THE EFFECT OF TEMPORAL SPACING ON AUTOSHAPING IN THE PIGEON

THE EFFECT OF TEMPORAL SPACING ON THE DEVELOPMENT OF AUTOSHAPED KEY PECKING IN THE PIGEON

By

ROSEMARY ANN BARNES

A Thesis
Submitted to the School of Graduate Studies
In Partial Fulfilment of the Requirements
For the Degree
Doctor of Philosophy

McMaster University
July, 1976

DOCTOR OF PHILOSOPHY (1976)
(Psychology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: The Effect of Temporal Spacing on the Development of Autoshaped Key Pecking in the Pigeon

AUTHOR: Rosemary Ann Barnes, B. A. (Colorado College)

SUPERVISOR: Professor H. M. Jenkins

NUMBER OF PAGES: xii, 130

Abstract

The central question of this thesis is how the temporal distribution of stimulus-reinforcer pairings affects an animal's tendency to regard the stimulus as a signal. The effect of trial (stimulus-reinforcer) spacing was studied in a situation where a brief key light is paired with food presentation in the absence of any response contingency (autoshaping). As the intertrial interval (ITI) decreases in duration from 290 to 20 seconds, the number of trials required to initiate pecking in naive, hungry pigeons reliably increases.

Several theoretical accounts argue that acquisition is slower with short ITI's because each trial is subject to interference from the events immediately preceding or following that trial. The possibility of such local interference was examined by placing stimuli or reinforcers directly before or after each of a series of widely spaced trials. Although acquisition was reduced, it was not reduced to the level obtained when all trials were closely spaced. Further, the proximity of the added stimuli or reinforcers to the trial was found to have no effect on acquisition. These results indicate that the spacing effect cannot be entirely explained by interference from stimuli or reinforcers in close temporal proximity to trials.

Since the immediate context of trial presentation is inadequate to explain the entire spacing effect, subsequent analysis focused on the overall pattern of trial spacing. The separation of trials by long, event-free intervals or waiting periods, seems to be essential to rapid peck acquisition. On logical and theoretical grounds, three characteristics of waiting periods are expected to be important to effective waiting periods: (1) the number of waits and their position in relation to trials, (2) the boundary events which define waits, and (3) the stimulus context in which waits occur. Experimental manipulations of the number and position of waits showed that peck acquisition was equally rapid whether trials were clustered in closely spaced blocks or uniformly distributed across a long experimental session; however, a single long wait was not sufficient to produce rapid peck acquisition in a subsequent series of closely spaced trials. The boundary events which define effective waits were explored in an experiment where only one trial occurred in each autoshaping session. Peck acquisition was rapid when the single trial occurred in the middle of a long series of widely spaced reinforcer presentations, but slow when the trial occurred in the middle of closely spaced reinforcer presentations. Finally, the importance of stimulus context was experimentally tested by arranging for the presence or absence of long waits in the stimulus situation which constituted the background for trial presentation. Pecking to the key light developed rapidly only in animals which experienced long waits in the stimulus situation present during autoshaping trials.

The preceding results indicate that the development of a

signalling stimulus is affected to a considerable extent by the conditions of waiting periods. Rapid peck acquisition requires an alternation between trials or reinforcer presentations and waiting periods in the stimulus situation. Although other accounts are not excluded, the present results are consistent with theoretical interpretations which argue that the spacing effect results from differential opportunity for the extinction of competing associations. Long intertrial or inter-reinforcer intervals allow considerable time for the extinction of stimulus- or response-reinforcer associations which would interfere with the development of pecking to the key-light stimulus. In contrast, short intertrial or inter-reinforcer intervals minimize the time available for extinction of competing associations, and consequently, response acquisition is slow. Alternatively, the present results may be explained by a theoretical account which holds that the development of a signalling stimulus is directly related to the duration of reinforcer-reinforcer intervals.

Acknowledgements

Many people contributed to the completion of this thesis. First, I would like to express appreciation to Dr. H. M. Jenkins; his thoughtful consideration of theoretical issues and experimental design influenced this study at every stage in its development. In addition, discussions with Dr. Jonathan Baron, Dr. John Platt, Dr. Rolf Morrison, and Dr. F. J. Barrera clarified many theoretical and methodological questions.

Colleen Ireland, Irene Laurie, Andrew Czerwinski, and F. J. Barrera helped at various times in running experimental sessions and analyzing data. JoAnne Brewster typed an early draft and the final copy of this manuscript. I am very grateful for the careful work done by these people.

Finally, I would like to thank Corinne Day, Ron Black, and Richard Day. These people stimulated my thinking in many discussions and offered unfailing encouragement during the uncertain periods which beset all human enterprises.

Table of Contents

List of Illustrations

Page

List of Tables

INTRODUCTION

A fundamental problem in the study of animal learning is how an animal comes to regard a neutral stimulus as a signal for a reinforcer, or unconditionally effective stimulus. Many factors are known to influence the development of the signalling relationship. The present thesis is directed to a systematic study of one of these factors, namely the temporal distribution of stimulus-reinforcer pairings.

In the traditional Pavlovian conditioning arrangement, the temporal distribution of stimulus-reinforcer pairings is known to affect the development of conditioned responding. When stimulus-reinforcer pairings are closely spaced in time, acquisition is generally retarded and response probability is often lower than when pairings are more widely spaced in time (Gormezano and Moore, 1969; Mitchell, 1974). In many respects, autoshaping resembles these traditional conditioning situations. In naive pigeons, regular pairings of a brief key light and food lead to the development of pecking in the absence of any explicit response requirement (Brown and Jenkins, 1968). Stimulus-reinforcer contingency is critical to the emergence of pecking (Gamzu and Williams, 1971; Bilbrey and Winokur, 1973); and the topography of the conditioned response is often similar to the consummatory behavior appropriate to the reinforcer (Jenkins and Moore, 1973). Given the general correspondence between autoshaping and traditional Pavlovian conditioning, it is not surprising to find that close temporal spacing of key-light-food pairings retards the acquisition of autoshaped keypecking (Terrace, Gibbon, Farrell, and Baldock, 1975; Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, and Ricci, 1975; Griffin, 1975; Martin and Golinko, under review).

Since the original demonstration of autoshaping, considerable research has concerned the role of stimulus-reinforcer correlations in producing directed, skeletal behavior. Several recent papers have discussed theoretical accounts of such behavior (Moore, 1973; Hearst and Jenkins, 1974; Williams, personal communication). Although the proposed explanations of autoshaping differ in important respects, all seem to agree that an analysis of the phenomenon involves two separate problems. The first problem concerns the stimulus-reinforcer relations which are sufficient to establish a stimulus as a signal for behavioral change; the second problem concerns the factors which determine the topography of behavior in the presence of a signalling stimulus. The experiments to be reported in this thesis focus on the first of these two problems.

The present experiments explore the processes underlying the spacing effect in autoshaping. The specific question of interest is how the temporal distribution of stimulus-reinforcer pairings affects an animal's tendency to regard the stimulus as a signal. No satisfactory answer to this question has emerged for the traditional Pavlovian conditioning situation, although considerable experimental work has been devoted to the problem (Prokasy and Whaley, 1961; Kraus and Prokasy, 1963; Prokasy, 1965; Mitchell, 1974). Thus the present experimental analysis may contribute to a general understanding of how a stimulus becomes a signal in Pavlovian conditioning arrangements.

THE IMMEDIATE CONTEXT OF TRIAL PRESENTATION

Theoretical Accounts: Pre-trial Interference

An attractively simple type of explanation of the spacing effect would be one in terms of interference from local events. Logically, this type of account derives from the observation that the immediate context of a single stimulus-reinforcer pairing (trial) is quite different in different trial spacing conditions. When trials are closely spaced, each trial is preceded and followed by other trials; in contrast, when trials are widely spaced, each trial occurs in relative isolation from other trials. It is possible that the effectiveness of a trial is reduced if other events occur in close temporal proximity to that trial. The important other event could be a stimulus, a reinforcer, or a stimulus-reinforcer pairing. If this notion is correct, response acquisition is slow with short intertrial intervals because each trial is subject to interference from events associated with adjacent trials. Separating trials by longer time intervals leads to more rapid response acquisition because the opportunity for such local interference is minimized. For convenience, theoretical explanations of this type will be referred to as local interference accounts.

There are several reasons to suppose that local interference might be sufficient to explain the entire spacing effect. Let us first consider how conditioning might be disrupted by events occurring just prior to a key-light - food pairing. Logical consideration of the experimental arrangement suggests that either stimulus presentations or food presentations might be responsible for local interference. These logical possibilities may be conceptualized theoretically in several ways. Food presentations immediately prior to a trial might retard acquisition because food-related cues compete with an external stimulus for association with subsequent food presentation. This interpretation argues that food presentation produces internal cues which persist for some period of time and may serve as discriminative stimuli. If a short time interval separates one food presentation from another, the animal may associate cues arising from the first reinforcer with the occurrence of the second reinforcer. Thus, if a trial is immediately preceded by a food presentation, the animal may form a stronger association between food-produced cues and the next trial reinforcer than between the trial stimulus and trial reinforcer; in other words, food-produced cues might overshadow the external trial stimulus as a signal for future food. In such a situation, one would observe that behavior was only weakly controlled by the external stimulus. According to this explanation, a short intertrial interval (ITI) retards response acquisition because food-produced cues arising from trial _n_ - 1 compete with the stimulus on trial _n_ for association with the reinforcer on trial _n_. In contrast, a long ITI leads to more rapid acquisition because the food-produced cues from trial _n_ - 1 do not persist for a sufficiently long time to overshadow the stimulus on trial _n_.

The strongest empirical support for this interpretation comes from a study reported by Egger and Miller (1963). In the first phase of their experiment, rats were trained to press a lever for food pellets. In the second phase, the lever was retracted and an external stimulus was paired with the delivery of food pellets. For one group of rats, only the external stimulus signalled the delivery of food (simple conditioning), while for a second group, the stimulus-food pairing was always preceded by the delivery of a food pellet (stimulus redundant). The effect of these pairing procedures was then tested during extinction of the lever-press response. The lever was reinserted, the food delivery mechanism was disconnected, and responses produced only a brief presentation of the external stimulus. Rats in the simple conditioning group made more responses in this extinction arrangement than did rats in the stimulus redundant group, presumably because the stimulus was a weaker secondary reinforcer in the latter group. Egger and Miller discuss these data in terms of the informativeness of cues, but their interpretation does not differ substantially from the overshadowing analysis outlined above. These results suggest that food-produced cues can indeed compete with external stimuli for association with subsequent reinforcer occurrence.

Thus, food presentations preceding each trial might disrupt conditioning in a short ITI situation by overshadowing the trial stimulus. However, prior food presentations could retard response acquisition for another reason. Catania (1973) has discussed some evidence which suggests that reinforcer presentations inhibit operant responding in concurrent schedule arrangements. Reinforcer presentations might also inhibit pecking in the autoshaping situation. If this inhibition is conceptualized as a transient effect, strongest just after food presentation and diminishing subsequently, reinforcer-produced inhibition could be responsible for the spacing effect. According to this interpretation, close trial spacing retards acquisition because inhibition generated on trial _n_ - 1 interferes with responding on trial _n_. A long time interval between trials permits the inhibition generated on trial _n_ - 1 to decline before the occurrence of trial _n_; hence, response acquisition is rapid.

The preceding discussion has dealt with theoretical reasons to expect disruption of conditioning due to reinforcers occurring just before each trial. Let us now briefly consider how stimuli occurring before each trial might produce a similar effect. Sokolov (1963) describes several psychological effects of stimulus presentation which are of interest to the present issue. Stimulus presentation frequently elicits an orientation reflex which serves to enhance the animal's contact with that stimulus. Repeated stimulus presentations lead to habituation, or in the terminology of Sokolov's report, extinction of the orientation reflex. Moreover, habituation of the orientation reflex to a particular stimulus hinders the development of a conditioned response when the habituated stimulus is subsequently paired with a reinforcer. If orientation to the lighted key is necessary to the development of approach and pecking in the autoshaping situation, then habituation of this response in a short ITI condition could account for the spacing effect. Since the rate of habituation is generally known to decrease as the time between stimuli increases (Thompson and Spencer, 1966; Davis, 1970), a long interval between trials presumably minimizes habituation of the orienting response and thus allows rapid peck acquisition.

Theoretical Accounts: Post-trial Interference

Within the domain of local interference accounts, another logical possibility is that interference arises from events immediately following each trial. Post-trial interference accounts assume that a trial initiates some activity essential to learning which perseverates into the intertrial interval, but is susceptible to disruption. The activity initiated by a trial may be characterized as either physiological or cognitive. Consolidation theory describes the perseverative activity in terms of biochemical or neurological processes (Glickman, 1961). This approach has received considerable experimental attention as an account for retrograde amnesia produced by electroconvulsive shock, hypothermia or various drug treatments. Papsdorf and his associates have shown that less severe stimulus events can retard classical conditioning of nictitating membrane responses in the rabbit and have interpreted such results in terms of consolidation disruption (Kettlewell and Papsdorf, 1967; Papsdorf and Kettlewell, 1968; Synder and Papsdorf, 1968). However, as Ost (1969) points out, the design of these experiments is not adequate to exclude other accounts of the data such as generalization decrement or reactive inhibition.

Cognitive characterizations of perseveration describe the activity following a trial as some sort of rehearsal of immediately preceding events. Wagner, Rudy, and Whitlow (1973) emphasize this type of conceptualization in a report of their experiments on post-trial interference. These experiments used rabbits in an eyelid conditioning situation. In the key experiment (Experiment II), the rabbits first received discrimination training where the positive stimulus (A+) was always reinforced by shock and the negative stimulus (B-) was never reinforced by shock. After the discrimination was learned to a criterion, the subjects were divided into four groups for conditioning to stimulus C, always followed by shock. Throughout acquisition in all four groups, the pairing of stimulus C and shock was followed immediately by a post-trial episode. In two of the groups, the post-trial episode consisted of a stimulus, either A+ or B-, reinforced as it was in the initial discrimination phase; in other words, for one group, the post-trial episode consisted of A+, reinforced, while for the other group, the post-trial episode consisted of B-, non-reinforced. Thus, in these groups, the stimulus relationships in the post-trial episode were congruent with the stimulus relationships learned during discrimination training. In the other two groups, the post-trial episode consisted of a stimulus, either A+ or B-, with reinforcer presentation reversed from the initial discrimination; i.e., one group received A+, non-reinforced in the post-trial episode, while the other group received B-, reinforced. Thus, for these groups, the stimulus relationships in the post-trial episode were incongruent with the stimulus relationships learned during discrimination training.

The results of this experiment showed that acquisition of a conditioned response to stimulus C was much slower when post-trial episodes were incongruent than when they were congruent with discrimination training. Although, as the authors mention, these results could be described in terms of consolidation theory, Wagner *et al.* choose to discuss the data in terms of a cognitive perseverative activity. Their interpretation procedes as follows: For an association to be formed, the event sequence must be in some sense surprising to the animal, and some period of time must be available immediately after the event for information processing or rehearsal. The animal's rehearsal capacity is engaged to the extent that events are surprising. Presumably, the reinforced occurrence of stimulus C was surprising to all animals in the experiment just described, so the question of interest was the extent to which post-trial episodes would compete with trial events for rehearsal capacity. Wagner et al. argue that post-trial episodes congruent with discrimination learning had little effect on the acquisition of stimulus C because, being expected, they engaged little of the animal's rehearsal capacity. In contrast, incongruent post-trial episodes retarded acquisition to stimulus C because they were unexpected and hence engaged much of the animal's rehearsal capacity.

Whether one adopts a neurological or cognitive description of perseverative activity, the results from the study by Wagner et. al. indicate that some disruption-free interval after a trial is important to learning. It should be noted that, except for extreme treatments (e. g., electroconvulsive shock), the class of events which will disrupt post-trial processing may be limited to unexpected sequences. A possibility of considerable interest is that the trial spacing effect might be understood by an extension of this theoretical conceptualization. To pursue such a possibility, one must assume that identical event sequences may interfere with their own processing. Post-trial episodes inconsistent with the animal's conditioning history are demonstrably effective as unexpected event sequences which disrupt perseverative activity.

However, when the animal is first exposed to a series of trial presentations, each trial is an unexpected event sequence. Thus, trial n + 1 might constitute a post-trial episode capable of disrupting perseverative activity initiated on trial n. If this assumption is correct, then a short intertrial interval retards conditioning because the processing initiated on trial n is disrupted by the immediate occurrence of trial n + 1. A long intertrial interval favors rapid conditioning because the processing initiated on trial n may perseverate over a longer time period before trial n + 1 occurs.

An Experimental Approach to Local Interference Accounts

The preceding discussion suggests several theoretical reasons to expect that stimuli or reinforcers occurring in the immediate vicinity of a trial interfere with conditioning and are responsible for the lower level of acquisition that is found with closely spaced trials. Accordingly, the first series of experiments is planned to test the possibility of local interference.

The data to be reported presently came from five separate experiments. These five experiments are quite similar both in procedure and in the general logic of design. Each experiment includes two reference groups where trials which consist of key-light-food pairings are separated by either long or short intertrial intervals. These groups are referred to as the long and short ITI reference groups. They provide the basic comparison for demonstrating the spacing effect. Therefore, they permit a replication of earlier results as well as providing reference data against which other experimental manipulations may be assessed. In other groups (experimental groups), key-light-food pairings are separated by long intertrial intervals, and events which might interfere with conditioning are placed immediately before or after each trial. The additional events are placed so that they occur at the same rate as in the short ITI reference condition. If the spacing effect is completely explained by interference from pre- or post-trial events, the acquisition in some or all of the experimental groups should be as slow as in the short ITI reference group, and much slower than in the long ITI reference group.

Within each autoshaping condition, there was considerable variability in both acquisition and maintenance of pecking to the key-light stimulus. When this variability was sufficiently extreme to produce some question about the interpretation of results, the doubtful conditions were replicated. As a consequence of proceding in this manner, not only the reference conditions, but also various experimental conditions were repeated in separate experiments. Comparisons of data combined from appropriate groups across all five experiments leads to very clear conclusions about the role of local interference in the trial spacing effect. However, such an analysis raises the question of whether the combined data reflect accurately the results of each separate experiment. Since the results of the first five experiments will be presented in combined form, this question merits some special attention.

With the exception of the experimental manipulations, the same training conditions and equipment were used in all five experiments. Since the reference conditions were repeated in each experiment, the crucial comparisons never involve groups from separate experiments. Further, examination of the data within each experiment leads to the same conclusions as examination of the combined data. Increasing the number of animals in a sample increased confidence in any particular outcome. Replications never led to results which were extremely discrepant from the results of earlier experiments, although differences in levels of pecking did occur across experiments.

The development and maintenance of pecking were analyzed in terms of a variety of measures, including various acquisition criteria, response rate, and response probability. The primary concern was to select measures which reliably differentiated the long and short ITI reference groups. The measures which satisfied this purpose were then used to assess the effect of the various experimental manipulations. Once pecking was initiated, no measure consistently differentiated groups across all experiments. However, in contrast to maintenance, differences in acquisition were highly consistent across experiments.

The presentation of the first five experiments is organized in terms of the empirical and theoretical issues which are of primary interest. We consider first the possibility that events immediately preceding each trial interfere with conditioning on that trial. Next, we consider the possibility that events immediately following each trial interfere with conditioning, and finally, we consider the combined effects of events before and after a trial.

1

EXPERIMENTS I - V

Pre- and Post-trial Interference

General Method

Subjects: Subjects were 138 experimentally naive White King pigeons, approximately one year of age. The sex of the birds was not determined. All birds were maintained at 75% of their free-feeding weights and fed Purina Pigeon Checkers both in the home cage and during experimental sessions. Six birds were discarded from the experiments when they failed to eat from the food hopper after manual training.

