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SECOND-ORDER SCHEDULES: COMPARISON OF DIFFERENT PROCEDURES FOR SCHEDULING PAIRED AND NONPAIRED BRIEF STIMULI

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Pigeons performed on a second-order schedule in which fixed-interval components were maintained under a variable-interval schedule. Completion of each fixed-interval component resulted in a brief-stimulus presentation and/or food. The relation of the brief stimulus and food was varied across conditions. Under some conditions, the brief stimulus was never paired with food. Under other conditions, the brief stimulus was paired with food; three different pairing procedures were used: (a) a response produced the simultaneous onset of the stimulus and food; (b) a response produced the stimulus before food with the stimulus remaining on during food presentation; (c) a response produced the stimulus and the offset of the stimulus was simultaneous with the onset of the food cycle. The various pairing and nonpairing operations all produced similar effects on performance. Under all conditions, response rates were positively accelerated within fixed-interval components. Total response rates and Index of Curvature measures were similar across conditions. In one condition, a blackout was paired with food; with this different stimulus in effect, less curvature resulted. The results suggest that pairing of a stimulus is not a necessary condition for within-component patterning under some second-order schedules.

A number of studies have shown that the scheduling of brief-stimulus presentations may have marked effects on behavior (Byrd and Marr, 1969; Clark and Sherman, 1970; de Lorge, 1969; Kelleher, 1966*a*; 1966*b*; Marr, 1969; Stubbs, 1971). One arrangement for scheduling brief stimuli involves use of second-order schedules. Under a second-order schedule, performance generated by one schedule is treated as a unitary response that is reinforced according to a schedule of reinforcement. Thus, an animal might be required to complete 10 fixed-interval components before food is presented. One may speak of fixed-interval components being maintained under a fixed-ratio schedule (FR 10). Brief stimuli may be scheduled by having the response that completes each component produce the brief stimulus. Brief-stimulus presentations affect the pattern of responding under second-order schedules. When brief stimuli accompany component completion, the pattern of responding within each component is similar to that generated by food presentation (Kelleher, 1966*a*; 1966*b*). When, for example, fixed-interval components are used, a positively accelerated rate within components has been observed (Kelleher, 1966*a*; 1966*b*; Stubbs, 1971).

Several studies on second-order schedules have suggested that a brief stimulus must be paired intermittently with food in order to maintain within-component patterning: the brief stimulus that occurs at the completion of each component must also be presented when food is presented (Byrd and Marr, 1969; de Lorge, 1967; 1969; 1971; Kelleher, 1966*a*; 1966*b*; Marr, 1969). In these studies, a stimulus intermittently paired with food produced patterning within components. Stimuli not paired with food often failed to produce patterning, or the degree of patterning was not as great as that observed under the pairing procedure.

The results of other studies, however, have demonstrated that stimuli not paired with food have strong effects on response rates and patterns of responding (*e.g.*, Neuringer and Chung, 1967). And Stubbs (1971) found that across a variety of second-order schedules, paired and nonpaired stimuli engendered similar effects on performance.

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A difference between Stubbs' procedure and some of the previous procedures concerns the method of pairing the brief stimulus with food. For the pairing operation, Stubbs had the "reinforced" response produce the simultaneous onset of the stimulus and food. In the previous studies, the more usual procedure involved the following: the reinforced response produced the brief stimulus which was followed shortly (generally 0.5-0.75 sec) by food. Thus, the pairing operations generally involved the brief stimulus preceding food. Previous research on conditioned reinforcement suggests that a stimulus that briefly precedes food might be more effective than a stimulus presented simultaneously with food (Bersh, 1951; Jenkins, 1950; Schoenfeld, Antonitis, and Bersh, 1950). The method of pairing a stimulus with food might be an important factor in determining whether paired and nonpaired stimuli have similar effects on behavior. Accordingly, the present study was designed to examine the effects of different pairing and nonpairing operations on second-order schedule performance.

EXPERIMENT I

Method

Subjects

Two male adult White Carneaux pigeons, #5 and #15, and one male adult Silver King pigeon, #29, were maintained at 80% of their free-feeding body weights. The White Carneaux had previous experience under concurrent schedules, and the Silver King had experience under visual and auditory discriminations.

Apparatus

A standard two-key pigeon chamber was used. The two keys (Ralph Gerbrands Company) were mounted 9.25 in. (23.5 mm) above the floor, 2.50 in. (6.35 mm) between centers. Only the right key was used. The left key was dark and inoperative. The key could be transilluminated by different color lights. The chamber contained two white houselights in the two upper corners of the work panel. A minimum force of 15 g (0.15 N) was required to operate the key. Each response produced an audible click from a relay located behind the response panel. A Lehigh Valley Electronics pigeon feeder presented grain. White masking noise was continuously present. Standard relay and timing circuitry, located in an adjacent room, controlled experimental sessions.

Procedure

Experimental sessions were conducted daily. Each session was terminated after 26 food presentations (except under the last experimental condition). Each food presentation consisted of 4-sec access to mixed grain during which the feeder was illuminated by orange light.

