Starr and Staddon, 1974). In these studies, the pause following a stimulus (black-out) was not as great as that following food. More directly related to the present study, Starr and Staddon found that the degree of temporal control was related to the size of the component schedule. They found that a black-out and food produced a similar degree of pausing at short intervals, but that the black-out produced relatively shorter pause times than food at longer intervals.

Our data are consistent with these results. Food as the prior event resulted in a higher degree of patterning (and choice accuracy) than did either brief stimulus. And, the degree of patterning generally declined as fixed-interval size was increased. The relatively large decrement in patterning with the 0.5-sec stimulus is analogous to and extends the results obtained by Starr and Staddon. Their results suggested a decline in the control exerted by a brief stimulus at fixed-interval values of 1 min or more. Our results indicate that a decline in temporal control depends on the specific stimulus used. Both brief stimuli showed a decline in temporal control when the schedule was changed from FI 20-sec to FI 100-sec, but the degree of change was much greater for the 0.5-sec stimulus. The 0.5-sec stimulus produced a near-zero Index of curvature at FI 100-sec, while the 2.5-sec stimulus produced a higher Index, much like that produced by food. Not only was there a decline in the temporal control exerted by the brief stimuli, but also in the control exerted by food (although

this effect was not consistently obtained). This decline may have resulted from the use of a 2.5-sec reinforcer duration. Others (*e.g.*, Dews, 1970) have observed that the degree of temporal control is similar across a wide range of fixed-interval schedules, but they have typically used longer reinforcer durations. Perhaps analogous to the case of the brief stimuli, the degree of temporal control is affected when a brief reinforcer duration is used, but not as much when a longer reinforcer duration is used. The combined results of the brief stimuli and food imply that a decline in temporal control occurs with all stimuli; the specific temporal parameters may differ, however, depending on the specific stimuli used.

That blackouts produce shorter pauses than food has led Staddon (1974) and Starr and Staddon (1974) to propose that "valued" events such as food will exert a higher degree of temporal control than will relatively neutral events, such as a brief stimulus (see also Staddon, 1972*a*; 1972*b*). Staddon (1974) suggested these results occur because neutral stimuli might not be as memorable as the more "valued" stimuli such as food. While our data support Staddon's interpretation, we are somewhat cautious about accepting it, since an alternative explanation emphasizing the stimulus properties of brief stimuli is possible. Several second-order schedule experiments, as well as the present experiment, have found that the degree of response patterning depends on the properties of brief stimuli used (Stubbs, 1971). The number of stimulus elements (Kello, 1972; Stubbs, 1971; Stubbs and Cohen, 1972), the duration of the brief stimulus (Cohen, Hughes, and Stubbs, 1973; Staddon and Innis, 1969), and the type of stimulus (*e.g.*, a keylight *versus* blackout) (Kelleher, 1966; Stubbs, 1971; Stubbs and Cohen, 1972), all affect the degree of response patterning. These findings have implications for the results of greater curvature following food than a brief stimulus. That food and brief stimuli engender different response patterns might be due to the use of different numbers, durations, and types of stimuli for food and brief-stimulus operations. In the present experiment, one brief stimulus involved a 0.5-sec duration of keylight change; the second stimulus involved a longer, 2.5-sec, duration of keylight change plus houselight. In contrast, the food operation involved turning off the keylight, turning

on the feeder light, and presenting food for 2.5 sec; this operation also involved implied kinesthetic stimuli (moving from the key to the feeder) and tactual and gustatory stimuli (from eating). Thus, the feeder operation involved more stimulus elements (and elements in more than one sense modality), and would be expected to produce a higher degree of patterning. In addition, the sensory after-effects of food presumably are greater than those of visual stimuli. Probably the "value" of an event affects the way it exerts temporal control over behavior, as Staddon suggests. However, the different effects of food and brief stimuli do not as yet offer unequivocal support for such a view (see Staddon, 1974, for other lines of evidence).

The present experiment demonstrated different effects of paired and nonpaired brief stimuli. Previous second-order schedule research has emphasized the pairing of the brief stimulus, since this operation supported a conditioned reinforcement interpretation of some brief-stimulus effects (Gollub, 1977; Kelleher, 1966). One group of experiments has found a difference in the effects of paired and nonpaired stimuli, supporting a conditioned reinforcement interpretation, while a second group has failed to find differences. Several papers have offered different explanations to explain the seeming discrepancies in results (Cohen, Hughes, and Stubbs, 1973, 1976; Gollub, 1977; Starr and Staddon, 1974; Stubbs, 1971). The present results clarify the seemingly discrepant results by suggesting conditions under which paired and nonpaired stimuli may have similar or different effects on behavior. The effectiveness of the pairing operation differed, depending on the brief stimulus in use. Striking differences resulted from pairing and nonpairing operations when the 0.5-sec stimulus was used. In contrast, only a negligible difference resulted when the more-salient 2.5-sec stimulus was used. The results suggest that the pairing operations may control schedule characteristic performance only to the extent that nonpaired stimuli control a low degree of patterning (as was the case with the 0.5-sec stimulus). When nonpaired stimuli exert a high degree of patterning, the pairing operation might be relatively ineffective. Salient brief stimuli might exert a nearly maximal degree of temporal control, with the result that pairing operations cannot modify performance.