Apparatus: Six standard Lehigh Valley operant conditioning chambers for pigeons were used. On the response panel in each chamber were two square keys, each 3.2 x 3.2 cm. The two keys were located 0.6 cm. apart and centered on the response panel 25.8 cm. above the floor of the chamber. During the present experiments, the right key was completely covered by an opaque card. In the center of the left key was a dot, 0.6 cm. in diameter, which could be lighted red. About 14 grams of pressure on the center of the key was sufficient to close the electrical circuit and record a response. The opening to the grain hopper was located 10.3 cm. above the floor of the chamber and centered on the response panel. During sessions, the chamber was continuously lighted by an 1820 lamp operated at 32 volts DC. The lamp was housed such that light was directed to the ceiling; the houselight was centered on the response panel 34.8 cm. above the floor of the chamber. White noise at 80 DB was supplied continuously during sessions by a speaker 7.7 cm. in diameter located on the response panel 12.9 cm. above the floor of the chamber and 6.4 cm. to the left of the grain hopper.

Hopper training procedure: In Session 1, each bird was placed in the experimental chamber for 50 minutes during which only the houselight and white noise were operated. In Sessions 2-16, all birds received automated hopper training. The food hopper was raised for 4 seconds at intervals which varied from 12 to 132 seconds ($\overline{X}$ = 75 seconds). Seven different temporal orders of hopper presentation were used; no order was repeated on two successive days, and a given order was used no more than 3 times. A session lasted for 50 minutes, and the mean number of hopper presentations was 40. The birds were run daily and fed whatever necessary to maintain their weight at the end of each session.

The birds were observed on Session 3 or 4 of the training procedure. Birds which were not eating from the hopper were given manual training as follows: A small amount of food was placed on the floor of the chamber, and the hopper was raised and heaped full of food. When the bird began to take food from the hopper, it was allowed to eat for at least 20 seconds; the hopper was then lowered and raised again almost immediately, and the bird allowed to eat for 6-10 seconds. Over the next 10-15 minutes, the duration of hopper presentations was gradually reduced and the duration of the inter-reinforcement intervals was gradually increased until eating was maintained by the hopper presentation schedule outlined above. If at any point in this manual training a bird did not eat for 10 minutes, the session was discontinued, and the bird was not fed in the home cage. This procedure was continued until the bird started eating from the hopper.

After manual hopper training was completed, and all birds were eating readily from the food hopper (about Session 14), the duration of the hopper presentation was reduced from 4 to 2.5 seconds. All birds were observed again in the last one or two sessions of the training condition to confirm that all were eating readily from the food hopper.

Autoshaping procedure: For all groups, a trial consisted of illumination of the red dot on the response key for 8 seconds, followed immediately by a 2.5-second hopper presentation. In the short ITI reference condition (Group S), trial onsets were separated by 30-second intervals; the intertrial interval was 19.5 seconds, and at the beginning of each session, the onset of the first trial occurred 30 seconds after the onset of the houselight and white noise. In the long ITI reference condition (Group L), trial onsets were separated by 300-second intervals so that the intertrial interval was 289.5 seconds, and in each session the onset of the first trial occurred 300 seconds after the onset of the houselight and white noise. The two reference groups never received event presentations between trials. In the experimental groups, trial onsets were separated by 300-second intervals, and unsignalled reinforcers or non-reinforced stimulus presentations were scheduled during the intervals between trials. In each session, the first trial occurred 300 seconds after the onset of the houselight and white noise.

Key pecks were recorded, but never had programmed consequences. For all groups, a session consisted of 20 trials; all groups were run daily for 12 sessions. The pigeons were fed whatever necessary to maintain their weight immediately after the daily session.

Experimental Tests: Pre-trial Interference

The experimental arrangements reported below test the possibility that events placed immediately prior to trials interfere with conditioning. Figure 1 shows the arrangement of intertrial intervals and intertrial events for each of the six groups. Two reference groups received trials separated by either long or short intertrial intervals. Two experimental groups received trials separated by a long ITI, but either reinforcers or non-reinforced stimulus presentations occur immediately before each trial. If the spacing effect is due entirely to disruption produced by pre-trial events, then peck acquisition in one or both of these experimental groups should be comparable to acquisition in the short ITI reference group, and much slower than acquisition in the long ITI reference group. Two control groups receive extra events randomly placed in long intertrial intervals. Comparisons among the reference, experimental, and control groups will indicate both the effect of adding extra events to the long ITI situation and the importance of placing these events in close temporal proximity to trials.

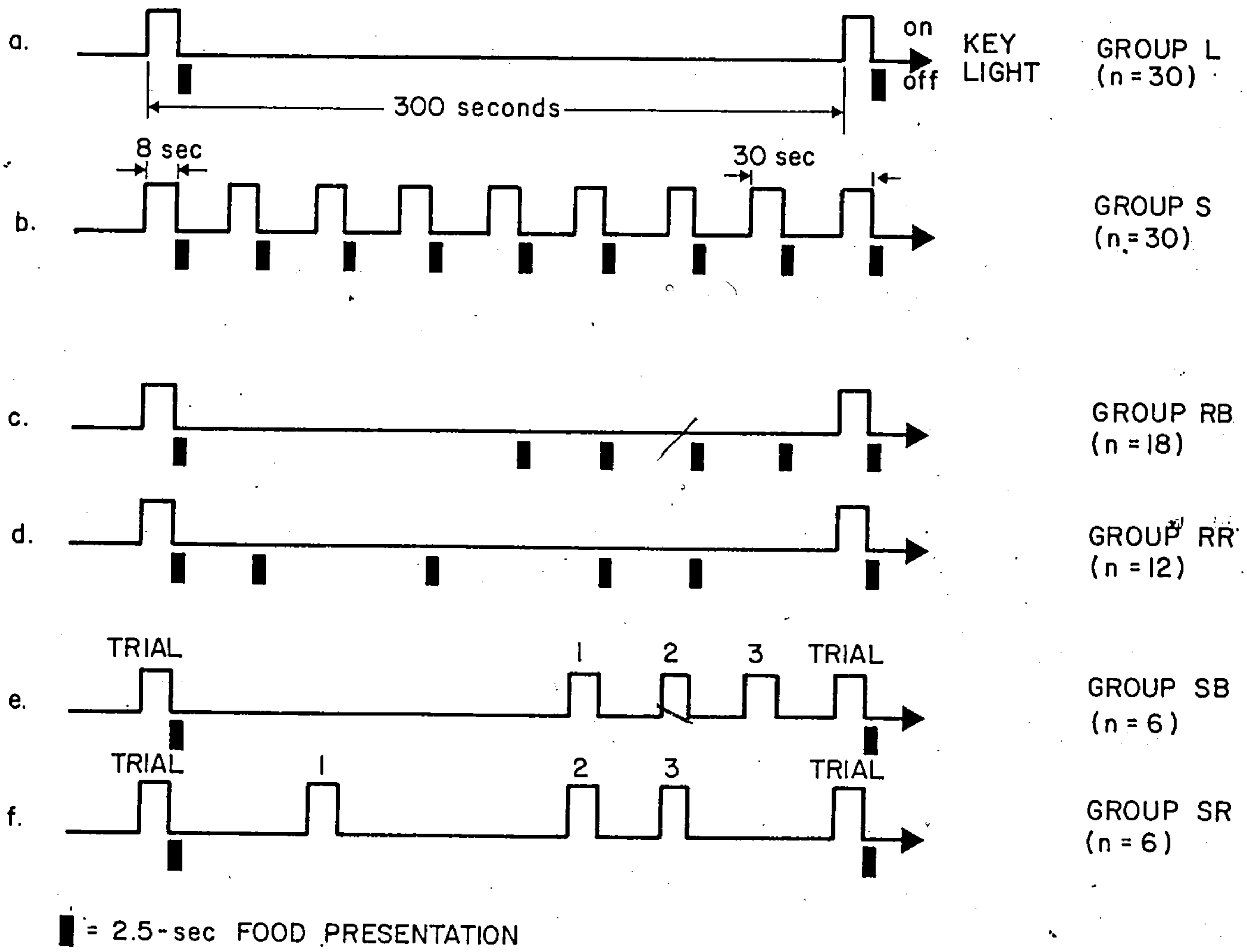
Autoshaping Conditions

In addition to the reference Groups L and S (Figure 1, a. and b.), there were two experimental groups and two control groups. These latter four groups received trials, that is, key-light-food pairings, at a fixed interval, once every 300 seconds. The before-trial reinforcers group (Group RB, Figure 1c.) received 2.5-second reinforcer presentations placed 120, 90, 60, and 30 seconds before the onset of each trial reinforcer. The before-trial stimuli group (Group SB, Figure 1e.) received 8-second illuminations of the red key light 90, 60, and 30 seconds before the onset of each trial stimulus. In the two control groups, four 2.5-second hopper presentations (Group RR, Figure 1d.), or three 8-second key-light illuminations (Group SR, Figure 1f.) were placed randomly in the intertrial interval. The locations of these randomly placed events varied after every trial with the constraints that (1) events could not occur 19.5 seconds before or after a trial and (2) an event could occur in a given 30-second segment of the intertrial interval no more than four times within one session. The second constraint had the effect of producing a distribution of events across the intertrial

Figure 1

Diagram of autoshaping conditions for reference, experimental, and control groups involved in pre-trial interference tests described in Experiments I-V.

AUTOSHAPING CONDITIONS



interval which was roughly uniform within one session. The number of birds in each autoshaping condition is shown on the right side of Figure 1.

Results

The reference groups in individual experiments differed more reliably in acquisition than in post-acquisition performance. The following account therefore emphasizes the characteristics of acquisition. The effect of trial spacing on the development of pecking is illustrated most clearly in a trial-by-trial analysis of responding. Figure 2 shows such an analysis for the reference Groups L and S over the first 40 trials (two sessions) of autoshaping. Although this figure shows three measures of pecking for each group, for the moment, we shall consider only the proportion of birds making at least one peck on trial n, or the peck probability on trial n.

As indicated in Figure 2, the long and short ITI groups were about equal in the probability of a key peck during the first stimulus presentation. After Trial 1, however, the probability of pecking diverged quite rapidly. Within the first session, most of the birds in Group L began pecking regularly to the trial stimulus, while birds in Group S showed little or no pecking. At Trial 40, peck probability was 0.70 for Group L and 0.17 for Group S. Clearly, a long intertrial interval led to the initiation of persistent pecking in fewer trials than a short intertrial interval.

Figure 2

Trial-by-trial analysis of the development of pecking in the first 40 trials (two sessions) of autoshaping. This graph shows data for the two reference conditions used in Experiments I-V.

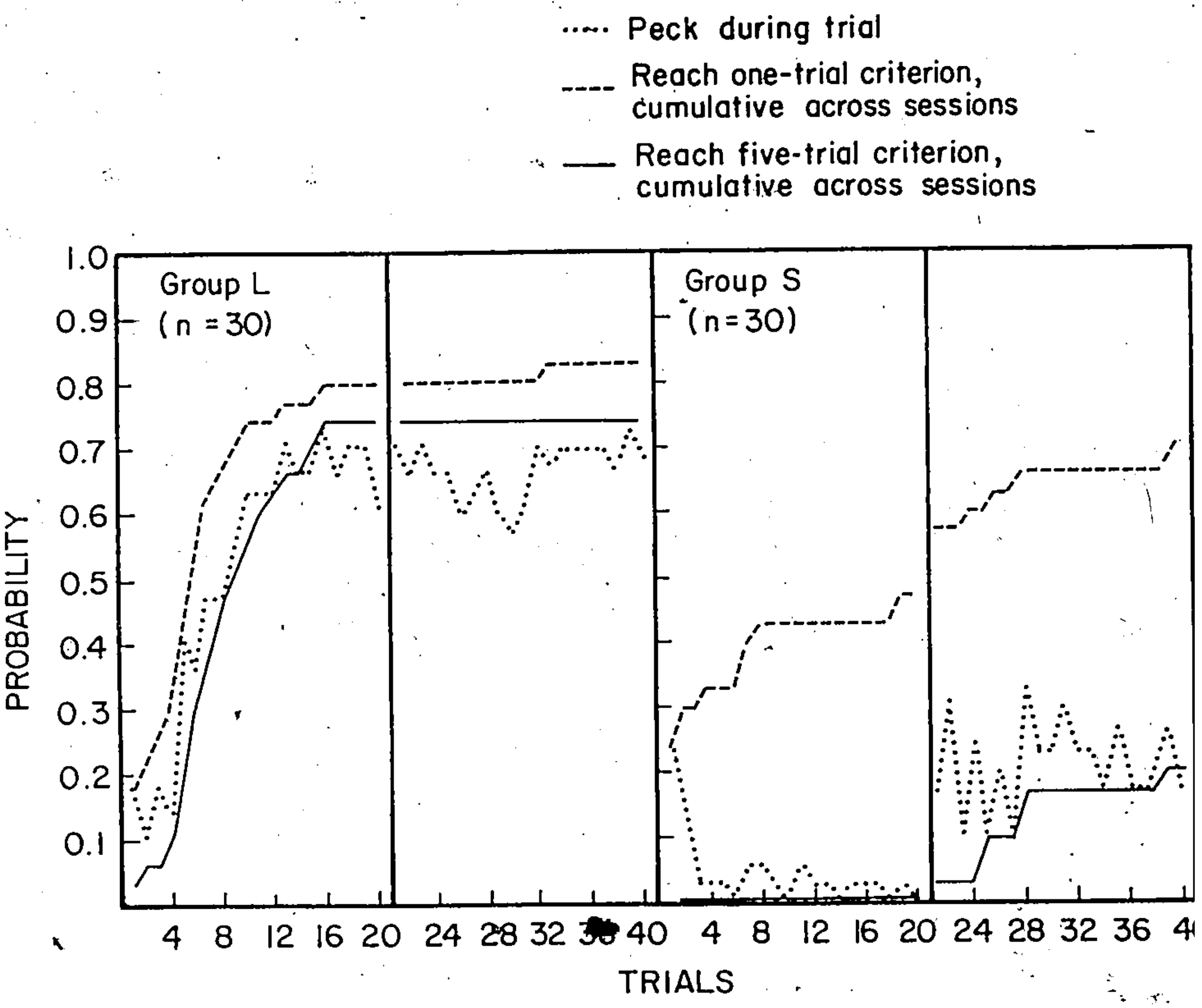
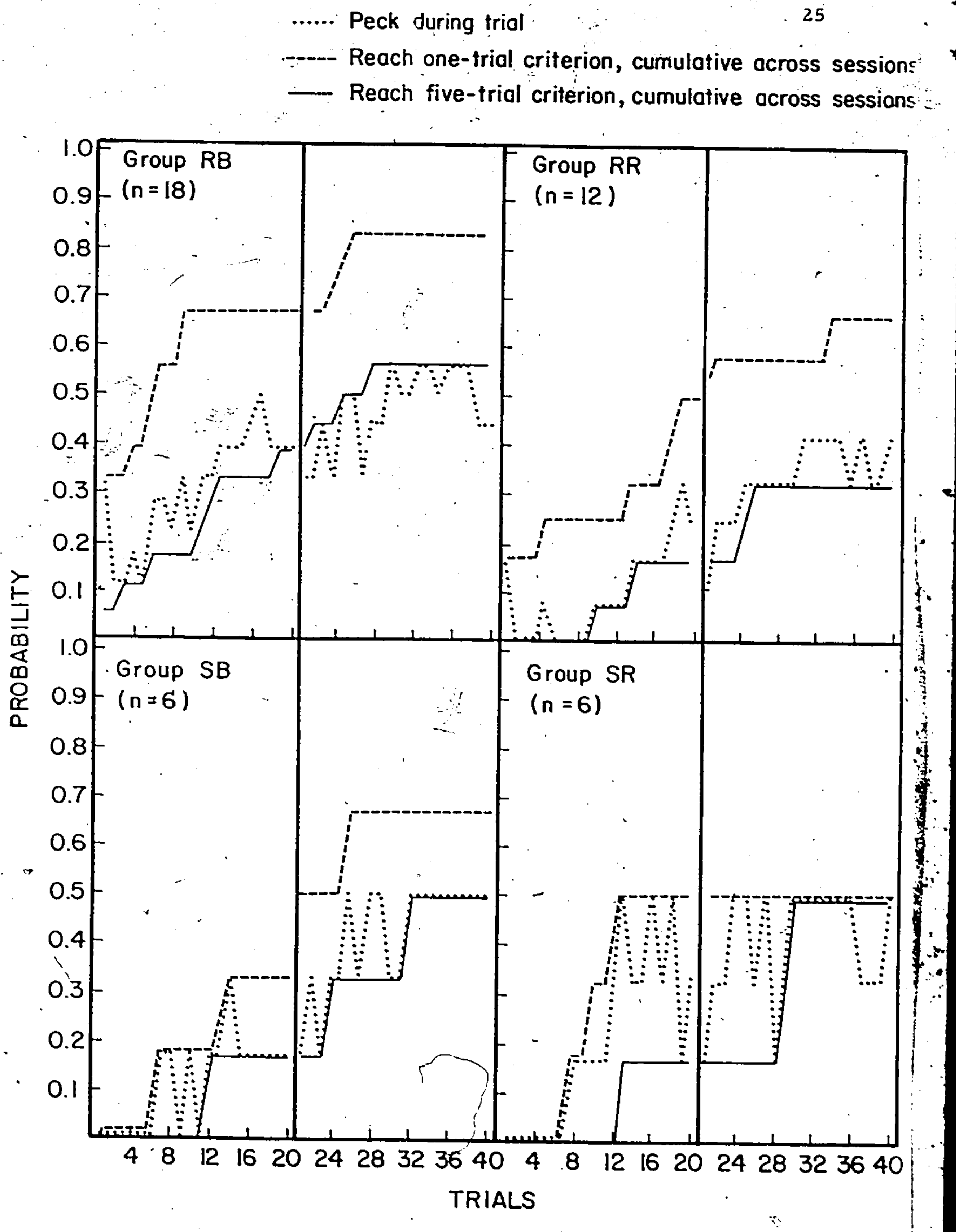

Peck during trial
Reach one-trial criterion, cumulative across sessions
Reach five-trial criterion, cumulative across sessions
Group L
(n =30)
Group S
(n=30)
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
32
36
40
4
8
12
16
20
24
28
32
36
TRIALS

Figure 3 shows similar data on acquisition for the experimental and control groups. In the two experimental groups, RB and SB, pecking to the trial stimulus began within the first two sessions for about half of the birds. At Trial 40, peck probability was 0.38 for Group RB and 0.50 for Group SB. Similar acquisition performance was evident in the two control groups, RR and SR, where peck probabilities at Trial 40 were 0.42 and 0.50, respectively. Peck acquisition in the experimental and control groups was somewhat slow compared to reference Group L, but substantially better than acquisition in reference Group S. As long as trials were separated by long intertrial intervals, reinforcers or key-light stimuli occurring in the ITI did not greatly interfere with the development of pecking. Moreover, placing these extra events just before each trial was no more detrimental to peck acquisition than placing the events randomly in the intertrial interval.

The probability of pecking on trial n is a measure which gives a fairly direct indication of the development and maintenance of pecking within any particular group. It is therefore of some interest to see the relationship between this measure and other, more convenient measures which might be taken as indices of peck acquisition. Accordingly, two other measures were used to evaluate the emergence of pecking. For both measures, an individual bird was judged to have acquired pecking on the trial when that bird reached a response criterion. In one case, the response criterion was at least one peck; in the second case, the

Figure 3

Trial-by-trial analysis of the development of pecking in the first 40 trials (two sessions) of autoshaping. This graph shows data for the experimental and control conditions involved in pre-trial interference tests described in Experiments I-V.


······ Peck during trial
------ Reach one-trial criterion, cumulative across sessions
—— Reach five-trial criterion, cumulative across sessions
Group RB
(n = 18)
Group RR
(n = 12)
Group SB
(n = 6)
Group SR
(n = 6)
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
32
36
40
TRIALS

criterion was at least one peck on each of five consecutive trials. When using the second measure, the first of the five trials with a peck was taken as the trial where acquisition was complete. Figures 2 and 3 show cumulative distribution of both these acquisition measures for each group.