Pigeons responded under a second-order schedule in which fixed-interval (FI) components were maintained under a variable-interval (VI) schedule of reinforcement. The response key was transilluminated red and both houselights were off. The completion of an FI 48-sec component produced food only if a time period of the VI schedule had elapsed. The VI schedule had an average interval of 240 sec and contained 16 intervals. The interval distribution was derived from the Catania and Reynolds formulation (1968, pp. 380-381). If the VI 240-sec tape had not set up, the completion of each FI 48-sec component produced a brief change in the keylight from red to white accompanied by the illumination of both houselights. The duration of this brief-stimulus change was 2 sec for the first six conditions of the experiment, and 0.5 sec for the last four (see Table 1). Using Kelleher's (1966*b*) notation system, the basic schedule may be designated a VI 240-sec (FI 48-sec:S).

Depending on which condition was in effect, the brief stimulus was either paired (S^p) or not paired (S^n) with food. Under the various pairing operations, VI 240-sec (FI 48-sec:S^p), the brief stimulus that terminated each FI 48-sec component also accompanied food presentations. Under the nonpaired condition, VI 240-sec (FI 48-sec:S^n), the brief stimulus terminated each component except components that produced food.

The method of pairing the brief stimulus with food was varied: Table 1 shows the order of conditions and the number of sessions under each. Except for the first condition (which was continued for approximately 50 sessions) and last condition (10 sessions), conditions were arbitrarily changed after 16 sessions.

Under the preceding nonoverlapping pair-

Table 1

Summary of Conditions in Order of Presentation

Condition	Schedule	Pairing or Nonpairing procedure	Brief stimulus duration
1	VI 240-sec (FI 48-sec:S^n)	key stimulus off during reinforcement	2 sec
2	VI 240-sec (FI 48-sec:S^p)	preceding nonoverlapping	2 sec
3*	VI 240-sec (FI 48-sec:S^n)	key stimulus on during reinforcement	2 sec
4	VI 240-sec (FI 48-sec:S^p)	preceding overlapping	2 sec
5	VI 240-sec (FI 48-sec:S^p)	simultaneous	2 sec
6	VI 240-sec (FI 48-sec:S^n)	key stimulus off during reinforcement	2 sec
7	VI 240-sec (FI 48-sec:S^n)	key stimulus off during reinforcement	0.5 sec
8	VI 240-sec (FI 48-sec:S^p)	preceding overlapping	0.5 sec
9	VI 240-sec (FI 48-sec:S^n)	key stimulus off during reinforcement	0.5 sec
10	Ext (FI 48-sec:S)	—	0.5 sec

* Pigeon 29 was not included in this condition due to a cracked beak.

ing condition, (Condition 2) the completion of an FI 48-sec component scheduled to produce food initiated the onset of the 2-sec brief stimulus. At the termination of the brief stimulus, the key was darkened and the 4-sec food cycle was initiated.

Under the preceding overlapping pairing condition, the brief stimulus began 2 sec or 0.5 sec (2 sec for Condition 4; 0.5 sec for Condition 8) before food and remained on during the 4-sec reinforcement cycle.

Under the simultaneous pairing condition (Condition 5), the brief stimulus and the reinforcement cycle started and terminated simultaneously.

Two different nonpaired brief-stimulus procedures were run. Under one procedure (Conditions 1, 6, 7, 9), the completion of a component scheduled to produce food darkened the response key and initiated the reinforcement cycle. Under the second nonpairing procedure (Condition 3), the response key remained red during the reinforcement cycle.

Under the last condition, food was omitted from the schedule (extinction). Completion of each FI 48-sec component produced only the occurrence of the 0.5-sec brief stimulus. Since food was not presented, it is inappropriate to refer to the brief stimulus as either paired or nonpaired. Each extinction session lasted 2 hr.

Results

Figures 1 to 4 show data on performance across the various conditions. Figure 1 shows response rates across quarters of fixed-interval components for the different conditions. The data are medians of the last five sessions under each condition. Rates were calculated for each session in the following way: responses were totalled across all components for the first 12 sec of each fixed-interval, second 12 sec, third 12 sec, and fourth 12 sec. Response totals for each quarter were divided by the total time in seconds spent in each quarter of all the intervals.

Under all conditions, response rates increased across fixed-interval quarters indicating a positively accelerated rate of responding within fixed-interval components. Performance for each pigeon was similar across all conditions. Rates in certain quarters, most noticeably the early quarters, varied somewhat, but the variability was not associated with any one class of conditions. Total response rates (not shown) were calculated in addition to the quarter rates shown in Figure 1. Inference from Figure 1 and examination of the total session rate measures showed that there was no trend for total rates to be higher or lower under paired as compared with nonpaired brief-stimulus conditions. No systematic