A primary interest of the study was the relation between brief-stimulus schedule research and memory research. Staddon (1974) has drawn several parallels between the findings of brief-stimulus research and research on animal short-term memory. Staddon argued that the brief-stimulus results may be placed within the conceptual framework of memory. The present combination of choice and schedule procedures provides more direct evidence than was available from schedule research alone. The schedule results of (1) a lower degree of curvature under larger schedule values, (2) a lower degree following a stimulus than food, and (3) a higher degree of patterning with the more-salient stimulus are all consistent with the findings of memory experiments. But the correlated results of choice responding provide a stronger link, since the choice aspect is closer in design to the usual animal memory procedures (*e.g.*, D'Amato, 1973), thus making closer contact with other memory research.

The present choice results are consistent with the results of memory experiments in several ways. The longer-duration brief stimulus produced a higher degree of choice accuracy than the shorter stimulus. Research using a delayed-matching-to-sample procedure has shown that longer-duration samples produce higher matching accuracy (Roberts and Grant, 1974; see also Riley and Leith, 1976). Choice accuracy was higher in the present study when the prior event was food than when it was a brief stimulus. These results are consistent with those of a delayed response experiment, showing a higher degree of choice accuracy when a larger amount of food was shown as the cue for a later choice response (Cowles and Nissen, 1937). Choice accuracy declined in the present experiment as the schedule value (and the time from a stimulus to a choice) increased. This result parallels the common findings of delayed response and delayed-matching-to-sample procedures that choice accuracy declines as time from the prior sample increases. The time parameters differ between the present task and the other tasks, but this difference probably stems from the different choice tasks used: choice responses were reinforced depending on the time elapsed since a prior event in the present task; choice responses were reinforced depending on which of two or more stimuli had been present at a prior time in the other tasks.

The discussion has emphasized the effects of prior stimuli, with choice responding viewed as a function of the duration elapsed since a prior event. However, the question may be raised of whether the prior events actually controlled choice behavior. The pigeons responded during the fixed-interval schedule and, as a result, center-key responses were emitted on choice trials. Typically, relatively few responses were emitted when the short-duration choice interrupted the interval and relatively many responses when the long-duration choice interrupted. Possibly, the pigeons responded on the side keys depending on the number of center-key responses emitted, few or many. Several experiments have demonstrated that the number of responses emitted by an animal can serve as discriminative stimuli (*e.g.*, Hobson, 1975; Pliskoff and Goldiamond, 1966; Rilling, 1967). Under these procedures, responses on one key produce a choice situation; one choice response is then reinforced if "few" responses had been emitted, and the alternate choice response is reinforced if "many" responses had been emitted. Using a similar procedure, Rilling (1967) had pigeons discriminate fixed-interval schedules. Rilling analyzed the responses that occurred during the intervals and found that choice responding was a function of the number of responses: when few responses were emitted during a particular interval, the animals' choice response was to the key associated with the shorter fixed interval and *vice versa*.

The previous research suggests that center-key responses may have played a role in the control of choice in the present experiment. However, the previous research should not be taken to mean that the present procedure simply involved discrimination of prior responses, with the prior events being of no relevance. Such a view would not explain some of the results. Under the FI 100-sec schedule, choice trials involved interruption of the interval 20 sec or 100 sec after a prior event. Under this schedule, the pigeons emitted approximately two to eight responses in the first 20 sec of the fixed interval and 40 to 60 responses during the entire interval (see Figure 1). The previous research has shown that such a response discrimination (two to eight responses *versus* 40 to 60 responses) should produce a high level of choice accuracy. Under some conditions (with food or the 2.5-sec

stimulus as prior events) choice accuracy was high. But choice accuracy was near chance when the 0.5-sec stimulus was the prior event. This finding shows the importance of the prior event and shows that different numbers of responses, although present, may not serve as an effective stimulus controlling choice behavior.

Followup research on the present experiment bears on the issue of responses as discriminative stimuli. A psychophysical analysis has been made in which choice trials interrupted the fixed-interval schedule at different times (e.g., short durations of 4, 8, 12, 16, and 18 sec as "short" versus 20 sec as "long" with the FI 20-sec schedule in effect). As part of this research, there were conditions in which both short and long durations occurred early in the interval (e.g., 1 sec versus 4 sec). Under these conditions, center-key responses did not occur on choice trials, since the animals typically paused longer than 4 sec since the prior event. But even though center-key responses did not occur, choice accuracy was high under these conditions.

The two examples show an instance in which differential responses were emitted, yet choice accuracy was low, and one in which responses were not emitted, yet choice accuracy was high. These examples indicate that the responses emitted do not by themselves establish the necessary or sufficient conditions for appropriate choice behavior. Responses emitted may contribute in some instances, comprising a complex set of stimuli that include the prior event and subsequent behavior. But a response analysis by itself does not adequately explain the data.

The present procedure used a combination of schedule and choice procedures. Such a combination need not be restricted to similar experiments, but rather, other combination procedures are possible, and in fact some have been reported. Different investigators have studied choice behavior that depended on (1) the size of a prior schedule requirement (Hobson, 1975; Pliskoff and Goldiamond, 1966; Rilling, 1967); (2) the duration of a prior interresponse time (Nelson, 1974); (3) response-reinforcer contingencies (Lattal, 1975); (4) the reinforcement density for a sequence of responses (Commons, 1973); and (5) a stimulus-response sequence (Shimp, 1976a). Combination procedures may prove useful for clarifying both schedule performance and dis-

crimination performance. The usefulness for the study of schedule performance is perhaps obvious: the addition of a choice situation provides information on the discriminative functions of stimuli, responses, consequences, and their relations. Combination procedures may be equally useful for the study of choice behavior. The procedures may be useful for development of new discrimination procedures (Shimp, 1976a, 1976b). Choice and schedule performance were correlated in the present study and complemented each other. Other procedures can be devised to integrate schedules with other choice procedures to clarify our understanding of choice behavior.

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