Within each autoshaping condition, the five-trial acquisition criterion corresponds fairly closely to peck probability at any given trial. In contrast, the one-trial acquisition criterion is sometimes quite discrepant with peck probability; the cumulative proportion of birds which made at least one peck may be much higher than the proportion of birds actually pecking at any given trial. These observations suggest that the five-trial acquisition criterion may be taken as a valid and sensitive indicator of pecking within any particular autoshaping group.

Table 1 summarizes acquisition performance for each group in terms of the proportion of subjects reaching the five-trial criterion and the median and range of the distribution of criterion scores. Within all groups, acquisition performance was quite variable. Across groups, five-trial criterion scores tended to have a bimodal distribution; birds either met the acquisition criterion within the first 60 trials (three sessions) of autoshaping or did not reach criterion within the limits of the experiment (240 trials). Eighty percent of the birds fell into one

Table I

Summary of Acquisition Performance for Reference, Experimental and Control Groups in Pre-trial Interference Experiments.

	Proportion of Birds Which Meet Criterion Within 240 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds Not Meeting Criterion are Excluded)	
		Median	Range
Group L (n = 30)	0.93	9.5	1-108
Group S (n = 30)	0.70	55.0	21-221
Group RB (n = 18)	0.94	28.0	1- 67
Group SB (n = 6)	1.00	38.0	12- 60
Group RR (n = 12)	0.92	56.0	10-222
Group SR (n = 6)	0.83	29.0	13- 66

of these two categories; 66% met criterion within the first 60 trials, while 14% never reached criterion.

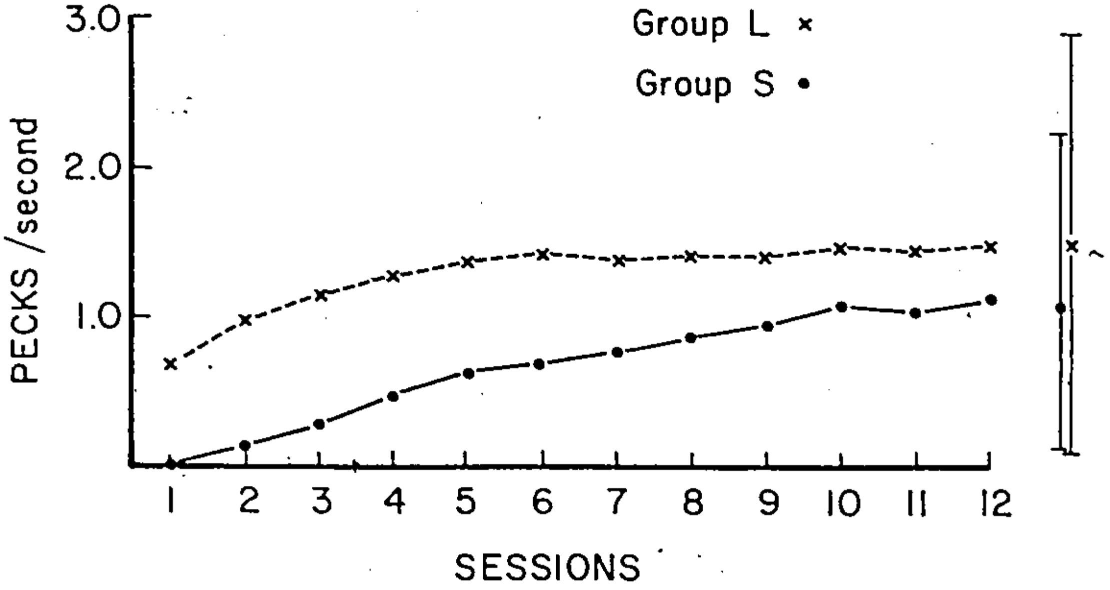
Distributions of trials to meet the five-trial acquisition criterion were used to make statistical comparisons of the reference, experimental and control groups. The Mann-Whitney U, two-tailed test was used for all comparisons. The method of adjusted significance levels suggested by Ryan (1960) was used in order to permit multiple comparisons among groups. Generally, the results of these tests confirmed the conclusions drawn from inspection of peck probabilities. Birds in Group L met the acquisition criterion in fewer trials than birds in Group S ($U = 138$, $p < 0.001$).[1] Group L showed more rapid peck acquisition than control Group RR ($U = 74$, $p < 0.001$), but did not differ significantly from control Group SR or either of the experimental groups. Acquisition in Group S was slower than acquisition in the experimental Groups RB ($U = 110$, $p < 0.001$) and SB ($U = 38$, $p < 0.05$) and control Group RR ($U = 141$, $p < 0.05$), but did not differ significantly from acquisition in control Group SR. Finally, since several investigators (Terrace, et al., 1975; Griffin, 1975; Martin and Golinko, under review) have used the trial of first peck to indicate peck acquisition, it should be noted that the long and short ITI reference groups in the present study differed significantly on this measure ($U = 184$, $p < 0.001$; Mann-Whitney U, two-tailed test, not adjusted for multiple comparisons).

In the ITI-stimuli Groups SB and SR, the acquisition criterion was used independently for the first, second, third, and trial stimulus presentations (see Figure 1, e. and f. for further clarification of these definitions). Thus far, acquisition in these groups has been considered only in terms of the development of pecking to the trial stimulus. However, the birds did not seem to distinguish reinforced from non-reinforced stimulus presentations. When a subject began pecking to one stimulus, it usually started pecking to all four stimuli within a few trials. Considering combined data from groups SB and SR, reliable pecking (as indicated by the criterion measure) began within five trials of pecking to the trial stimulus in 75% of the birds, and within 20 trials of pecking to the trial stimulus in 100% of the birds. Neither group showed any tendency to initiate pecking to any stimulus, including the trial stimulus, earlier than to any of the other stimuli.

The maintenance of pecking during stimulus presentations was measured in terms of rate and in terms of proportion of trials on which at least one peck occurred (peck probability). Figure 4 shows the mean peck rates over sessions for all birds in Groups S and L. Peck rates tended to be slightly lower in Group S than in Group L. Although the variability within groups was large, a comparison of mean peck rates over the last 80 trials (three sessions) was statistically significant ($U = 352$, $p < 0.001$, Mann-Whitney U, two-tailed test). The same pattern of results was evident when peck probability was used to measure the maintenance of responding. However, neither of these measures

Figure 4

Mean trial peck rates as a function of sessions for Group L (n = 30) and Group S (n = 30) in Experiments I-V. The points and bars shown to the right of the graph give the mean and standard error of peck rates during the last three sessions (80 trials) for each group.


Group L ×
Group S •
PECKS /second
3.0
2.0
1.0
1
2
3
4
5
6
7
8
9
10
11
12
SESSIONS

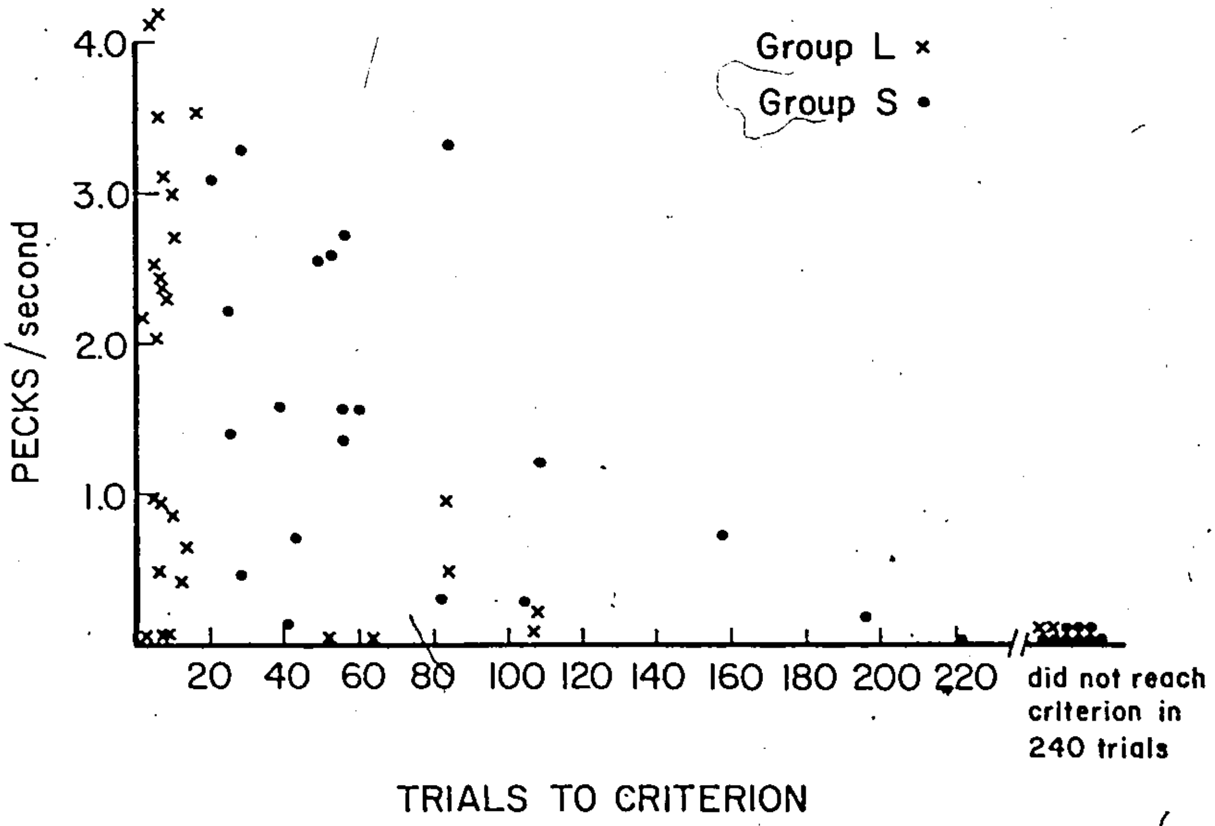
reliably distinguished the reference groups when one considers comparisons within individual experiments.

A few observations concerning the maintenance of pecking are, however, of interest. As indicated in Figure 5, the five-trial acquisition score was not closely related to the level of pecking in later sessions of the experiment. After a bird met criterion, pecking was usually sustained throughout the remainder of the experiment. However, while birds that met criterion late usually showed only moderate peck rates or probabilities, birds that met criterion early varied from moderate to high in the level of pecking maintained over later sessions. Moreover, the presence or absence of a peck on Trial 1 did not predict the trial on which the acquisition criterion was met. In Groups L and S, the number of trials required to reach the five-trial acquisition criterion was no different for the birds which pecked on Trial 1 than for birds which did not peck on Trial 1; this comparison did not reach statistical significance for Group L, Group S, or Groups L and S combined ($U = 48$, $U = 69$, $U = 209$, respectively, in all cases $p > 0.10$, Mann-Whitney U, two-tailed test). The lack of relationship among these various observations suggests that within individual birds, there was no unitary characteristic, such as a general pecking tendency, which exerted a strong influence on all response measures.

In the ITI - stimuli Groups SB and SR, pecking at the lighted key was analyzed in terms of the location of the stimulus presentation in the

Figure 5

The relation between trials to meet five-trial acquisition criterion and mean peck rate over last three sessions for individual birds in Groups L and S, Experiments I-V.


Group L ×
Group S ●
PECKS/second
4.0
3.0
2.0
1.0
20
40
60
80
100
120
140
160
180
200
220
did not reach criterion in 240 trials
TRIALS TO CRITERION

intertrial interval. The intertrial period was divided into nine 30-second segments beginning 19.5 seconds after the end of a trial. In Group SB, non-reinforced stimulus presentations always occurred in positions 7, 8, and 9, i.e., 90, 60, and 30 seconds before the reinforced trial stimulus. In Group SR, non-reinforced stimulus presentations could occur at any ITI position. In order to determine whether pecking was dependent on ITI location, peck probabilities over Sessions 8-12 were averaged across stimulus presentations occurring at each ITI location. Figure 6 shows mean peck probabilities as a function of ITI location for Groups SB and SR. For purposes of comparison, Figure 6 also gives the mean peck probability for reference Group L from the same experiment (Experiment I). In Group SB, the probability of pecking was lowest on the first stimulus presentation, and higher during the second, third, and trial stimulus presentations. After the first stimulus presentation, the birds did not seem to distinguish between non-reinforced stimuli and the trial stimulus. In Group SR, the probability of pecking was about the same at all ITI locations and the trial stimulus. Neither Group SB nor Group SR differed appreciably from the reference Group L in the probability of pecking to the trial stimulus. Individual birds in each group showed patterns of peck probability similar to the mean data of Figure 6.

Pecking during the intertrial interval was generally infrequent, and followed no particular pattern either within or across groups.

Figure 6

Mean stimulus peck probabilities over the last 80 trials as a function of ITI location. The data shown in this graph are from long ITI reference groups and experimental and control groups which received additional non-reinforced stimulus presentations; all data are from Experiments I and II.

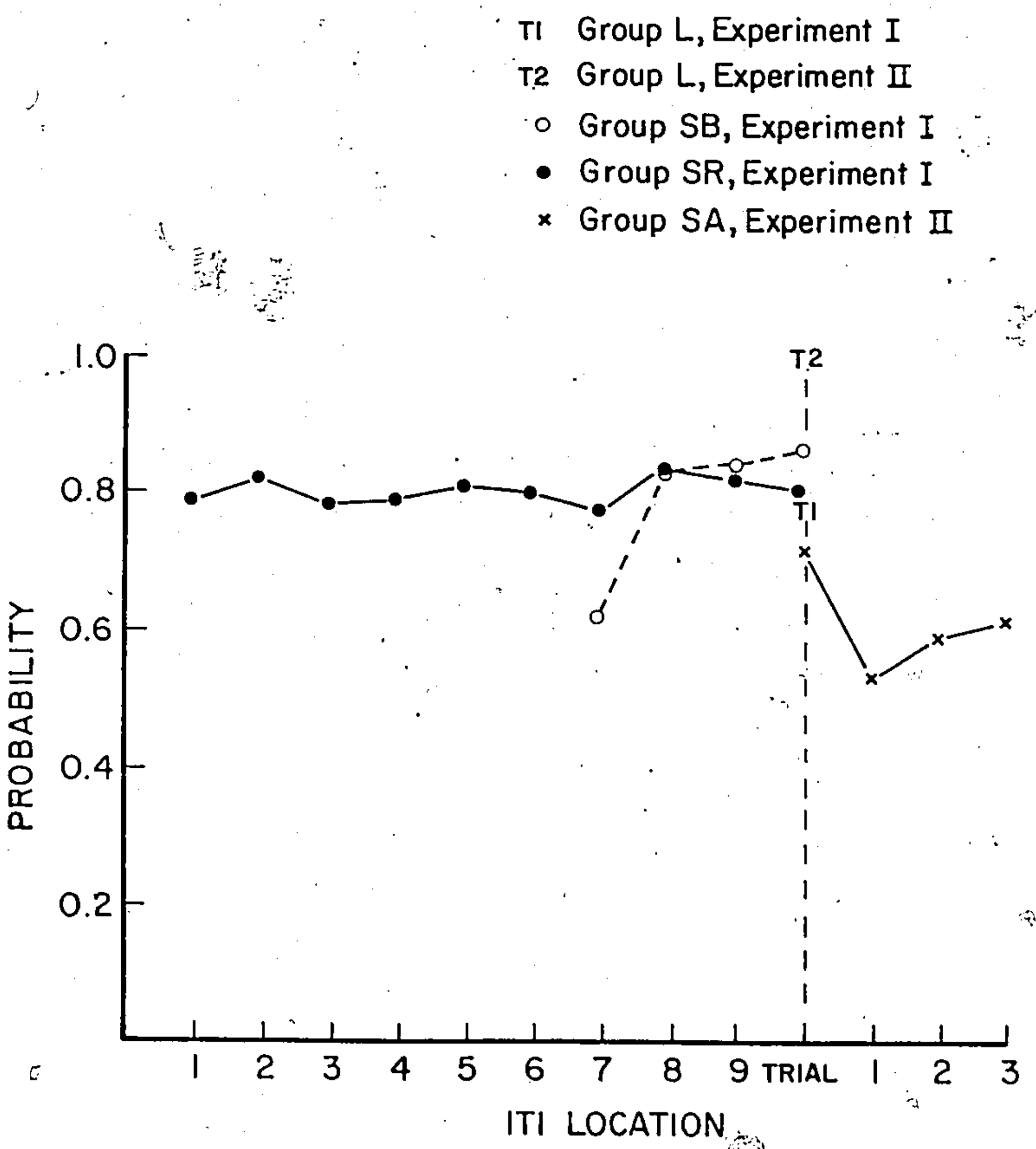

T1 Group L, Experiment I
T2 Group L, Experiment II
○ Group SB, Experiment I
● Group SR, Experiment I
× Group SA, Experiment II
PROBABILITY
1.0
0.8
0.6
0.4
0.2
T2
T1
1
2
3
4
5
6
7
8
9
TRIAL
1
2
3
ITI LOCATION

Table 2 shows the distribution of peck rates during the intertrial interval for all birds in Experiments I-V. For 102 of the 132 birds, ITI pecking occurred rarely, if at all, during the first two autoshaping sessions. The remaining 30 birds came from eight of the nine autoshaping conditions, and, without exception, showed low mean rates of pecking. In the last two autoshaping sessions, 114 birds showed little or no pecking. The other 18 birds came from seven autoshaping conditions, and no bird had a mean peck rate above 0.30 pecks/second. In no case was the rate of pecking during the trial lower than the rate of pecking during the intertrial interval.

Discussion

The results of this study provide striking evidence of the importance of trial spacing for the emergence of pecking to the signalling stimulus. When trials were separated by long intertrial intervals, pecking at the signalling stimulus began very rapidly; most birds started pecking within the first three autoshaping trials. When trials were separated by short intertrial intervals, pecking at the signalling stimulus was quite infrequent in the first 20 trials and developed slowly, if at all, during later trials. These acquisition data replicate and extend the results on trial spacing reported by other investigators (Terrace, et al., 1975; Perkins, et al., 1975; Griffin, 1975; Martin and Golinko, under review). The present analyses suggest that acquisition is indicated with less

Table 2

Distribution of Peck Rates During Intertrial Interval (ITI) For All Birds (n= 132) in Experiments I-V.

	Proportion of Birds Whose Mean Rate Falls Within Each Category*			
	0 pecks/second	0.01-0.10 pecks/second	0.11-0.20 pecks/second	0.21 pecks/second
Sessions 1-2	0.77 (102)	0.21 (27)	0.02 (3)	0 (0)
Sessions 11-12	0.86 (114)	0.12 (15)	0 (0)	0.02 (3)

*Numbers in parentheses represent the number of birds in each category.

variability and no loss of sensitivity by a five-trial criterion measure than by the trial of the first key peck.

The experimental conditions in the present study tested the possibility that events immediately preceding trials might interfere with conditioning. When trials were separated by long intertrial intervals, reinforcers or key-light stimuli placed before each trial slowed the development of pecking to a slight extent, but failed to produce the large deficits evident in the short ITI group. Peck acquisition in these experimental groups was similar to acquisition in control groups where extra events were randomly placed in the ITI. Thus, it appears that adding reinforcers or key-light stimuli to a long ITI condition leads to somewhat slower peck acquisition, but that placing these events immediately before each trial is no different from placing the same events at random in the ITI.[2]

These results provide little support for theoretical explanations of the spacing effect which emphasize local overshadowing, inhibition, or stimulus habituation, since such accounts predict poor conditioning in one or both of the experimental groups.

Results from the before-trial stimuli group also fail to support an account of the spacing effect in terms of the stimulus fluctuation model of learning developed by Estes (1950, 1955). Estes' model may be described as follows: A given stimulus consists of a set of elements, but only a portion of the elements in the set is available to an organism on a particular trial. Elements move in and out of the subset available to the animal randomly and at a constant rate over time. On any given trial, only the elements in the available subset are conditioned by the outcome of that trial. Response probability is proportional to the number of conditioned elements in the subset available to the animal on any given trial.