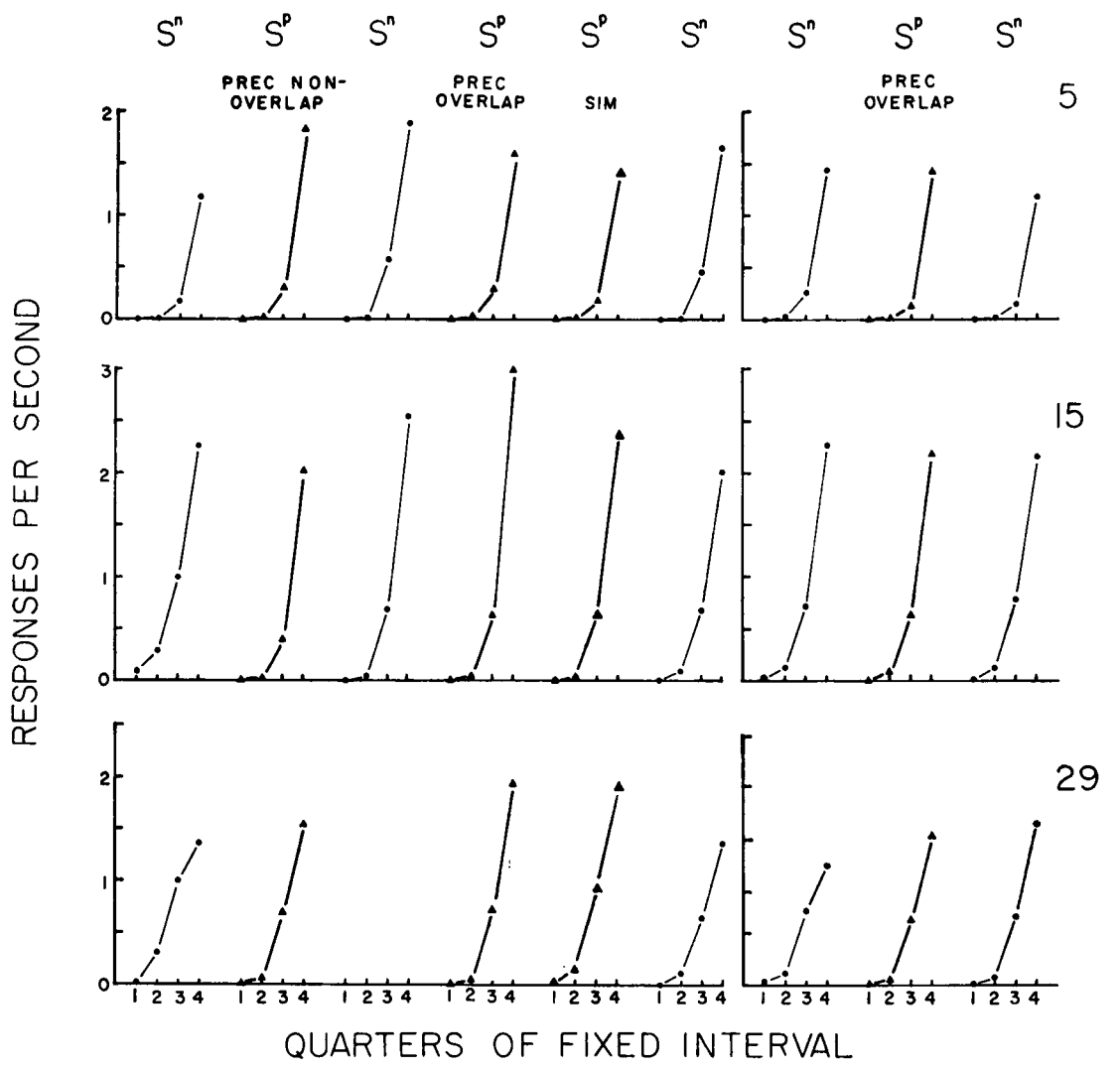

Fig. 1. Response rates across quarters of fixed-interval components under the various conditions. The conditions are arranged, left to right, in the order of presentation (see Table 1). For the left-hand portions the duration of the brief stimulus was 2 sec; for the right-hand portions the duration was 0.5 sec. S^p refers to a paired brief stimulus and S^n refers to a nonpaired brief stimulus.

differences were found among the various pairing procedures or between the nonpairing procedures.

Figure 2 shows representative cumulative records. The records show performance under three pairing procedures and one nonpairing procedure. Two records show performance when the brief-stimulus duration was 2 sec, and the other two show performance when the duration was 0.5 sec. In addition, the records span the course of the experiment with the top record coming from the second condition and the bottom record coming from the ninth. Performance was quite similar across conditions: the positively accelerated rate occurred in almost every fixed-interval component. Cumulative records for the other subjects were similar to the records shown in Figure 2.

Figures 3 and 4 show Index of Curvature measures; the data are from the last 16 sessions of the first conditions and for every session under the remaining conditions. The Index of Curvature is a measure of the extent of curvature in a cumulative response record and allows one to assess the extent of patterning

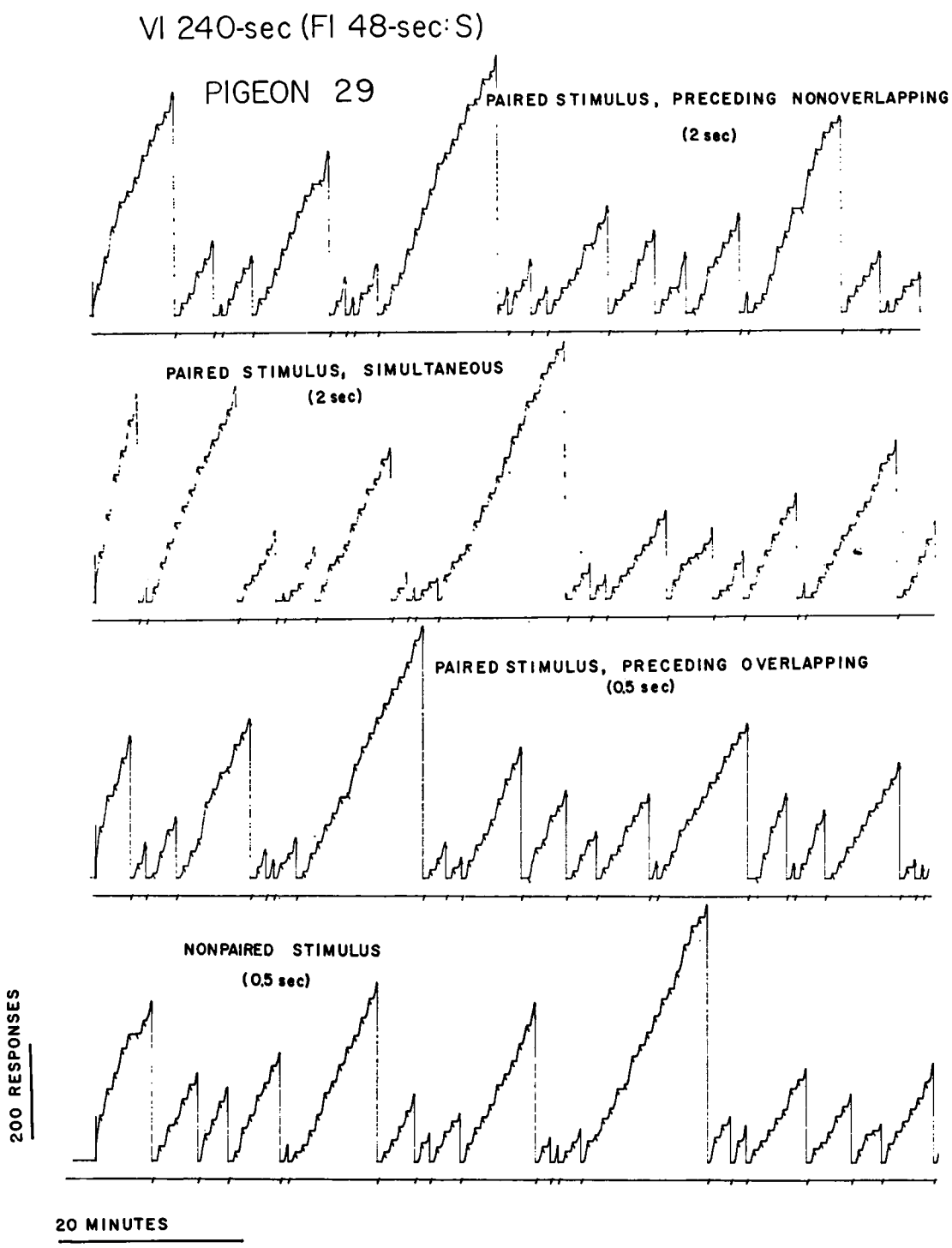

Fig. 2. Portions of cumulative records for one pigeon. The records from top to bottom came from the last session of Conditions 2, 5, 8, and 9. Each response stepped the pen once. Brief-stimulus presentations are indicated by downward deflections of the response pen. Food presentations are indicated by downward deflections of the event pen plus the resetting of the response pen. The recorder motor ran except during brief stimulus and food periods.

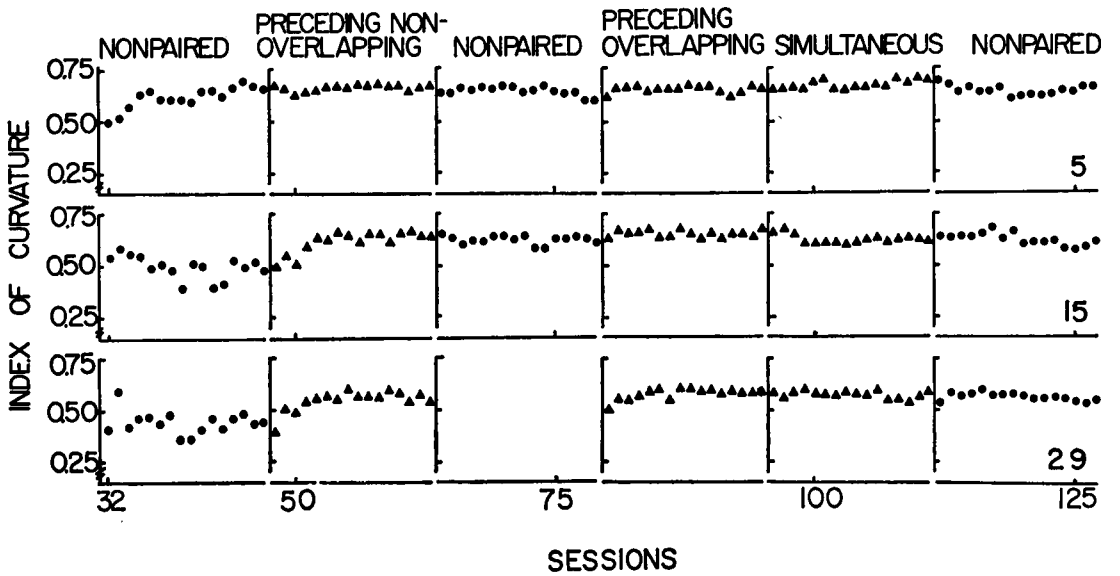

Fig. 3. Daily Index of Curvature measures across conditions when the brief-stimulus duration was 2 sec. The measures are from the last 16 sessions of the first condition and from all following sessions. The conditions are arranged from left to right in the order of presentation (see Table 1). Closed circles indicate nonpaired brief stimulus conditions while triangles indicate paired.