According to this model, non-reinforced stimulus presentations lead to either non-conditioning or extinction of the stimulus elements in the available subset, and short intervals between stimulus presentations allow little time for new elements to come into the subset. Hence, the model predicts that early acquisition performance should be better in the short than in the long ITI condition. The present experimental findings are obviously incompatible with this prediction. In addition, the model predicts that placing non-reinforced stimulus presentations before each trial will produce both slow response acquisition and overall low probabilities of pecking as compared to a condition where all stimulus presentations were reinforced. Neither of these predictions are confirmed by the data from the before-trial stimuli group. Thus, Estes' stimulus fluctuation model does not seem to provide a satisfactory account of the trial spacing effect in autoshaping.

Experimental Tests: Post-trial Interference

The results reported in the preceding section indicate that slower peck acquisition in the short ITI autoshaping condition cannot be attributed entirely to the interfering effects of events occurring immediately prior to each trial. However, local interference may yet account for the spacing effect if one argues that such interference arises not from events preceding trials, but from events following trials. The following general design was used to test the validity of post-trial interference as an explanation for the spacing effect in autoshaping. For the purpose of this test, reinforcers or stimuli are assumed to be events which disrupt the perseverative activity initiated by a trial. Figure 7 shows the arrangement of intertrial intervals and intertrial events for each of the four autoshaping conditions of interest in this section. Two reference groups receive trials separated by either long or short intertrial intervals. Two experimental groups receive trials separated by a long ITI, but either reinforcers or non-reinforced stimulus presentations occur immediately after each trial. If the spacing effect is due entirely to disruption produced by post-trial events, then peck acquisition in one or both of these experimental groups should be comparable to acquisition in the short ITI reference group, and much slower than acquisition in the long ITI reference group.

Autoshaping Conditions

In addition to the reference Groups L and S (Figure 7, a. and b.), there were two experimental groups where trial onsets were separated by 300-second intervals. The after-trial reinforcers group (Group RA,

Figure 7

Diagram of autoshaping conditions for reference and experimental groups involved in post-trial interference tests described in Experiments I-V. The reference conditions are the same as those shown in Figure 1.

AUTOSHAPING CONDITIONS

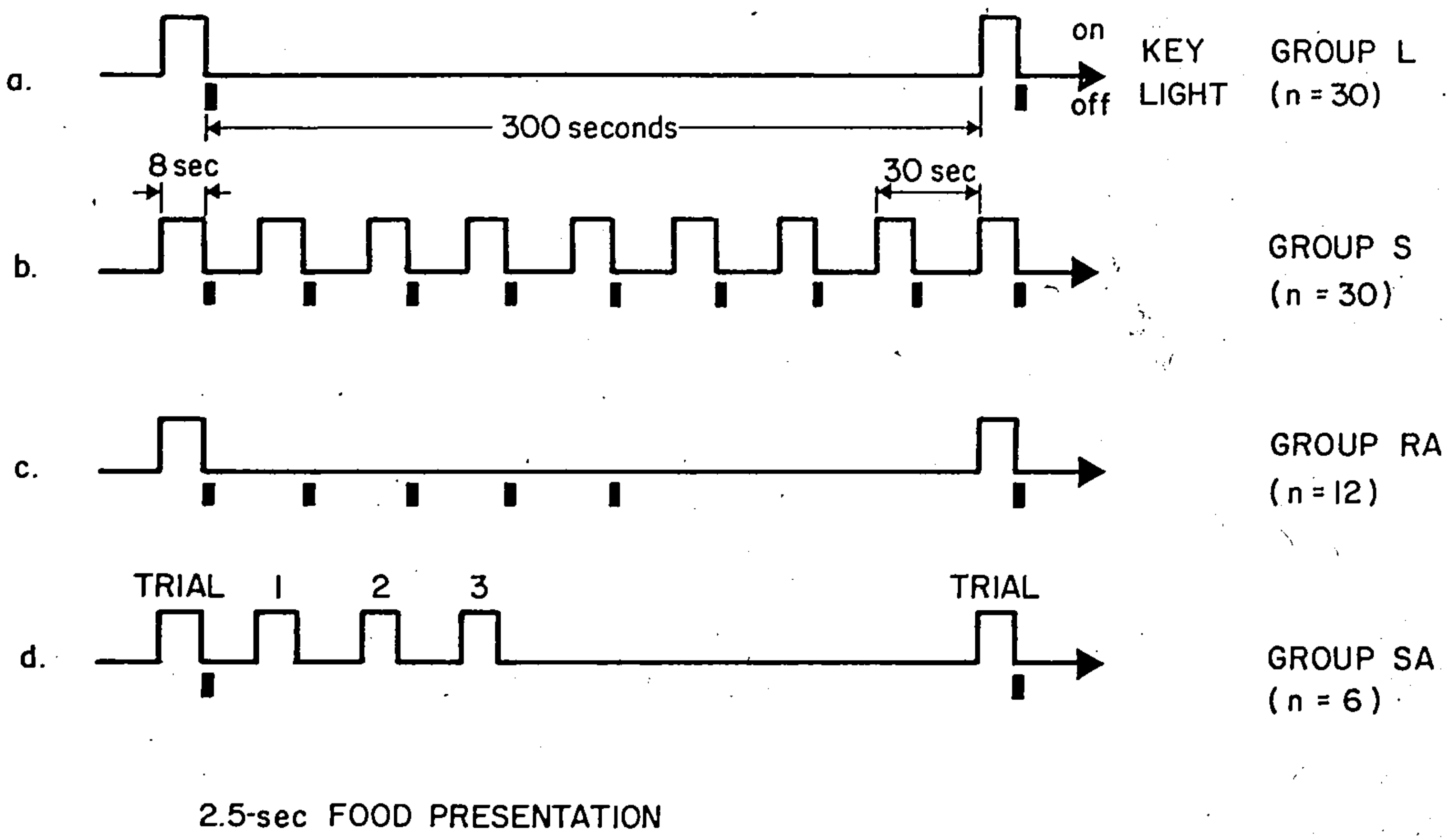


Figure 7b.) received 2.5-second hopper presentations 30, 60, 90, and 120 seconds after the onset of each trial reinforcer. The after-trial stimuli group (Group SA; Figure 7d.) received 8-second illuminations of the red key light 30, 60, and 90 seconds after the onset of each trial stimulus. The number of birds run in each autoshaping condition is shown on the right side of Figure 7.

Results

Figure 8 shows trial-by-trial results for peck acquisition for the three experimental groups which received events just after each trial. In Groups RA and SA, pecking to the trial stimulus began within two sessions for about half of the birds. At Trial 40, peck probability was 0.42 for Group RA and 0.67 for Group SA. Compared to reference Group L (Figure 2), both of these experimental groups were slightly retarded in peck acquisition, but neither group showed the very poor acquisition observed in reference Group S. Acquisition in these experimental groups resembled acquisition in the random control Groups RR and SR (Figure 3).

The five-trial acquisition criterion again provided an accurate indication of the development of pecking in each group. Table 3 summarizes the acquisition performance of each group in terms of the proportion of birds meeting criterion and the median and range of the distribution of criterion scores. Distributions of trials to criterion

Figure 8

Trial-by-trial analysis of the development of pecking in the first 40 trials (two sessions) of autoshaping. This graph shows data for the experimental conditions involved in post-trial interference tests described in Experiments I-V.

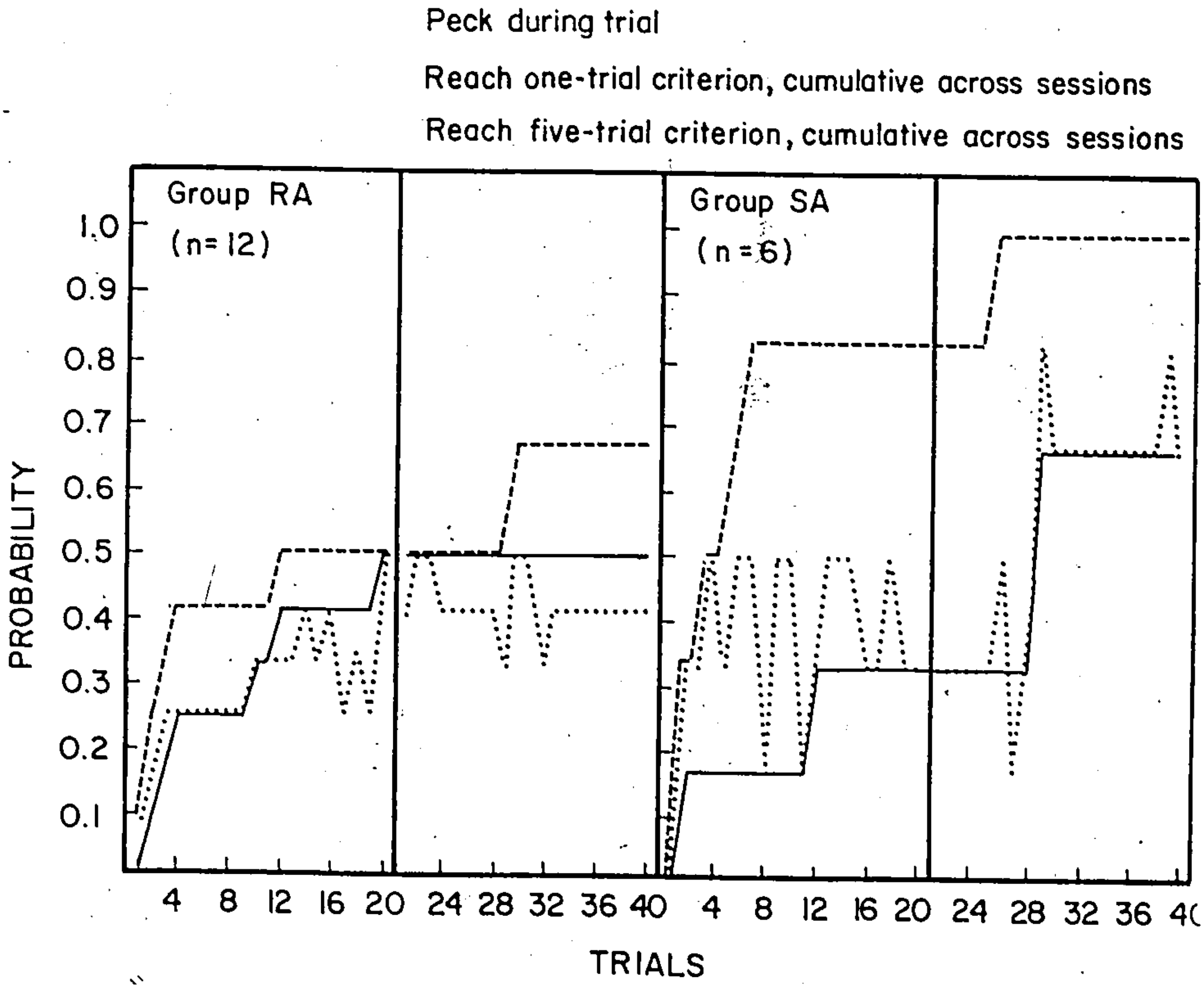

Peck during trial
Reach one-trial criterion, cumulative across sessions
Reach five-trial criterion, cumulative across sessions
Group RA
(n= 12)
Group SA
(n = 6)
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
32
36
40
TRIALS

Table 3

Summary of Acquisition Performance for Reference and Experimental Groups in Post-trial Interference Experiments.

	Proportion of Birds Which Meet Criterion Within 240 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds Not Meeting Criterion are Excluded)	
		Median	Range
Group L (n =30)	0.93	9.5	1-108
Group S (n = 30)	0.70	55.0	21-221
Group RA (n = 12)	0.83	16.0	2-209
Group SA (n = 6)	0.83	29.0	2-141

were used for statistical comparisons of the experimental and reference groups. All of these comparisons used the Mann-Whitney U, two-tailed test with adjusted significance levels (Ryan, 1960). Group L showed faster acquisition than Group RA ($U = 129$, $p < 0.05$), but did not differ from either of the other two experimental groups. Acquisition in Group S was slower than acquisition in Group RA ($U = 123$, $p < 0.05$) and did not differ significantly from acquisition in Group SA.

In Group SA, the birds did not seem to distinguish between reinforced and non-reinforced key-light presentations in acquisition, but did show some discrimination in terms of the levels of maintained pecking. As described in the preceding section, the acquisition criterion was used independently for the trial and for the first, second, and third non-reinforced stimulus presentations (see Figure 7d.). Again, the acquisition of pecking to the three non-reinforced stimulus presentations occurred almost simultaneously with the onset of reliable pecking to the trial stimulus. Levels of maintained pecking were analyzed by averaging peck probabilities over Sessions 8-12 for the trial stimulus and non-reinforced stimuli at each ITI location. Figure 6 shows the results of this analysis as well as the mean trial peck probability for the reference Group L run in the same experiment (Experiment II). Peck probability dropped rather noticeably between the trial stimulus and subsequent non-reinforced stimulus presentations. Also, Group SA showed a lower probability of pecking to the trial stimulus than the reference Group L.

Discussion

The experimental conditions reported in the present section were designed to test the possibility that events immediately following trials might retard conditioning by disrupting some sort of consolidation or rehearsal process. Trials were separated by long intertrial intervals and potentially disruptive events were placed just after each trial. Compared to the reference Group L, peck acquisition was somewhat slow when reinforcers or key-light presentations followed each trial. However, the experimental groups did not show the very poor acquisition evident in reference Group S. Moreover, neither group differed noticeably from the control groups, described in the previous section, where reinforcers or key-light presentations were randomly placed in the intertrial interval. While adding extra events to a long ITI condition slows the rate of peck acquisition to some extent, the location of these events is not an effective variable.

In conclusion, theoretical explanations which attribute the spacing effect to local post-trial interference receive little support from the present results. Trials may initiate some perseverating activity essential to learning, but neither reinforcer presentations nor stimulus presentations seem to be events which are capable of a major disruption of such activity.

Experimental Tests: Combined Effect of Pre-Trial and Post-trial Interference

The results described in the two preceding sections indicate that stimuli or reinforcers before or after each trial do not greatly increase the number of trials required to initiate pecking as compared to the long ITI reference groups. These results have been interpreted as providing little support for theoretical accounts which attribute the spacing effect to local overshadowing, inhibition, or habituation, or to disruption of some consolidation or rehearsal process. However, there remain some modifications of local interference notions which are consistent with the present results, and yet still capable of predicting the effect of trial spacing. One of these modifications assumes that the slight decrements in acquisition observed when events either precede or follow each trial sum to produce the large decrement observed in the short ITI condition, where events both precede and follow most trials.

The following experimental arrangement is designed to provide some evidence concerning this possibility. Two reference groups receive trials separated by either long or short intertrial intervals. An experimental group receives trials separated by a long ITI, but with reinforcers occurring before and after each trial. If reinforcers are interfering events, and a summation of pre- and post-trial interference is sufficient to explain the entire spacing effect, then peck acquisition in the experimental group should resemble acquisition in the short ITI reference group.

Autoshaping Conditions

In addition to the reference Groups L and S, there was one experimental group where trial onsets were separated by 300-second intervals. In the experimental Group RC, 2.5-second hopper presentations occurred 60 and 30 seconds before and 30 and 60 seconds after the onset of each trial reinforcer. This autoshaping group consisted of 12 pigeons.

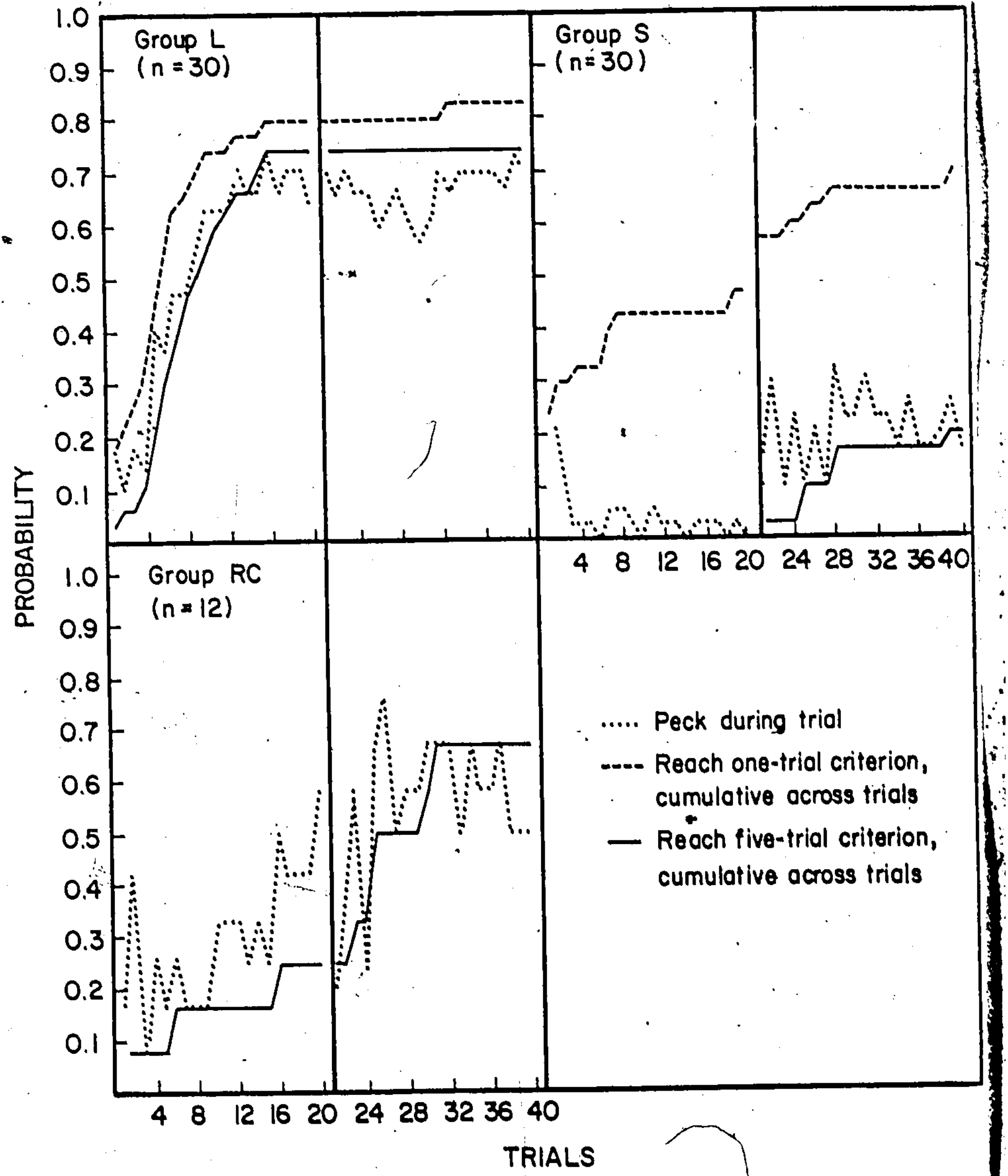
Results and Discussion

Figure 9 shows peck acquisition over the first 40 trials for the two reference groups and experimental Group RC. In Group RC, peck acquisition began within two sessions for about half of the birds; at Trial 40, peck probability was 0.50. Statistical comparisons using the five-trial acquisition criterion showed that Group RC differed from Group S ($U = 98$, $p < 0.01$; Mann-Whitney U, two-tailed test with adjusted significance levels), but did not differ from Group L. In Group RC, the proportion of birds which met criterion within 240 trials was 0.83; for those birds meeting criterion, the median number of trials to criterion was 24.0 and the range was from 1 to 122 trials.

Although peck acquisition in Group RC was somewhat slower than acquisition in Group L, Group RC did not show the very slow acquisition observed in Group S. Acquisition in Group RC closely resembled acquisition in the experimental and control groups described in the earlier

Figure 9

Trial-by-trial analysis of the development of pecking in the first 40 trials (two sessions) of autoshaping. This graph shows data for the reference and experimental conditions involved in testing combined pre- and post-trial interference in Experiments I-V. The data for the two reference conditions is the same as that shown in Figure 2.