within fixed-interval schedules (Fry, Kelleher, and Cook, 1960; Gollub, 1964). A measure of 0.0 would indicate no patterning (a constant rate across quarters of the fixed-interval) while larger numbers (reaching a maximum of 0.75 when the fixed interval is divided into quarters) indicate greater curvature. The Index allows a comparative measure even though response rates might differ across conditions. The measures show that there were no systematic differences between pairing and nonpairing operations. There was a tendency under the first condition for the measures to be slightly lower for Pigeons 15 and 29 than under subsequent conditions; curvature measures were similar for Pigeon 5 across all conditions. However, the measures taken as a whole do not indicate that curvature was higher under any of the pairing operations as compared with the nonpairing operations. Curvature was similar whether the brief-stimulus duration was 2 sec (Figure 3) or 0.5 sec (Figure 4).

For the final condition (extinction), food was omitted for 10 sessions and the only scheduled consequence for responding (other than a feedback relay click) was the presentation of the brief stimulus. Response rates declined to a near-zero level. The number of responses per 2-hr session ranged below 100 by the end of the tenth session for all subjects. Responding was not maintained in the absence of intermittent food presentations.

EXPERIMENT II

In the first experiment, paired and nonpaired stimuli produced the same effects on behavior. No differences resulted from the various pairing and nonpairing operations. Also, an arbitrary criterion of 16 sessions was adopted for the change from condition to condition. Possibly the effects of the pairing operation did not have sufficient time to dissipate in 16 sessions when the stimulus was no longer paired. Accordingly, the number of sessions with a nonpaired stimulus in effect was increased in Experiment II to see if patterning would decrease with continued exposure to the nonpaired brief stimulus.

In addition, a different stimulus was used for one condition in Experiment II. In Experiment I, the same stimulus was used in all conditions. Here, a blackout was used to compare the effects of two different brief stimuli.

Method

Apparatus

The apparatus was the same as in Experiment I.

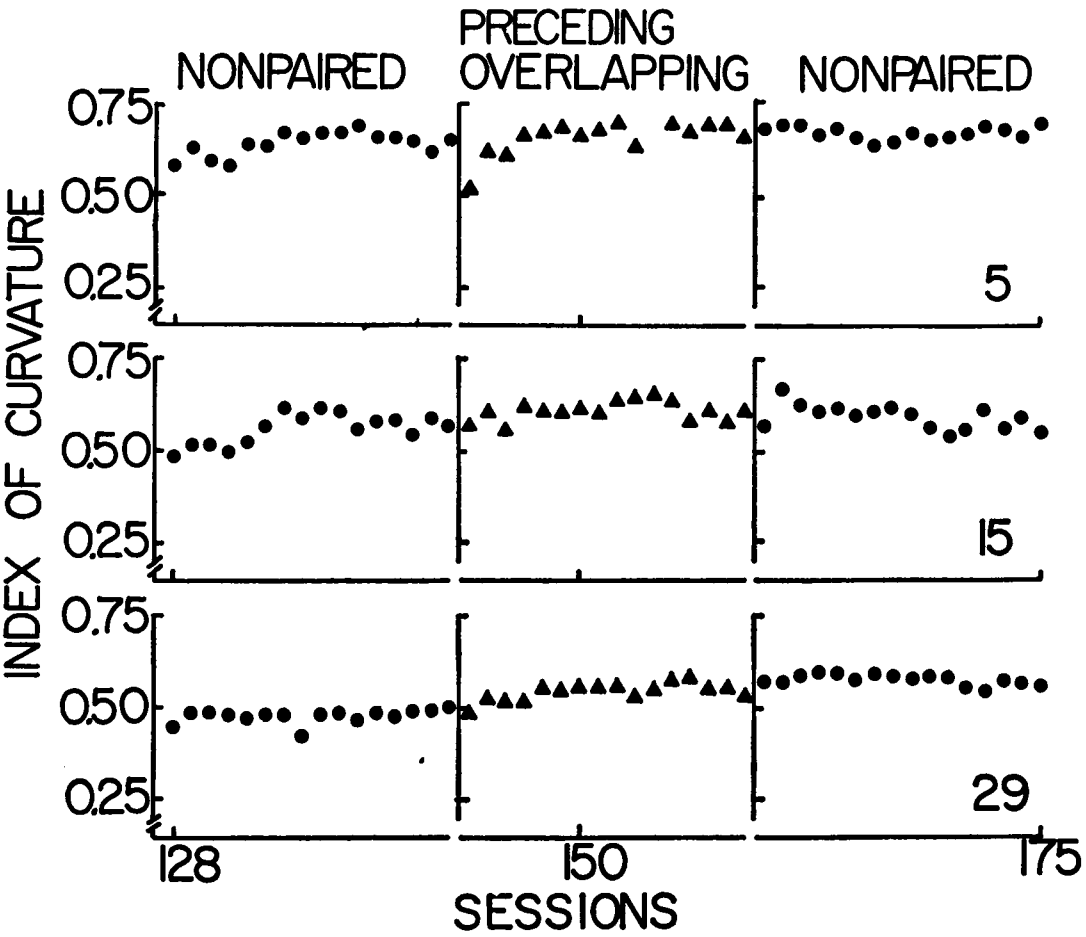

Fig. 4. Daily Index of Curvature measures across conditions when the brief-stimulus duration was 0.5 sec. The conditions are arranged in order of presentation. Closed circles indicate nonpaired brief-stimulus conditions while triangles indicate paired.

Subjects

Pigeons 5 and 15 served; Pigeon 29 died following Experiment I. The pigeons served in another experiment between Experiments I and II.

Procedure

The procedure was basically the same as that of Experiment I. The schedule remained VI 240-sec (FI 48-sec:S); the key color remained red; and the brief stimulus in the first, second, and fourth conditions remained the combinations of white keylight plus houselight. Only the color of the magazine light was changed from orange to blue. Brief-stimulus durations were 2 sec in all conditions.

For the first experimental condition, the preceding nonoverlapping brief stimulus was used (see Experiment I for details). This condition lasted 16 sessions. Next, the brief stimulus was nonpaired (the key was dark during reinforcement); this condition lasted 32 sessions. For the third condition, a blackout was used as a paired stimulus. After each fixed-interval component was completed, a 2-sec blackout resulted, during which the chamber was totally dark. When food was to be delivered, the 2-sec blackout was followed by 4-sec access to grain; the food magazine was illuminated by blue light during food presentations. The blackout condition was in effect until behavior was stable from session to session, 20 sessions for Pigeon 5 and 24 sessions for Pigeon 15. The fourth condition reinstated the white keylight plus houselight as a nonpaired brief stimulus. This condition was in effect for 16 sessions for Pigeon 5 but only 12

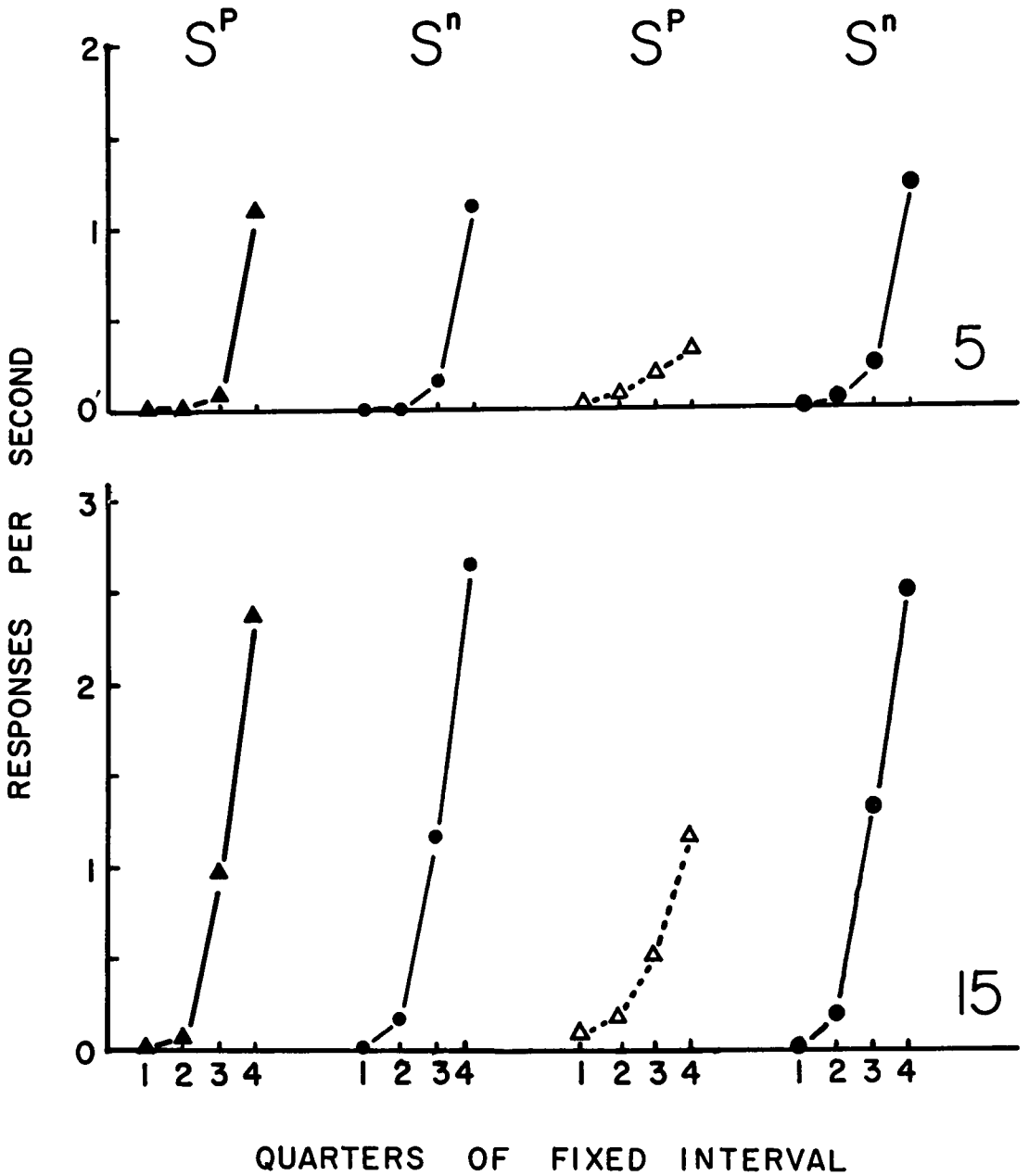

Fig. 5. Response rates across quarters of fixed-interval components under the various experimental conditions. Conditions are arranged left to right in order of presentation. The first condition (closed triangles) represents the preceding nonoverlapping brief-stimulus condition. The second and fourth (closed circles) represent the nonpaired brief-stimulus condition. And, the third (open triangles) represents the paired blackout condition.

sessions for Pigeon 15 due to a severely cracked beak, which necessitated termination of the experiment for this pigeon.

Results

Figure 5 shows responding per fixed-interval quarter across the various experimental conditions. The pattern of responding was the same for the three conditions in which the white keylight plus houselight served as the brief stimulus. Performance was similar whether the brief stimulus was paired or not. The data for Pigeon 15 in the fourth condition do not represent stable performance be-