Group L
(n = 30)
Group S
(n = 30)
Group RC
(n = 12)
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
32
36
40
TRIALS
····· Peck during trial
---- Reach one-trial criterion, cumulative across trials
— Reach five-trial criterion, cumulative across trials

sections of this paper. The placement of reinforcers before and after each trial does not seem to affect acquisition beyond what has been observed when extra reinforcers are added to the long ITI situation. Thus, the spacing effect cannot be explained entirely in terms of pre- and post-trial, reinforcer-produced interference.

EXPERIMENT VI

Local Interference from Stimulus-Reinforcer Pairings

The results from Experiments I-V indicate that so long as trials are separated by long temporal intervals, neither unsignalled food presentations nor non-reinforced stimulus presentations substantially reduce the rate of peck acquisition. However, the possibility remains that what is detrimental to peck acquisition is not stimuli or reinforcers adjacent to trials, but rather stimulus-reinforcer pairings occurring before or after each trial. This account receives some empirical support from the study reported by Wagner, Rudy, and Whitlow (1973). As described earlier, the results of this study indicated that post-trial events interfered with conditioning only when such events were surprising to the animal. Familiar sequences of events produced little or no interference with conditioning to the test stimulus. The conclusions of this study could be extended to the present autoshaping results by arguing that in acquisition, each trial is unexpected, and hence surprising to the animal. If this view is correct, then each trial, except the last, in a short ITI condition is subject to interference from succeeding trials, and one would expect poor peck acquisition. The relatively rapid acquisition observed when events occurred after each trial could be explained by assuming that stimuli alone or reinforcers alone are not as surprising to the pigeon as stimulus-reinforcer pairings.

Logically, this modification of the local interference account could also apply for events occurring before each trial. That is, one could assume that stimuli or reinforcers before trials have little effect on acquisition, but that stimulus-reinforcer pairings before each trial produce considerable interference. At present, however, there is no clear theoretical rationale to accompany such a possibility.

The preceding version of a local interference account attributes poor peck acquisition in the short ITI condition to trials (stimulus-reinforcer pairings) occurring before or after any given trial. If this account is correct, then one would expect that blocks of closely spaced trials would lead to poor peck acquisition, even if the period of time between blocks is relatively long. The following experiment is designed to test this prediction. A diagram of the various conditions is shown in Figure 10. The two reference conditions used in Experiments I-V are repeated. A third group spends the same amount of time in an experimental session as the long ITI reference group. However, for this experimental group, trials are presented in six blocks, rather than being regularly spaced throughout the session. Within trial blocks, stimulus-reinforcer pairings occur at the same rate as in the short ITI reference condition. Thus, for this experimental group, all trials are either preceded or followed by additional trials, and most trials are both preceded and followed by other trials. If the trial spacing

Figure 10

Diagram of autoshaping conditions for the reference and experimental groups in Experiment VI.

effect is due to interference produced by stimulus-reinforcer pairings, then acquisition in this experimental group should be slow and hence similar to acquisition in the short ITI reference group.

Method

Subjects: Subjects were 19 experimentally naive White King pigeons, approximately one year of age. The sex of the birds was not determined. All birds were maintained at 75% of their free-feeding weights and fed Purina Pigeon Checkers both in the home cage and during experimental sessions. One bird was discarded from the experiment when it failed to eat from the food hopper after manual training.

Apparatus: The apparatus was the same as that described in the General Method for Experiments I-V, with one modification. Two additional houselights, identical to the original houselight, were installed on the response panel in each experimental chamber. These houselights were located 2.5 cm. to the left and right of the original houselight, and at the same height above the floor of the chamber.

Hopper training procedure: For the purposes of another experiment, the hopper training procedure was arranged to train the birds on a discrimination between two colors of houselight illumination. Since this discrimination procedure is not relevant to the present experiment, the procedure is not described in detail; however, a detailed account of the procedure may be found in the Appendix.

Autoshaping procedure: Six birds were run in each of three autoshaping conditions. For all groups, the chamber was illuminated throughout the autoshaping session by a houselight color different from the two colors used in the preceding discrimination training. The first trial presentation occurred 30 minutes after the onset of the experimental session. Trials consisted of an 8-second illumination of the red key light, followed by a 4- second hopper presentation. In the long ITI reference group (Group L, Figure 10a.), trial onsets were separated by 300-second intervals; in the short ITI reference group (Group S, Figure 10b.), trial onsets were separated by 30-second intervals. For the experimental group (Group X, Figure 10c.), sessions were equal in duration to sessions in the long ITI reference condition. However, trials were presented in six five-trial blocks. Within each block, trial onsets were separated by 30-second intervals. Each block was followed by a 21.5-minute interval.

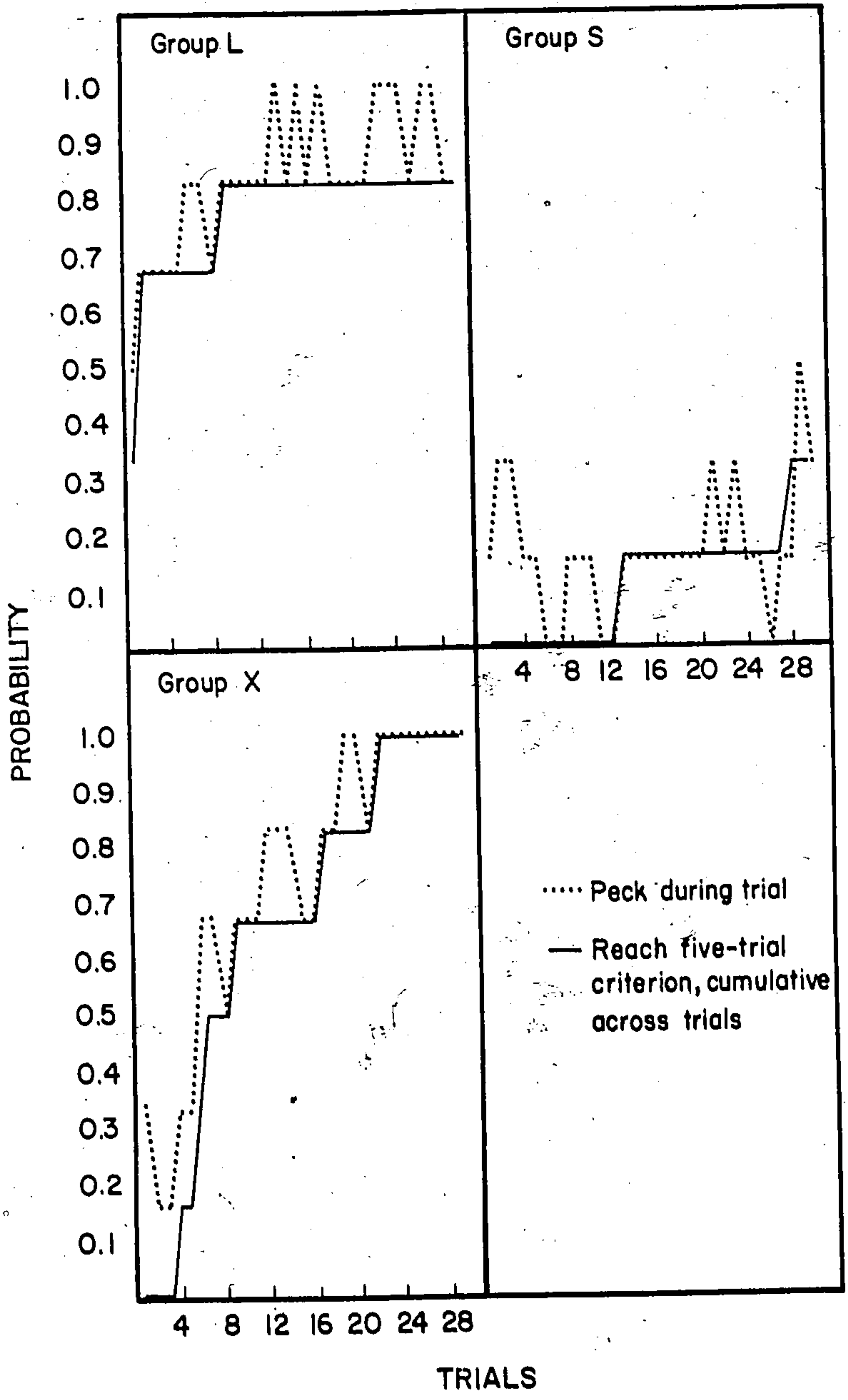
Key pecks were recorded but never had programmed consequences. A session consisted of 30 trials, and all groups were run daily for eight sessions. The pigeons were fed whatever necessary to maintain their weight immediately after the daily session.

Results

Figure 11 shows the development of pecking during Session 1 within each autoshaping condition. Comparison of the reference Groups L and S shows the usual effect of trial spacing. Most of the birds in

Figure 11

Trial-by-trial analysis of the development of pecking in the first 30 trials (one session) of autoshaping for reference and experimental groups in Experiment VI.


Group L
Group S
Group X
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
TRIALS
Peck during trial
Reach five-trial criterion, cumulative across trials

Group L required very few trials to begin pecking, and peck probability at Trial 30 was 0.83. In contrast, most birds in Group S did not begin to peck reliably within the first session, as indicated by a peck probability of 0.33 at Trial 30. Peck acquisition in the experimental Group X was very rapid, and closely resembled acquisition in the reference Group L; peck probability at Trial 30 was 1.0.

As in previous experiments, the change in peck probability within each autoshaping group was closely related to the cumulative distribution of trials required to reach the five-trial acquisition criterion. Table 4 summarizes the acquisition performance of each group in terms of the proportion of birds meeting criterion and the median and range of the distribution of criterion scores. The Mann-Whitney U test with adjusted significance levels was used for statistical comparison of the distributions of criterion scores. As expected, Group L showed faster acquisition than Group S ($U = 4$, $p < 0.05$; one-tailed test); Group X showed faster acquisition than Group S ($U = 2$, $p < 0.02$; two-tailed test), and did not differ significantly from Group L.

Key pecking during the intertrial interval was infrequent. Most birds never pecked the key, and only three of the 18 birds had peck rates which exceeded 0.10 pecks/second in any one session. Intertrial pecking tended to occur more frequently during early autoshaping sessions than during later sessions.

Table 4

Summary of Acquisition Performance for Reference and Experimental Groups in Experiment VI.

	Proportion of Birds Which Meet Criterion Within 240 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds Not Meeting Criterion are Excluded)	
		Median	Range
Group L	1.00	2.0	1-31
Group S	1.00	31.0	13-91
Group X	1.00	7.5	4-22

Discussion

These results provide no support for the idea that the trial, i.e., the stimulus-reinforcer pairing, is an event which interferes with conditioning. Peck acquisition is equally rapid whether trials are clustered in blocks or uniformly distributed across a long experimental session. The equivalence of acquisition rates in these two groups is, however, subject to another interpretation. Suppose, for example, that trials occurring immediately after trial n do interfere with some perseverating activity initiated on trial n. If the perseverating activity persists for longer than 300 seconds, then the effectiveness of almost all trials in the long ITI reference condition is reduced by disruption from subsequent trials. In the condition where trials occur in blocks, the effectiveness of four out of five trials is greatly reduced by immediately subsequent trials. However, one out of every five trials is followed by a 20-minute event-free interval; consequently, one would expect one trial to be highly effective. Moreover, the effectiveness of the last trial in each block might account for the observation that peck acquisition is quite rapid in the group where trials are clustered. In order to evaluate this possibility, it would be necessary to compare acquisition in the preceding two conditions with acquisition in a control condition where one trial occurred every 20 minutes. If the present account is correct, then every trial in the control condition would be highly effective, and peck acquisition should be much more rapid than in the clustered or distributed trial situations.

Separating single trials by 20-minute intervals might indeed produce extremely rapid peck acquisition. Although such a finding would be compatible with the notion that a trial is an interfering event, the observation would also be susceptible to a variety of other explanations. Some alternative explanations assume that long waiting periods are beneficial to conditioning, not because such waits reduce the possibility of local interference, but because waits provide ample opportunity for the operation of other time-dependent mechanisms which enhance the effectiveness of a trial. Since the latter type of explanation is obviously consistent with the observation of a trial spacing effect, it is impossible to decide between the two types of explanation without some further information about the empirical characteristics of an effective waiting period.

Let us review briefly the conclusions from the first series of experiments. The results from long and short ITI reference conditions indicate clearly the importance of trial spacing for the development of a signalling stimulus in autoshaping. When key-light - food pairings were separated by long temporal intervals, pecking to the signalling stimulus began within the first 20 trial presentations for most birds. In contrast, close temporal spacing reliably increased the number of trials required to initiate pecking; in this condition, pecking was very infrequent within the first 20 trial presentations. The present finding is consistent with results reported previously by other investigators (Terrace, <u>et al.</u>, 1975; Perkins, <u>et al.</u>, 1975; Griffin, 1975; Martin and Golinko, under review); in naive pigeons, the rate of peck acquisition is positively related to the duration of the temporal interval between autoshaping trials. In addition, the present data show that the number of trials to a five-trial acquisition criterion is a convenient measure which is closely related to trial-by-trial changes in peck probability within any autoshaping group.

A simple type of theoretical explanation for the spacing effect is one which argues that response acquisition is slow when trials are closely spaced because events occurring before or after trials interfere with conditioning. To test the possibility of such local interference, some groups received experimental treatments in which trials were separated by long temporal intervals and potentially disruptive events were placed immediately before or after each trial. The results from these experimental groups indicate that neither unsignalled food presentations nor non-reinforced stimulus presentations produce any substantial reduction in the rate of acquisition as compared to the long ITI reference group. In no case was acquisition reduced to the level observed in the short ITI reference group. Moreover, comparisons with appropriate control groups suggest that the small decrease in acquisition rate is due to the introduction of extra events to the long ITI situation, rather than to the temporal location of these events. Finally, peck acquisition was observed to be equally rapid whether trials were clustered in blocks or uniformly distributed across a long experimental session. This result can be explained within the context of local interference accounts only if one makes special assumptions about the optimal temporal interval for trial spacing. In summary, the results from Experiments I - VI show that when trials are separated by long intertrial intervals, events placed before or after each trial do not greatly affect the development of pecking.

THE OVERALL PATTERN OF EVENT PRESENTATION

A Logical Analysis of Intertrial Waits

The experiments reported up to this point have focused on the immediate context of a single trial presentation. In a short ITI condition, each trial is closely preceded and followed by other trial presentations, whereas in a long ITI condition, each trial occurs in temporal isolation. The results of the preceding experiments indicate that the same effect is obtained from placing these events before the trial, after the trial, surrounding the trial, or at random times between trials. The local context of the trial is not the source of the interfering effect of the close spacing of trials. Thus, it does not seem that the trial spacing effect can be understood in terms of the immediate context of trial presentation. This conclusion suggests that analysis of the spacing effect must be broadened to consider the patterns of event presentation across an entire experimental session.

One way of considering differences in the overall pattern of event presentation is to observe that the two spacing conditions differ in respect to the presence or absence of a long, event-free interval between trial presentations. Long, event-free intervals, or waiting periods, have the effect of producing rapid acquisition of the response. Accordingly, further exploration of the spacing effect will attempt to identify the characteristics of waiting periods which are essential to rapid response acquisition. The first question of interest concerns the number of waiting periods and their position in relation to trial presentations. In the long ITI condition, all trial presentations are separated by waiting periods. However, the results of Experiment VI show that this particular configuration of trials and waiting periods is not critical to the rate of peck acquisition; peck acquisition was observed to be equally rapid whether trials were spaced at regular intervals or clustered into six blocks within a long experimental session. Since six long waiting periods appear to be as effective as 30 shorter waiting periods, one wonders whether a more extreme variation in the number and position of waiting periods would also be equivalent to uniformly wide spacing. Is a single wait sufficient to produce rapid peck acquisition in a subsequent series of closely spaced trials? Experiment VII is directed to this question.

The second question of interest involves the boundary events which define effective waiting periods. Waiting periods between trial presentations lead to rapid peck acquisition. However, trials consist of two discrete events, stimulus and reinforcer. Logically, therefore, the effectiveness of waiting periods could derive, not from the temporal separation of stimulus-reinforcer pairings, but from the temporal separation of stimuli or reinforcers. Does rapid peck acquisition depend on waiting periods between trials or on waiting periods between stimuli or reinforcers? Experiment VIII is designed to answer this question with respect to reinforcer presentations. The importance of waiting periods between reinforcers is assessed by varying the temporal distribution of the reinforcer presentations when the interval between trials is held constant.

The third question about waiting periods concerns the importance of stimulus context in determining the effectiveness of the wait. In the long ITI condition, intertrial waits occur in the experimental chamber and thus in the stimulus situation present during autoshaping trials. Is rapid peck acquisition dependent on waiting in the stimulus conditions which constitute the background for autoshaping? Experiment IX addresses this question by manipulating the situational stimuli during the waiting period.

In terms of the overall pattern of event occurrence, short and long ITI spacing conditions differ by virtue of the presence or absence of long, event-free intervals between trial presentations. The preceding discussion suggests that, logically, the effectiveness of such intervals or waiting periods may depend on their number and position, boundary events, and stimulus context. Current theories of conditioning provide further support for the notion that an understanding of the characteristics of effective waits may be of considerable importance to a general understanding of the spacing effect. These theoretical accounts will now be considered in more detail.

Theoretical Accounts: Extinction of Competing Stimulus Associations

Several investigators in the area of stimulus control have noted that the effectiveness of a stimulus-reinforcer pairing is dependent on the general context in which that pairing occurs (e.g., Kamin, 1969; Wagner, 1971). Rescorla and Wagner (1972; Wagner and Rescorla; 1972) have formalized this notion in a model of discrimination learning that rests on the following general assumptions. All stimuli present within a brief time interval are assumed to change in associative strength at the end of the interval. The direction of change is positive if the interval ends with a reinforcer and negative if the interval ends without a reinforcer. In a simple case where two stimuli are present in the brief time interval, the changes which occur at the end of the interval are described by the following equations:

$$\Delta V_1 = \alpha_1 \beta (\lambda - V_{1+2})$$

$$\Delta V_2 = \alpha_2 \beta (\lambda - V_{1+2}).$$

ΔV_1 and ΔV_2 represent the change in associative strength for stimuli 1 and 2, respectively; α_1 and α_2 represent the saliences of these two stimuli. β represents the rate of conditioning produced by the terminal event (presence or absence of a reinforcer), and λ represents the maximum level of associative strength which is possible for that terminal event. It should be noted that β and λ will not be the same for all terminal events. Finally, V_{1+2} represents the sum of associative strengths for stimuli 1 and 2 prior to the end of the particular interval.

As indicated by these equations, the magnitude of changes at the end of an interval is directly related to the difference between V_{1+2}, the total strength of the available stimuli, and λ, the maximum associative strength supported by the terminal event. For a particular stimulus, for example stimulus 1, the magnitude and direction of change, ΔV_1, depends on its salience, α_1, and the current strengths, V_1 and V_2, of all stimuli present at the end of the interval.

In discussions of this model, Rescorla and Wagner have suggested that associations between reinforcer presentations and background or situational stimuli play an important role in a variety of classical conditioning arrangements. For example, the observation that the strength of conditioning depends on the degree of stimulus-reinforcer correlation is explained in terms of a division of associative strength between the discrete conditioned stimulus (CS) and the background stimuli in the experimental situation. The observation that a negative stimulus-reinforcer correlation makes the CS a conditioned inhibitor is explained in terms of non-reinforcement of the CS in the context of excitatory background stimuli.

In addition to the range of data which can be explained using this assumption, several experimental reports provide some more direct support for the idea that the animal associates reinforcer presentations with situational stimuli. It is well known that the addition of unsignalled reinforcer presentations greatly interferes with the development of a conditioned response to a CS. Rescorla and Wagner argue that this observation is due to the strong associations formed between reinforcer and situational stimuli. Such associations presumably reduce the strength of an association between the CS, presented in the context of situational stimuli, and the reinforcer. In terms of the equations discussed earlier, a strong association between situational stimuli (stimulus 1) and the reinforcer implies that V_1 is large relative to the maximum level, i.e., the value of λ. When the conditioned stimulus (stimulus 2) is presented in conjunction with stimulus 1, the difference between λ and V_{1+2} will be small; therefore, ΔV_2 will be proportionally small. Hence, one observes little conditioning to the conditioned stimulus, stimulus 2. However, Rescorla and Wagner assume that the association between situational stimuli and reinforcer extinguishes (i.e., the value of V_1 decreases) when the animal is exposed to the experimental environment in the absence of reinforcers.