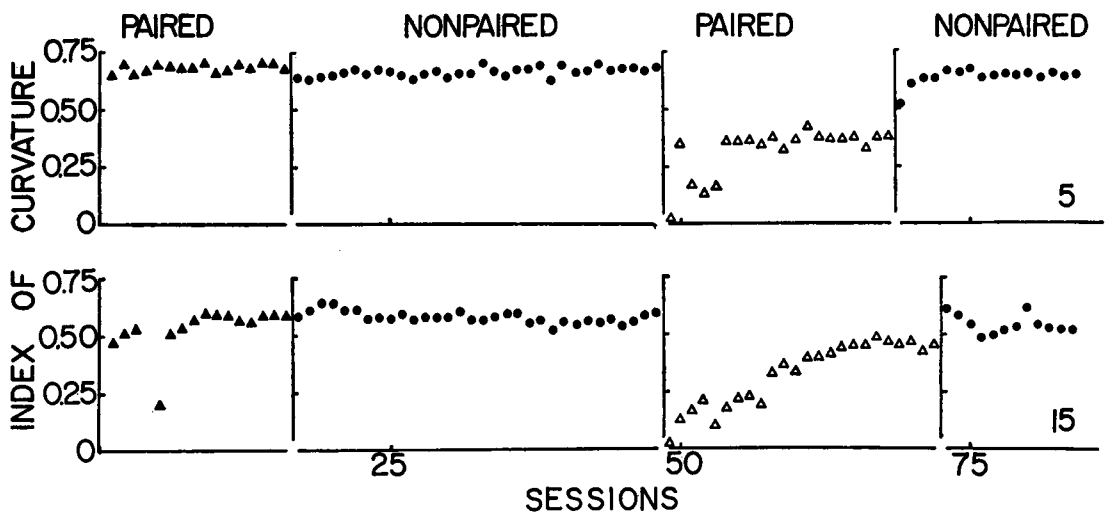

Fig. 6. Daily Index of Curvature measures across conditions. Conditions are arranged left to right in order of presentation. The first condition (closed triangles) represents the preceding nonoverlapping brief-stimulus condition. The second and fourth (closed circles) represent the nonpaired brief-stimulus condition. And, the third (open triangles) represents the paired blackout condition.

cause the condition had to be terminated after 12 sessions. Response rates were increasing for this bird when the experiment stopped. Despite the lack of stability for this pigeon, the data compare well with the previous conditions. The data for both pigeons are quite similar to those found in Experiment I. When a blackout served as the brief stimulus, response rates were higher in the first quarter and lower in later quarters than rates observed in other conditions. The pattern shows less curvature than in other conditions.

Figure 6 shows the daily Index of Curvature measures across conditions. The measures were similar for both pigeons in the conditions involving the keylight plus houselight. Curvature did not decrease with prolonged exposure to the nonpaired brief stimulus (second condition). And, following the blackout condition, curvature again increased to the previous level. Curvature measures for Pigeon 15 were slightly lower in the fourth condition than in the first two conditions. Had stability been obtained, the curvature measures presumably would have been higher. (Though the Index measures were lower in the fourth condition there was overlap with those obtained under both the first and second conditions).

The blackout resulted in lower Index measures than those found in the other conditions. Comparison of the last five sessions of all conditions show that there was no overlap in the measures under the blackout condition with the measures observed in the other conditions.

DISCUSSION

Under the second-order schedule examined, paired and nonpaired brief-stimulus procedures had similar effects on behavior. Intermittent pairing of a stimulus with food was not a necessary operation for generating patterning within components. The present results support the findings of Stubbs (1971).