Dweck and Wagner (1970) tested this argument using rats in an arrangement intended to produce a conditioned emotional response (CER). During CER training, shocks occurred only in the presence of the CS for two correlated groups; shocks occurred in the presence and in the absence of the CS for two uncorrelated groups. One correlated and one uncorrelated group received additional sessions in the experimental chamber when neither the CS nor shock were presented. The remaining correlated and uncorrelated groups received no sessions apart from the basic CER training. All four groups were tested by measuring the suppression of operant responding during non-reinforced CS presentations. The results of this experiment support the theoretical account outlined above. Correlated and uncorrelated groups which received additional sessions in the experimental chamber showed greater suppression to the CS than correlated and uncorrelated groups without additional sessions. Dweck and Wagner concluded that the strength of the CS-shock association depends on the strength of the association between situational stimuli and shock. Exposure to the experimental situation in the absence of shock presumably leads to the extinction of associations between situational stimuli and shock; as associations with situational stimuli are thus weakened, the CS-shock association becomes stronger.

The theoretical model proposed by Rescorla and Wagner lends itself quite easily to an account of the trial spacing effect. Reinforcers presented to the animal in the experimental chamber lead to associations between the background, chamber stimuli and the occurrence of food. In the long ITI condition, the associative strength of situational stimuli decreases as a result of extinction occurring during the intertrial interval; the key-light stimulus is not subject to extinction, and thus exerts strong control over behavior during trials. In the short ITI condition, however, the strength of situational stimuli diminishes very little between trials; thus, situational stimuli compete strongly with the key light for control of behavior during trials. In short, the development of pecking is taken to reflect the acquisition of a discrimination between situational stimuli alone and the compound of situational stimuli plus key light.

Some empirical support for this argument comes from autoshaping experiments reported by Blanchard and Honig (1976). In these experiments, naive pigeons were first trained to eat from the food hopper, and then exposed to several sessions where the chamber was illuminated by one color (S +) when food presentations occurred at varying time intervals and by a different color (S-) when no food presentations would occur. During autoshaping the pigeons experienced one of three conditions. In one condition, the S + color illuminated the chamber during key-light - food pairings; in a second condition, the S- color illuminated the chamber, and in a third condition, a novel color illuminated the chamber. The results of these experiments showed that pecking at the key light was stronger in the groups where the chamber was illuminated by the S- color than in the groups where the chamber was illuminated by the S + color. Unfortunately, the level of pecking in groups where a novel color illuminated the chamber was inconsistent across the two experiments. However, these data demonstrate that conditioning to diffuse, situational stimuli can interfere with autoshaped pecking to a lighted response key. The results support the possibility that conditioning to situational stimuli might interfere with the development of pecking in a short ITI autoshaping condition.[3]

The Rescorla and Wagner model of discrimination learning suggests that extinction of competing stimulus associations is the process underlying the effectiveness of intertrial waiting periods. Characteristics of waits such as number and position, boundary events, and stimulus context are expected to be important to the course of conditioning, because such characteristics will determine the acquisition of competing associations and the time available for extinction. Unfortunately, despite the quasi-quantitative form of the model, it is impossible to derive more specific predictions about the effects of waiting periods. The vagueness of the model in this respect is due to the fact that very little is known about the values which should be assigned to particular parameters, such as stimulus salience or effect of reinforcement and non-reinforcement. However, the discrimination learning model does lend theoretical support to the notion that varying the conditions of waits in terms of number and position, boundary events, and stimulus context should affect the development of a signalling stimulus.

Theoretical Accounts: Extinction of Competing Response Associations

Martin and Golinko (under review) have suggested, among other possibilities, that the spacing effect in autoshaping might be explained in terms of a differential strengthening of behaviors which compete with key pecking. This account is based on Skinner's (1948) observation that behaviors other than pecking are adventitiously conditioned when reinforcer presentations occur in the absence of any explicit response contingency. Since in the autoshaping procedure reinforcer presentations are not contingent on behavior, it seems possible that, particularly in early trials, behaviors other than pecking may increase in strength. Furthermore, if such behaviors remain strong, they might interfere with the subsequent development of pecking. Martin and Golinko suggest several reasons to expect that closely spaced reinforcers strengthen non-pecking behavior to a greater extent than widely spaced reinforcers. Basically, short inter-reinforcer intervals increase the probability that a particular behavioral pattern will be followed by a reinforcer, whereas long inter-reinforcer intervals reduce the probability that such adventitious pairings will occur. From this notion, one might argue that pecking develops slowly in a short ITI autoshaping condition, because behaviors incompatible with key pecking are maintained at a high level of strength.

This theoretical argument may be restated in terms of the time available between autoshaping trials for extinction of behaviors incompatible with key pecking. When the intertrial interval is short, incompatible behaviors are often followed by a reinforcer and therefore do not extinguish; in contrast, when the intertrial interval is long, incompatible behaviors are rarely followed by a reinforcer, and therefore extinguish relatively quickly. When stated in this way, it is clear that the present account is very similar to an account of the spacing effect in terms of differential opportunity for extinction of competing stimulus associations. Accordingly, varying the number and position of waits, or boundary events, is expected to alter the course of conditioning because these factors influence the acquisition of incompatible behaviors and the time available for extinction. Moreover, it is not unreasonable to assume that incompatible behaviors reinforced in a particular situation are associated with the stimulus cues arising from that situation; when situational stimuli are altered, these behaviors are not emitted and thus not subject to extinction. With the addition of this assumption, the response competition account agrees with the discrimination learning model in the expectation that effective waiting periods must occur in the stimulus situation which constitutes the background for trial presentations. In summary, then, the response competition account, like the discrimination learning model, predicts that the effectiveness of waiting periods depends to a large extent on their number and position, boundary events, and stimulus context.

EXPERIMENT VII

Number and Position of Waiting Periods

The results of Experiment VI show that peck acquisition is equally rapid whether trials are spaced at regular intervals or clustered into six blocks within a long session. Experiment VII is designed to provide information about the effectiveness of an extreme arrangement of the waiting periods within a long experimental session. Is a single long wait sufficient to produce rapid peck acquisition in a subsequent series of closely spaced trials?

Method

Subjects: Subjects were 24 experimentally naive White King pigeons, approximately one year of age. The sex of the birds was not determined. All birds were maintained at 75% of their free-feeding weights and fed Purina Pigeon Checkers both in the home cage and during experimental sessions.

Apparatus: The apparatus was the same as that described in the General Method, Experiments I - V.

Hopper training procedure: The hopper training procedure was the same as that described in the General Method, with two changes. Following the first adaptation session, there were seven sessions of automated hopper training. Each hopper presentation was 4 seconds in duration throughout hopper training.

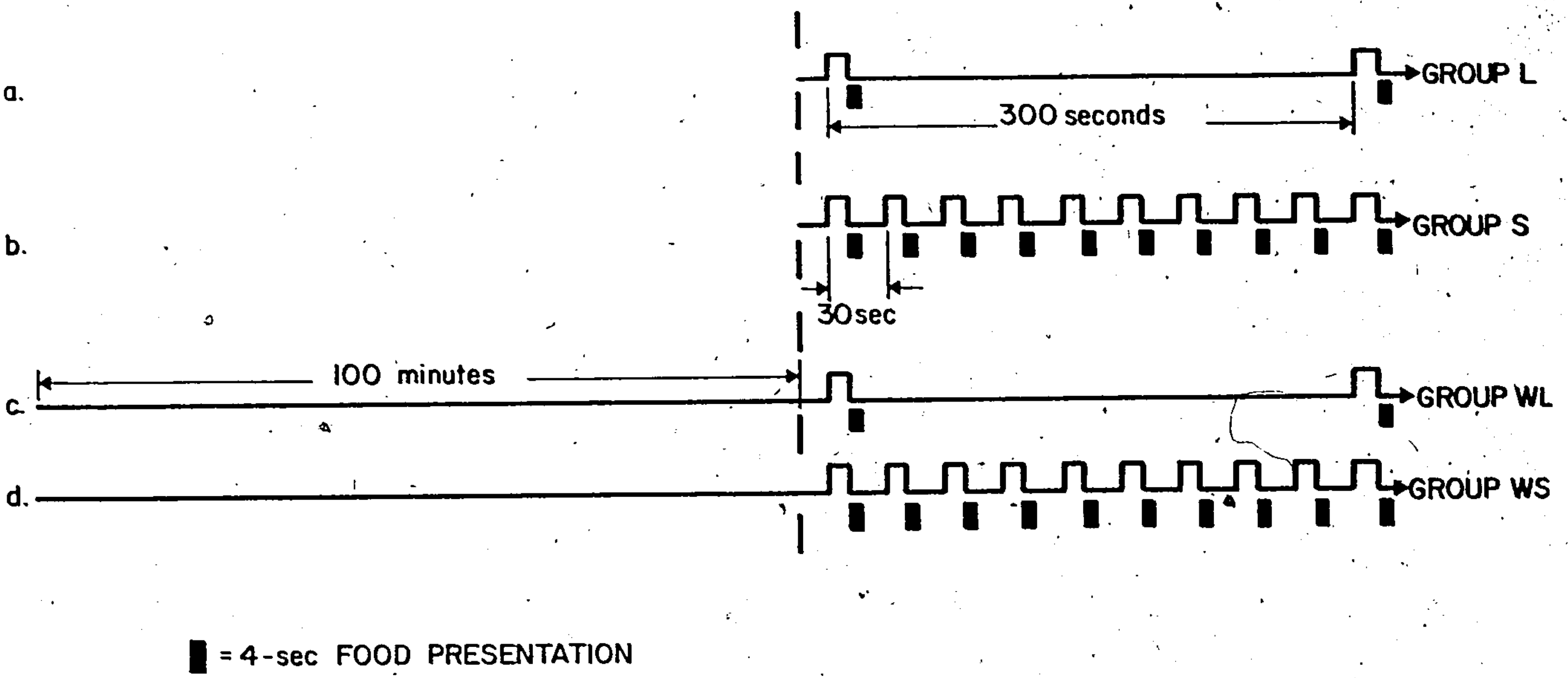
Autoshaping procedure:. A diagram of the various conditions is shown in Figure 12. Six birds were run in each of the four autoshaping conditions. As in previous experiments, a trial consisted of an 8-second illumination of the red dot on the response key, followed immediately by a 4-second hopper presentation. The present experiment had a two-by-two factorial design, where one factor was the waiting period before the first autoshaping trial and the other factor was time between trials. The two reference groups waited for 30 seconds from the onset of the houselight and white noise to the onset of the first trial (Groups L and S, Figure 12, a. and b.); the two experimental groups waited for 100 minutes from the onset of the houselight and white noise to the onset of the first trial (Groups WL and WS, Figure 12, c. and d.). For one reference group and one experimental group, trial onsets were separated by 30-second intervals (Groups S and WS, respectively); for the other reference and experimental groups, trial onsets were separated by 300-second intervals (Groups L and WL, respectively).

Key pecks were recorded but never had programmed consequences. Each session consisted of 30 trials, and all groups were run daily for 8 sessions. The pigeons were fed whatever necessary to maintain their weight immediately after the daily session.

Figure 12

Diagram of autoshaping conditions for the reference and experimental groups in Experiment VII.

AUTOSHAPING CONDITIONS



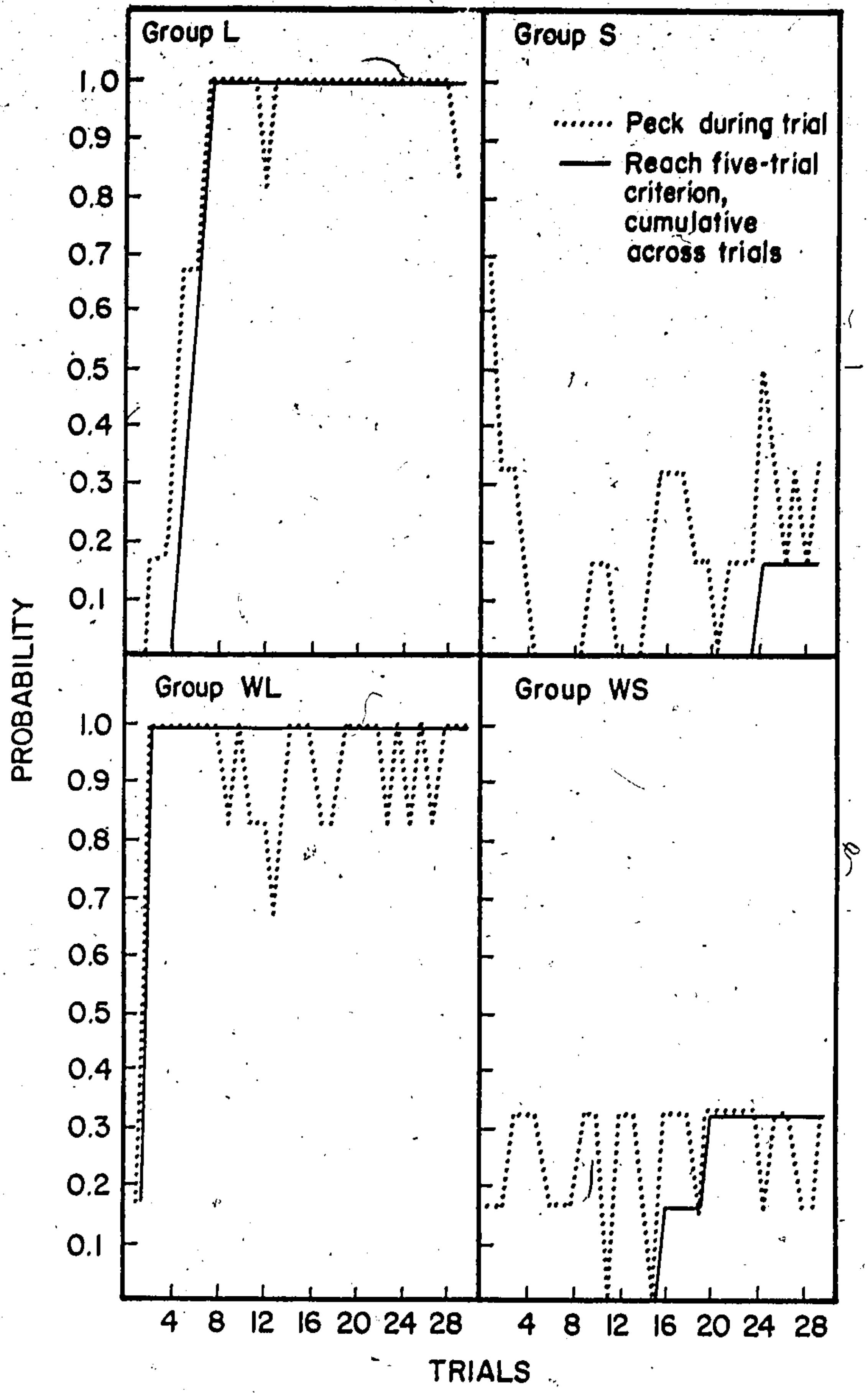
Results

As shown in Figure 13, the usual patterns of peck acquisition were observed in the reference Groups L and S. Very few trials were required to initiate pecking in Group L, and by Trial 30, peck probability was 0.83. Group S, on the other hand, showed much lower levels of pecking, and by Trial 30, peck probability was 0.33. Statistical comparison using the five-trial acquisition criterion confirmed this difference between Groups L and S ($U = 0$, $p < 0.01$; Mann-Whitney U, one-tailed test with adjusted significance levels). The same pattern of peck acquisition was evident in the experimental Groups WL and WS. In Group WL, all birds began pecking by Trial 2, and peck probability was 1.0 at Trial 30; in Group WS, peck probability was low, reaching 0.33 by Trial 30. This difference was statistically significant ($U = 0$, $p < 0.01$, Mann-Whitney U, two-tailed test with adjusted significance levels). Group WS also showed significantly slower peck acquisition than Group L ($U = 0$, $p < 0.01$; Mann-Whitney U, two-tailed test with adjusted significance levels).

Since one might expect that a long waiting period would increase the salience of a stimulus presentation, it is of interest to observe that the peck probabilities on Trial 1 are quite similar within each waiting condition. For Groups L and S combined, mean peck probability on Trial 1 is 0.33; for Groups WL and WS, mean peck probability is 0.17.

Figure 13

Trial-by-trial analysis of the development of pecking in the first 30 trials (one session) of autoshaping for reference and experimental groups in Experiment VII.



Group L
Group S
Group WL
Group WS
Peck during trial
Reach five-trial criterion, cumulative across trials
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
TRIALS

Thus, the long waiting period preceding autoshaping did not seem to enhance the initial tendency to peck at the lighted key in the two experimental groups.

A long waiting period preceding autoshaping did, however, lead to somewhat more rapid peck acquisition in the experimental groups, as indicated in Figure 13 and in Table 5 which summarizes acquisition performance. In Group WL, all birds reached the acquisition criterion by Trial 8. Although this difference was slight, distributions of the criterion measure did not overlap for Groups WL and L; consequently the difference was statistically significant ($U = 0$, $p < 0.01$; Mann-Whitney U, two-tailed test with adjusted significance levels). In Group WS, two birds reached criterion by Trial 20, while in Group S, no bird had reached criterion by Trial 20. The advantage shown by Group WS was also reflected in a comparison of the median number of trials required to reach criterion, 32.0 for Group WS and 63.0 for Group S. However, distributions of the criterion measure overlapped considerably for these two groups, so this small difference was not statistically significant.

Discussion

The present results show that peck acquisition is slow when all trials are closely spaced, even though a long waiting period precedes the series of trials. Groups experiencing a single long wait in the

Table 5

Summary of Acquisition Performance for Reference and Experimental Groups in Experiment VII.

	Proportion of Birds Which Meet Criterion Within 240 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds not Meeting Criterion are Excluded)	
		Median	Range
Group L	1.00	6.0	5- 8
Group S	1.00	63.0	31-151
Group WL	1.00	2.0	1- 2
Group WS	0.83	32.0	16- 66

experimental chamber did show slightly faster peck acquisition than groups which did not experience such a wait prior to the beginning of autoshaping. It will be recalled that Experiment VI showed that it is not necessary for every trial to be temporally isolated from other trials in order for pecking to develop rapidly. It now appears that rapid peck acquisition depends on some aspect of an alternation between trials and event-free waiting periods.

EXPERIMENT VIII

Boundary Events

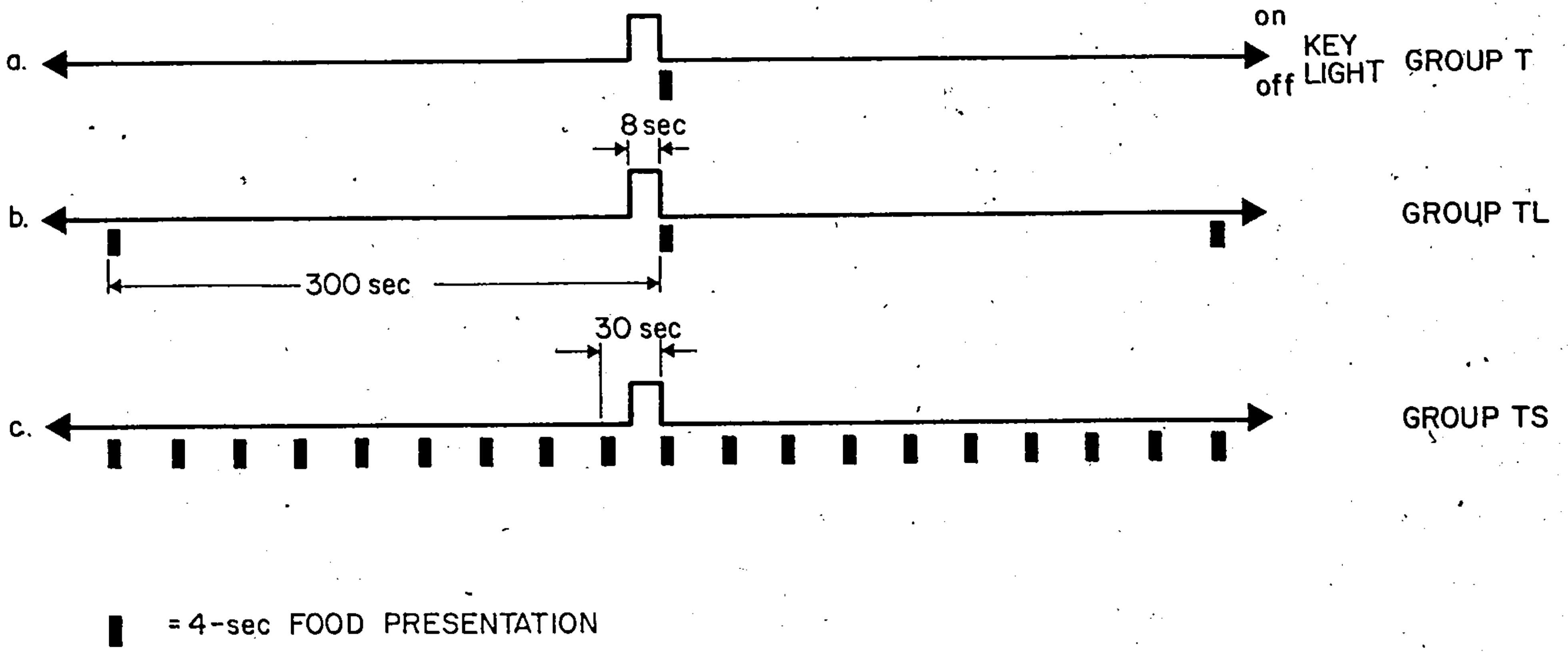
Experiment VIII is designed to provide information about the boundary events sufficient to produce an effective waiting period. Clearly, waiting periods which separate trials, i.e., stimulus-reinforcer pairings, lead to rapid peck acquisition. Are waiting periods which separate reinforcer presentations sufficient to produce rapid peck acquisition?

Figure 14 shows a diagram of the experimental arrangement used to address this question. The interval between trials is held constant by presenting only one trial within each daily autoshaping session. The single trial occurs in the middle of a long series of reinforcer presentations. For one group, reinforcer presentations are separated by long intervals; for a second group, reinforcer presentations are separated by short intervals. In other words, these groups are exposed to the same spacing of food deliveries as in the long and short ITI spacing conditions, except that only one food presentation is signalled by a prior key-light illumination. A third group received only the single trial in each daily autoshaping session. This design separates the rate of reinforcer presentation from the rate of

Figure 14

Diagram of autoshaping conditions used in Experiment VIII.

AUTOSHAPING CONDITIONS



trial presentation. If trials are the events which define effective waiting periods, then peck acquisition should be similar for all groups. On the other hand, if the reinforcer presentations are sufficient to define effective waiting periods, then the group with widely spaced reinforcer presentations should show rapid peck acquisition, while the group with closely spaced reinforcer presentations should show slow peck acquisition.

Method

Subjects: Subjects were 16 experimentally naive White King pigeons, approximately one year of age. The sex of the birds was not determined. All birds were maintained at 80% of their free-feeding weights and fed mixed grain both in the home cage and during experimental sessions.

Apparatus: The apparatus was the same as that described in Experiment VI.

Hopper training procedure: The hopper training procedure was the same as that described in Experiment VII.

Autoshaping procedure: For all of the three autoshaping groups, a trial consisted of an 8-second illumination of the red dot on the response key, followed immediately by a 4-second hopper presentation; one trial occurred in each autoshaping session. For one group (Group T, Figure 14a.), the autoshaping session was 15.5 minutes in duration and included no events other than the single trial presentation; the onset of the trial occurred 7.5 minutes after the onset of the session. For the second group (Group TL, Figure 14b.), the autoshaping session was 150.5 minutes in duration and included 30 4-second hopper presentations. Beginning 38 seconds after the onset of the session, hopper presentation onsets occurred at 300-second intervals. In each session, the sixteenth hopper presentation was preceded by the brief key-light illumination, so that this single trial occurred 75.5 minutes after the onset of the session. For the third group (Group TS, Figure 14c.), the autoshaping session was 15.5 minutes in duration and included 30 4-second hopper presentations. Beginning 38 seconds after the onset of the session, hopper presentation onsets occurred at 30-second intervals. In each session, the sixteenth hopper presentation was preceded by the brief key-light illumination, so that this single trial occurred 7.5 minutes after the onset of the session.

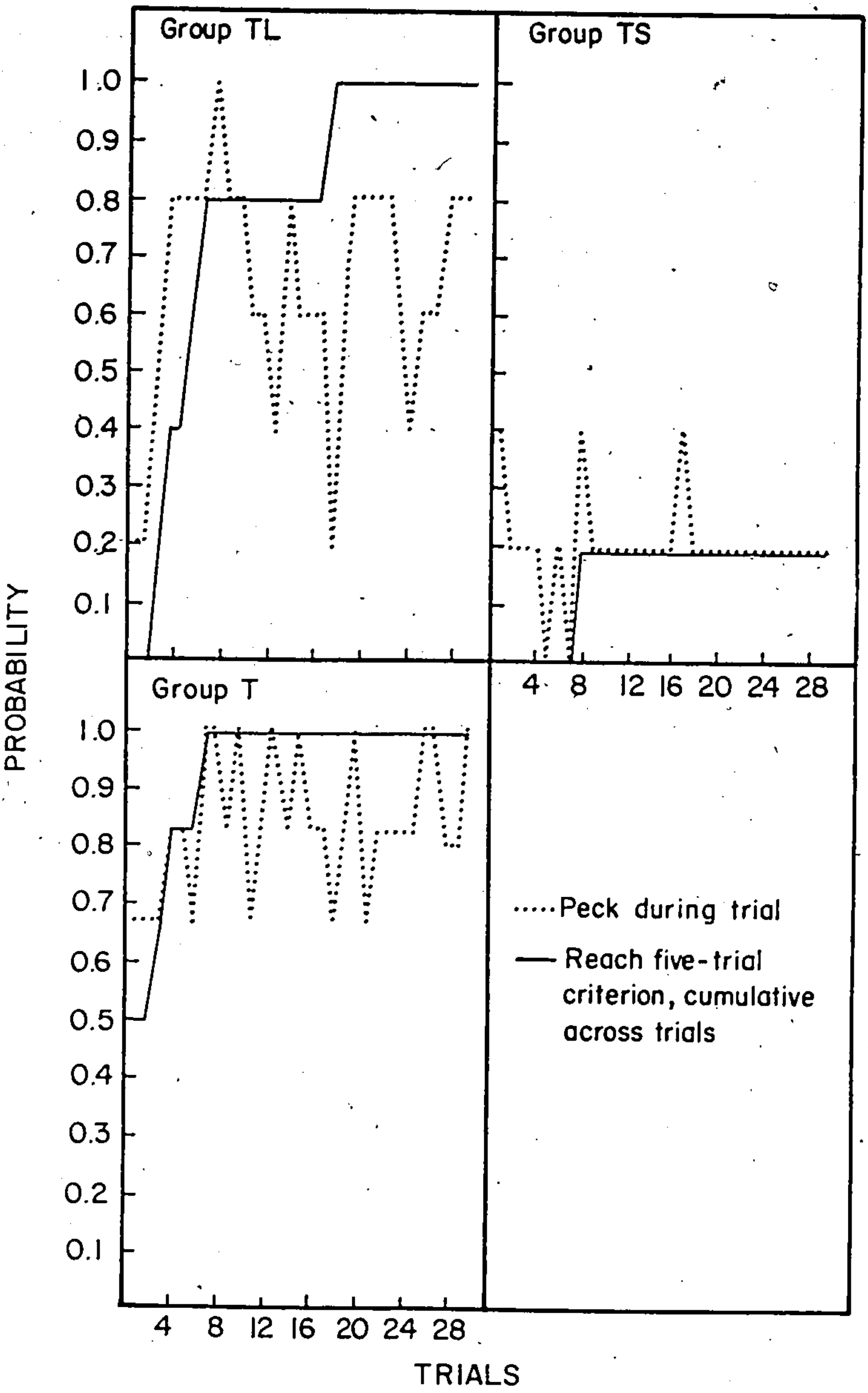
Key-pecks were recorded but never had programmed consequences. Six birds were assigned to Group T, five birds to Group TS, and five birds to Group TL. The birds in all groups were run for 30 sessions, and fed whatever necessary to maintain their weight immediately after each session.

Results

Figure 15 shows a trial-by-trial analysis of the development of

Figure 15

Trial-by-trial analysis of the development of pecking in the first 30 trials (30 sessions) of autoshaping for all groups in Experiment VIII.


Group TL
Group TS
Group T
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
8
12
16
20
24
28
TRIALS
·····Peck during trial
— Reach five-trial criterion, cumulative across trials

pecking for each of the three autoshaping groups. Peck acquisition was very rapid for Group T, and peck probability at Trial 30 was 1.0. Although somewhat slower than Group T, Group TL also showed rapid peck acquisition; in this group, peck probability at Trial 30 was 0.80. In contrast to the other two groups, Group ~~TS~~ showed very slow peck acquisition; peck probability at Trial 30 was 0.20. Statistical comparisons using the five-trial acquisition criterion confirmed these observations. Group TS was significantly different from Group T ($U = 0$, $p < 0.05$; Mann-Whitney U, two-tailed test with adjusted significance levels) and from Group TL ($U = 1$, $p < 0.05$; Mann-Whitney U, two-tailed test with adjusted significance levels). Table 6 summarizes acquisition performance for each group in terms of the proportion of birds reaching criterion and the median and range of the distribution of criterion scores.

Key pecking in the interval between event presentations was infrequent. Most birds never pecked the key, and the rate of pecking within any one session never exceeded 0.10 pecks/second.

Discussion

Peck acquisition was quite rapid when pigeons were exposed to one trial in each daily autoshaping session. When the single trial occurred in the middle of a series of widely spaced reinforcer presentations, peck acquisition was still rapid, although somewhat slower

Table 6

Summary of Acquisition Performance for Autoshaping Groups in Experiment VIII.

	Proportion of Birds Which Meet Criterion Within 30 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds Not Meeting Criterion are Excluded)	
		Median	Range
Group T	1.00	2.5	1- 7
Group TL	1.00	6.0	3-19
Group TS	0.20	8.0*	-*

*In Group TS, only one bird reached the five-trial acquisition criterion within 30 autoshaping trials.

than when the trial occurred in the absence of additional reinforcer presentations. It is of some interest to note that peck acquisition was quite similar in these two conditions despite a drastic reduction in the stimulus-reinforcer contingency in Group TL. In contrast, when the single trial occurred in the middle of a series of closely spaced reinforcer presentations, peck acquisition was very poor. Thus, varying the temporal separation of reinforcer presentations produces large differences in the rate of peck acquisition, even when trial separation remains constant. These results indicate that reinforcer presentations alone are sufficient to define effective waiting periods.

The present results also permit a final consideration of the possibility that local interference might account for the trial spacing effect. Earlier experimental data demonstrate that reinforcers placed before, after, or before and after each trial do not substantially reduce the rate of peck acquisition so long as trials are separated by long temporal intervals. Stimulus presentations placed before or after each trial are likewise ineffective in reducing the rate of peck acquisition. Within the domain of local interference, the only remaining logical possibilities are that interference arises either from stimulus-reinforcer pairings or from a summation of the slight disruptive effects observed when stimulus presentations occur before and after each trial. However, the present results show that a single trial suffers a considerable loss of effectiveness when the trial is embedded within a long series of closely spaced reinforcer presentations. Since trial presentations are separated by 24-hour intervals, the poor peck-acquisition observed in this arrangement cannot be due to interference from temporally proximal stimulus or trial presentations. This finding, together with the earlier results, suggests that local interference notions cannot provide a completely adequate account of the trial spacing effect in autoshaping. Since the immediate context of trial presentation does not seem to be critical to the spacing effect, the effect must be due to some feature of the pattern of events within an entire experimental session.

EXPERIMENT IX

Stimulus Context

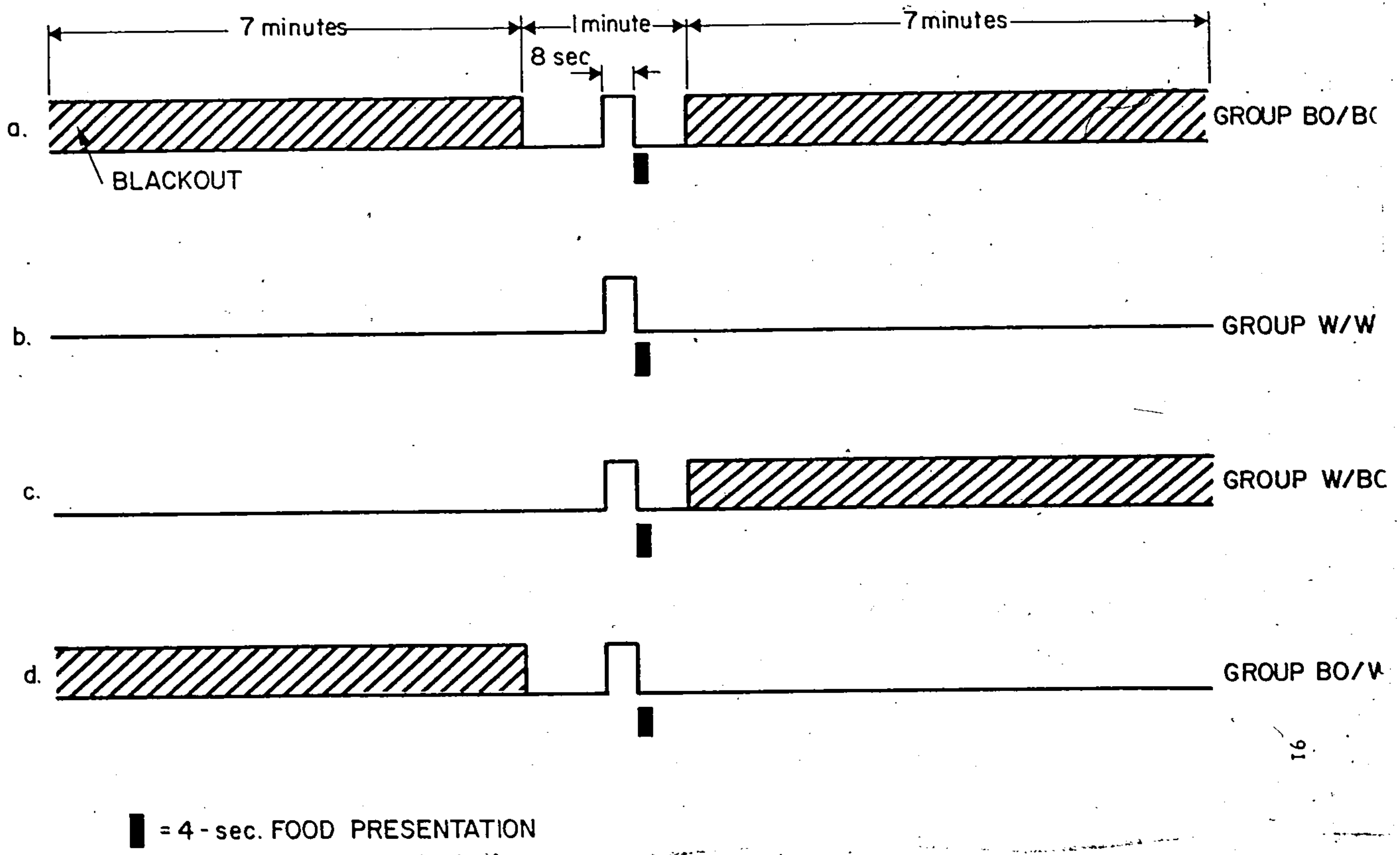
In exploring the characteristics of waiting periods which are important to rapid peck acquisition, the preceding experiments have provided information concerning the number and position of waits and boundary events. Experiment IX is designed to evaluate a third potentially important feature of waiting periods, namely the stimulus context in which the wait occurs. Is rapid peck acquisition dependent on waiting in the stimulus conditions which constitute the background for trial presentations?

The present experiment attempts to assess the importance of such stimulus conditions by varying the situational stimuli during waits across a long series of trial presentations. A diagram of the experimental conditions is shown in Figure 16. One trial occurs within each autoshaping session. In one condition, the houselight and white noise are present continuously, both during the trial and during long waits before and after the trial. If the effectiveness of a waiting period depends on the presence of situational stimuli similar to those occurring during trials, then peck acquisition should be more rapid in the second than in the first of these two autoshaping conditions. Two other conditions are included in order to explore the possibility that not only

Figure 16

Diagram of autoshaping conditions used in Experiment IX.

AUTOSHAPING CONDITIONS



stimulus context, but also the position of the wait is important to peck acquisition. In one condition, the wait in the presence of the houselight and white noise precedes the trial, while a wait in the blackout conditions follows the trial; in the other condition, the blackout precedes the trial, while the wait with houselight and white noise follows the trial.

Method

Subjects: Subjects were 24 experimentally naive White King pigeons, approximately one year of age. The sex of the birds was not determined. All birds were maintained at 75% of their free-feeding weights and fed Purina Pigeon Checkers both in the home cage and during experimental sessions.

Apparatus: The apparatus was the same as that described in Experiment VI.

Hopper training procedure: The hopper training procedure was the same as that described in Experiment VII, with one addition. After the final session of the usual hopper training procedure, all birds received two additional sessions designed to permit adaptation to brief experimental sessions and blackout. During each adaptation session, a bird waited in the experimental chamber for 7 minutes in the absence of houselight and white noise. Following the blackout, the houselight and white noise were operated for 60 seconds; one

4-second hopper presentation was initiated 38 seconds after the onset of houselight and white noise. After the offset of the houselight and white noise, the bird remained in the blackout conditions for 7 minutes before being removed from the experimental chamber and returned to the home cage. The two adaptation sessions were separated by an 11.5-hour interval, and the first autoshaping session occurred 11.5 hours after the last adaptation session.

<u>Autoshaping procedure</u>: Six birds were assigned to each of the four autoshaping conditions. For all autoshaping groups, a trial consisted of an 8-second illumination of the red dot on the response key, followed immediately by a 4-second hopper presentation; one trial occurred in each 15-minute session. For one group (Group BO/BO, Figure 16a.), blackout conditions were in effect for 14 minutes of the experimental session. The houselight and white noise were operated only during a 1-minute interval which began 7 minutes after the onset on the session; the onset of the trial presentation occurred 0.5 minutes after the onset of the houselight and white noise. For the second group (Group W/W, Figure 16b.), houselight and white noise were present continuously throughout the experimental session; the onset of the trial presentation occurred 7.5 minutes after the onset of the session. For a third autoshaping group (Group W/BO, Figure 16c.), the houselight and white noise were present continuously during the first 8.0 minutes of the experimental session; the onset of the trial presentation

occurred 7.5 minutes after the onset of the session. Blackout conditions were in effect during the final 7.0 minutes of the session. For a fourth group (Group BO/W, Figure 16c.); blackout conditions prevailed during the first 7.0 minutes of the experimental session; the houselight and white noise were operated continuously during the remaining 8.0 minutes of the session. The onset of the trial presentation occurred 7.5 minutes after the onset of the session and 0.5 minutes after the onset of houselight and white noise.