Stubbs compared the effects of the pairing and nonpairing of stimuli across a wide variety of second-order schedules. Fixed-interval and fixed-ratio schedules were used as component schedules while fixed-ratio, fixed-interval, variable-ratio, and variable-interval schedules were used as the schedules of components. Over the various experiments, both paired and nonpaired brief-stimuli engendered similar behavioral effects (see also Stubbs and Silverman, 1972). Further, the present study suggests that Stubbs' results are not limited by the type of pairing procedure used in that study (simultaneous pairing procedure only). Preceding overlapping, preceding nonoverlapping, and simultaneous pairing procedures all produced similar behavioral effects.

The present results, as well as Stubbs' results, are inconsistent with several previous studies that showed that a nonpaired brief

stimulus generally did not maintain within-component patterning to the same degree as did a paired stimulus (Byrd and Marr, 1969; deLorge, 1967; 1969; 1971; Kelleher, 1966*b*; Marr, 1969). Similar effects of different pairing procedures suggest that the difference between Stubbs' results and the other results is not a function of different pairing procedures used in the different studies. Stubbs (1971) suggested a possible factor to account for the difference in results. In the present study and Stubbs' study the same stimulus was used in both pairing and nonpairing operations. Other researchers typically have used one stimulus for the pairing operation and a different stimulus for the nonpairing operation (see de Lorge, 1971, for an exception). Where different stimuli are used for pairing and nonpairing operations, stimulus differences unfortunately confound possible differences due to pairing and nonpairing. In the present study, the blackout produced less curvature than the white keylight plus houselight. The difference in curvature with the two stimuli indicates that the particular stimuli used might be a more important determinant of patterning than whether the stimulus is paired or not. Curvature was less when the paired blackout followed component completion than when the nonpaired keylight and houselight followed component completion. The present results agree with those of Stubbs, who also found differences in the effects of different nonpaired stimuli.

The traditional view of conditioned reinforcement is that a stimulus gains reinforcing properties by the intermittent pairing of that stimulus with some reinforcer (Kelleher and Gollub, 1962; Wike, 1966). Further, one suggestion is that conditioned reinforcers are established by means of respondent conditioning. The respondent-conditioning hypothesis suggests that different pairing procedures would have different effects on behavior. In respondent conditioning, the method of pairing a brief stimulus and food (*e.g.*, trace conditioning, delay conditioning, *etc.*) as well as the interval between stimuli are important determiners of conditioning (Pavlov, 1927). Early conditioned reinforcement studies suggest that the optimal interval for pairing a stimulus with food to establish a conditioned reinforcer is between 0.5 and 1.0 sec, interestingly the optimal interval between stimuli in many classical conditioning studies (Bersh, 1951; Jenkins, 1950; Schoenfeld, Antonitis, and Bersh, 1950). In the present study, the methods of pairing did not produce differential effects nor were differences found when the brief stimulus was 2 or 0.5 sec. Thus, the traditional view of conditioned reinforcement gains no support from the present results.

Index of Curvature measures were not quite as high for two pigeons in the first condition as in later conditions (Figure 3). One might argue that asymptotic levels of curvature resulted from the introduction of the pairing operation in the second condition. There are, however, several difficulties with this argument. First, an asymptotic level of curvature was obtained by Pigeon 5 in the first condition, before the pairing of the brief stimulus. Thus, pairing was not always necessary to produce maximum curvature. Second, even though curvature increased after the first condition, substantial degrees of patterning were observed in the first condition for all three pigeons. The major portion of the general effects of brief stimuli were produced by either paired or nonpaired stimuli. Third, in other studies (Stubbs, 1971, and ongoing research in our laboratories) the degree of patterning in first conditions often is less than that in second conditions. Even when the degree of patterning has appeared stable over numerous sessions, the degree of patterning has increased with a change from first to second conditions. Increases have resulted not only when brief stimuli were changed from nonpaired to paired, but also when changed from paired to nonpaired or from one nonpaired condition to another. Increases in patterning seem to represent a metastability phenomenon rather than a phenomenon dependent on the pairing of a stimulus (Staddon, 1965).

Two different nonpaired brief-stimulus procedures were examined. Under the first nonpaired condition, the red key was darkened during food cycles. Although the brief stimulus was not directly paired with food, some subtle pairing could have occurred. Brief stimulus presentation consisted of a change in key color from red to white accompanied by houselight illumination; reinforcement consisted of the change in the red key color to a dark key accompanied by the feeder stimuli. The red key stimulus was off both during brief stimulus and reinforcement periods. The absence of red

during both periods could have provided an indirect pairing. Accordingly, the red key stimulus remained on during reinforcement under the second nonpaired brief-stimulus condition. This procedure eliminated the similarity of stimulus conditions (absence of the red stimulus) during brief-stimulus and food periods, providing a nonpaired condition in a more restrictive sense.

The extinction procedure checked the possibility that the brief stimuli were reinforcers, like food and water. The extinction procedure indicates that the brief stimuli were not reinforcers *per se* but rather developed reinforcing properties by means of appropriate scheduling and the intermittent presentation of food.

While pairing was not necessary in the present study for patterning to occur, differences between paired and nonpaired stimuli have been demonstrated in other procedures (*e.g.*, Clark and Sherman, 1970; Thomas, 1969). Further research is necessary to clarify the conditions under which paired and nonpaired stimuli have similar or dissimilar effects (see Stubbs, 1971, for a detailed discussion of some possible conditions).

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