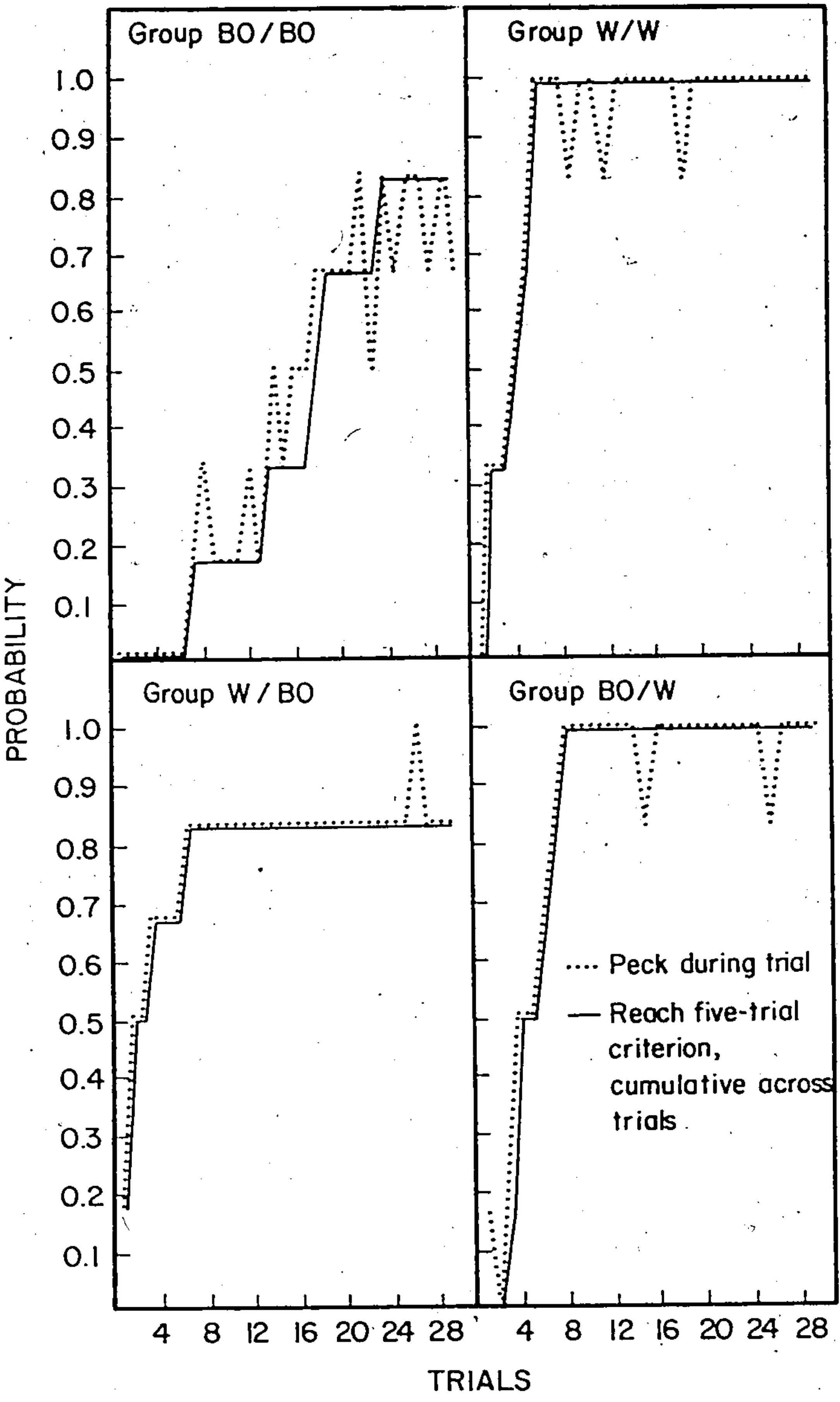
Key pecks were recorded but never had programmed consequences. All autoshaping sessions were separated by 11.5-hour intervals. The birds were run for 30 sessions and fed whatever necessary to maintain their weight immediately after each session.

Results

Figure 17 shows a trial-by-trial analysis of the development of pecking for all autoshaping groups. Peck acquisition was slower in Group BO/BO than in any of the other three autoshaping groups. At Trial 30, peck probability was 0.83 for Group BO/BO, and 1.0, 0.83, and 1. 0 for Groups W/W, W/BO, and BO/W, respectively. The median number of trials required to reach the five-trial acquisition criterion was 18.5 for Group BO/BO, and 3.5, 3.0, and 3.0 for Groups W/W, W/BO, and BO/W, respectively. Statistical comparisons based on distributions of criterion scores showed significant differences between

Figure 17

Trial-by-trial analysis of the development of pecking in the first 30 trials (30 sessions) of autoshaping for all groups in Experiment IX.


Group BO/BO
Group W/W
Group W/BO
Group BO/W
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4 8 12 16 20 24 28
TRIALS
···· Peck during trial
— Reach five-trial criterion, cumulative across trials

Group BO/BO and Group W/W ($U = 0$, $p < 0.01$, Mann-Whitney U, two-tailed test with adjusted significance levels) and between Group BO/BO and Group BO/W ($U = 2$, $p < 0.05$, Mann-Whitney U, two-tailed test with adjusted significance levels). No other comparison was statistically significant. Table 7 summarizes acquisition performance for each group in terms of the proportion of birds reaching criterion and the median and range of the distribution of criterion scores.

Key pecking during non-trial intervals was infrequent. Most birds never pecked the key, and only 4 of the 24 birds had peck rates which exceeded 0.10 pecks/second in any one session. Pecking during waiting periods tended to occur more frequently during early autoshaping sessions than during later sessions.

Discussion

The results of this experiment indicate that the effectiveness of a waiting period is influenced by stimulus context. Waiting in the stimulus situation which constitutes the background for trial presentation leads to rapid peck acquisition, while waiting in a very different stimulus situation leads to much slower peck acquisition. So long as the animal experiences one long wait in the appropriate stimulus context, it seems to be unimportant whether this wait occurs before or after the trial presentation. This latter observation rules out two other possible interpretations of the slow acquisition shown by

Table 7

Summary of Acquisition Performance for Autoshaping Groups in Experiment IX.

	Proportion of Birds Which Meet Criterion Within 30 Trials	Trials to Criterion of Five Consecutive Trials With One or More Pecks (Birds Not Meeting Criterion are Excluded)	
		Median	Range
Group BO/BO	0.83	18.0	7-24
Group W/W	1.00	3.5	2-5
Group W/BO	0.83	2.0	1-7
Group BO/W	1.00	5.0	3-7

Group BO/BO. First, one might argue that a blackout occurring just before or after trial presentation has unconditioned effects which interfere with the development of pecking during the trial. However, if such unconditioned effects did interfere with peck acquisition, then acquisition should be slow in the groups which experienced a blackout either before or after each trial. Since acquisition in Groups W/BO and BO/W is as rapid as acquisition in Group W/W, slow acquisition in Group BO/BO cannot be attributed to the unconditioned effects of blackouts adjacent to the trial.

Secondly, one might argue that poor acquisition in Group BO/BO was due to the fact that the houselight onset served as a signal for the immediately subsequent food presentation. According to this argument the important signalling event is not the situational stimuli which are present during the brief interval when the reinforcer is presented, but the initiation of these stimuli just prior to the reinforcer occurrence. If this were correct, then peck acquisition should be slow in Group BO/W, which, like Group BO/BO, experienced the houselight onset immediately before food was presented. However, the data show that Group BO/W began pecking as soon as Groups W/W and W/BO, which did not experience houselight onset just before food presentation. Thus, poor acquisition in Group BO/BO must be due to the fact that situational stimuli were absent during the waiting periods before and after each trial.

GENERAL DISCUSSION

Conclusions

The central issue of this thesis is how the temporal spacing of stimulus-reinforcer pairings influences the development of the stimulus as a signal for the reinforcer. In agreement with results reported previously by other investigators, the present experiments demonstrate that the initiation of pecking in an autoshaping situation requires many more trial presentations if trials are separated by short, as compared to long, intertrial intervals. The results of Experiments I-VI show that the influence of trial spacing on the development of a signalling stimulus cannot be attributed entirely to variations in the immediate context of trial presentation.

In considering the pattern of events across an entire experimental session, it was noted that the two spacing conditions differ in respect to the presence or absence of a long, event-free interval between trial presentations. Long intervals or waiting periods lead to rapid peck acquisition. Three characteristics of waits were discussed as being potentially important to rapid peck acquisition. The three characteristics are the number and position of waits, the boundary events which define waits, and the stimulus context in which waits occur. Subsequent experiments explored changes in peck acquisition which follow from systematic variation of these characteristics of waits.

Experiments VI and VII concerned the number of waits and their position relative to trial presentations. The results of these experiments show that peck acquisition is equally rapid whether trials are spaced at regular intervals or clustered into six blocks within a long experimental session. A single long waiting period preceding a series of closely spaced trial presentations leads to slightly more rapid peck acquisition than a series of closely spaced trials without a wait; however, a long wait preceding closely spaced trials does not lead to the rapid peck acquisition observed when all trials are separated by waits. Therefore, while it is not necessary for every trial to be temporally isolated, rapid peck acquisition seems to require some alternation between trials and event-free waiting periods.

Experiment VIII concerned the boundary events which define effective waiting periods. One trial is presented in the middle of a long series of reinforcer presentations. Varying the temporal separation of reinforcers produces large differences in the rate of peck acquisition, even though the temporal separation of trials remains constant. Thus, in order for a waiting period to affect the development of pecking, it is sufficient to vary the interval between reinforcer presentations alone.

Finally, Experiment IX concerned the stimulus context of a wait. The results from this experiment demonstrate that waits in the stimulus situation which constitutes the background for trial presentation lead to more rapid peck acquisition than waits in a very different stimulus situation. So-long as the animal experiences waits in the stimulus situation, the location of these waits, before or after the trial, seems to be unimportant.

Theoretical Interpretation:
Stimulus and Response Competition

An earlier section of this thesis described two theoretical accounts which emphasize the role of intertrial waiting periods in their explanations of the trial spacing effect. Both of these accounts assume that long event-free intervals are important to the development of pecking because such intervals permit the extinction of competing associations. The discrimination learning model, based on the work of Rescorla and Wagner (1972; Wagner and Rescorla, 1972), focuses on the extinction of competing stimulus associations; the response competition account discussed by Martin and Golinko (under review) focuses on the extinction of incompatible behaviors. However, the results of Experiments VII-IX suggest that these theoretical explanations should be considered in light of a question which is more basic to the understanding of how signalling relationships develop. This more general question concerns the nature of conditioning to situational stimuli and the relation of such conditioning to a signalling stimulus. Discrimination learning and response competition accounts assume that reinforcers or response-reinforcer sequences may be associated with situational stimuli, and that such associations compete with the signalling stimulus for the control of behavior. However, an alternative possibility is that situational stimuli are associated with reinforcer-reinforcer intervals; in this case, development of a signalling stimulus may depend on the duration of reinforcer-reinforcer (R-R) intervals. The following discussion first reviews these two types of accounts in the context of the present experimental findings. In the concluding section of the thesis, the notion of stimulus-R-R interval associations is contrasted with discrimination learning and response competition accounts, and an experimental test is suggested to evaluate the two types of theoretical explanations.

Let us now consider response and stimulus competition accounts of the experimental data concerning waiting periods. First, both competition accounts predict that the number and position of waiting periods should affect the development of pecking. A single long wait prior to a series of trial presentations leads to improved peck acquisition. Since the pigeons receive numerous food presentations in the experimental chamber during hopper training, competing associations may be quite strong prior to the beginning of autoshaping. A long period of time without food presentations should allow these associations to extinguish. Although peck acquisition improves only slightly when trials are closely spaced following a long wait, this result is not surprising. The onset of autoshaping leads both to conditioning of the key light and to reconditioning of competing stimulus or response associations. In the absence of additional long extinction periods, competing associations might be expected to regain sufficient strength to interfere considerably with the emergence of pecking to the key light. This explanation is consistent with the observation that rapid peck acquisition requires a series of alternations between trials and long waiting periods.

Secondly, the present theoretical accounts anticipate the finding that the effectiveness of waiting periods depends on the temporal spacing of reinforcer presentations. Unsignalled reinforcer presentations increase the strength of competing associations. When reinforcer presentations are closely spaced, the time available for extinction of these associations is minimized. However, when reinforcer presentations are widely spaced, considerable time is available for extinction of competing associations. Consequently, one would expect the observation that peck acquisition during a single trial depends on the temporal spacing of surrounding reinforcer presentations.

Finally, the discrimination learning account of the spacing effect is based on the assumption that waiting periods provide the opportunity for extinction of associations between situational stimuli and reinforcer presentations. Obviously, it follows that a waiting period should improve peck acquisition only to the extent that the stimulus conditions of the wait are the same as the stimulus conditions present during autoshaping trials. The response competition account is consistent with the present results when one assumes that incompatible behaviors are controlled by the stimulus situation in which they emerge. An animal would not emit the incompatible behaviors in a stimulus situation where reinforcers never occurred; such behaviors would not, therefore, be subject to extinction and would interfere with the development of pecking to the key light.

The discrimination learning account and the response competition account are both consistent with the present set of empirical results concerning waiting periods. However, a review of these accounts in light of the results from experiments concerning influence of local events (Experiments I-V) produces some puzzling observations. First, the addition of non-reinforced key-light presentations to the long ITI spacing condition does not greatly reduce the rate of peck acquisition. Neither of the preceding accounts provide a ready explanation for this finding, since non-reinforced stimulus presentations should weaken associations between the key light or key pecking and the occurrence of food. Secondly, the addition of unsignalled food presentations to the long ITI condition also fails to reduce the rate of peck acquisition to a large extent. Again, this finding presents a difficulty for both accounts, since unsignalled food presentations should strengthen associations with situational stimuli or incompatible behaviors, and hence interfere with the development of pecking.

Although findings concerning the effects of local events challenge both discrimination learning and response competition accounts of the trial spacing effect, these findings are not sufficient to reject either theoretical description. Either account might predict such findings if one selects appropriate values for rates of acquisition and extinction to the key light, situational stimuli, key pecking and incompatible behaviors. Consider, for example, an explanation of the effects of unsignalled reinforcer presentations based on the discrimination learning model. The key light stimulus is assumed to be more salient, and thus more easily conditioned, than the background, situational stimuli. Given these parameter values, one would expect the observation that unsignalled food presentations have little effect on the rate of peck acquisition. When the key light is paired with food, the association between key light and food is greatly strengthened, while the association between situational stimuli and food is only slightly strengthened. When food is presented in the absence of the key light, the situational stimuli-food association is somewhat strengthened; however, the association between situational stimuli and food is weakened throughout the reinforcer-free interval between key-light-food pairings. Thus, the key-light-food association is always much stronger than the situational stimuli-food association, despite unsignalled food presentations.

Both discrimination learning and response competition accounts might be elaborated in the manner illustrated above to describe all of the results involving additional intertrial events. In summary, then, both theoretical accounts are capable of explaining not only the basic trial spacing effect, but also the present set of empirical investigations into this phenomenon. Unfortunately, the present results are not sufficient to select one of these explanations over the other. The most direct evidence concerning a response competition account would come from observation of the behavior of individual animals during hopper training and autoshaping. The response competition account would receive strong support if animals were observed to develop behaviors during hopper training or early autoshaping trials which persisted throughout key-light presentations when trials were closely spaced and diminished in frequency when trials were widely spaced. If such behavioral patterns were not evident from the observation of individual animals, then the spacing effect would have to be explained in terms other than overt response competition.

In the absence of observational data to indicate response competition, the two accounts of the trial spacing effect may be compared from a logical perspective. The discrimination learning model is concerned with the basic processes underlying the formation of stimulus-reinforcer associations. As a result, there are two logical arguments which favor discrimination learning over response competition as an account for the trial spacing effect in autoshaping. First, as discussed earlier, the discrimination learning model provides an explanation for behaviors observed in a wide variety of conditioning arrangements, including blocking, overshadowing, and conditioned inhibition (Rescorla and Wagner, 1972; Wagner and Rescorla, 1972). By comparison, response competition is an ad hoc account which may apply to the trial spacing effect but does not offer a general explanation of associative processes.

The second logical reason for favoring the discrimination learning model is more directly related to the autoshaping phenomenon. As was discussed in the introduction to the thesis, several recent review papers agree in concluding that an understanding of autoshaping involves two problems: (a) the stimulus-reinforcer relations sufficient to establish a stimulus as a signal for behavioral change, and (b) the factors which determine the topography of behavior in the presence of a signalling stimulus (Moore, 1973; Hearst and Jenkins, 1974; and Williams, 1974). This analysis implies that stimulus-reinforcer association is essential to initiate the approach and contact behaviors observed in autoshaping situations. Since the discrimination learning model offers a general account of stimulus-reinforcer associations, the model relates directly to the origin of autoshaped behaviors, as well as providing an explanation of the trial spacing effect. The response competition account, however, emphasizes the role of response-reinforcer relations in the initiation of behavioral change. While response-reinforcer contingencies are sufficient to produce behavioral change in many situations, a number of experimental studies demonstrate that such contingencies are not essential to the development of approach and contact behaviors in autoshaping (Williams and Williams, 1969; Herrnstein and Loveland, 1972; Hearst and Jenkins, 1974). Thus, in contrast to the discrimination learning model, the response competition account is based on processes which are not central to the origin of autoshaped behaviors.

In considering the trial spacing effect in autoshaping, the discrimination learning model explains both the origin of behavioral change and variations in the strength of such change within a single theoretical framework. The response competition account suggests a way in which response-reinforcer relations might constrain the development of autoshaped approach and contact, but does not bear on the acquisition of such behaviors. In summary, then, the discrimination learning model provides the more general and parsimonious interpretation of the trial spacing effect in autoshaping.

Theoretical Interpretation: Stimulus - R-R Interval Associations

The preceding discussion concludes that either discrimination learning or response competition accounts are adequate to explain the basic spacing effect and the present experimental results. The discrimination learning model is particularly attractive because it relates the spacing effect to theoretical mechanisms which are perhaps fundamental to a broad range of behavioral phenomena (Rescorla and Wagner, 1972; Wagner and Rescorla, 1972). Let us now turn our attention to an alternative possibility, namely, the idea that associations between situational stimuli and R-R intervals may influence the development of a signalling stimulus.

Consider first how associations between situational stimuli and R-R intervals might lead to the observation of a trial spacing effect in autoshaping. When trials are separated by long intertrial intervals, situational stimuli are associated with long R-R intervals. In this condition, the brief key-light stimulus provides considerable information about the time of food arrival; peck acquisition is, therefore, fast.

Experiments I-V tested local interference accounts of the spacing effect by placing extra key-light or food presentations between widely spaced trials. Either of these arrangements produces only a slight change in the information value of the brief key-light stimulus relative to the R-R interval; hence the findings from these experiments are readily explained in terms of the present theoretical account. The duration of the R-R interval may be defined as either the average time between reinforcer presentations or the maximum time separating two reinforcer presentations; regardless of which of these definitions one selects, the addition of unsignalled reinforcers to a long ITI condition reduces the R-R interval. Thus, one expects the result that peck acquisition is somewhat slower with this arrangement than acquisition in the standard long ITI condition. However, the addition of four unsignalled reinforcers does not reduce the R-R interval to the duration in effect for the short ITI condition. Since the key light remains relatively informative about the time of food arrival, peck acquisition in groups receiving extra reinforcers is much more rapid than acquisition in the short ITI reference groups. When non-reinforced key-light presentations are added to the long ITI situation, peck acquisition is somewhat slower than in the standard long ITI condition, presumably because the key light is, in this case, somewhat less informative about the time of food arrival. However, since the R-R interval is long, acquisition in the presence of additional key-light stimuli is still much more rapid than acquisition in the short ITI reference condition.

One further point is worth mentioning while considering the stimulus - R-R interval account in light of the results from Experiments I - V. The data from these experiments on local interference indicate that introducing extra events slows peck acquisition somewhat even though trials are widely spaced; the reduction does not, however, depend on the temporal location of extra events in relation to trials. As was noted in an earlier discussion, this conclusion is difficult to explain in terms of stimulus or response competition models. Reinforcers occurring just prior to a trial should strengthen interfering associations; the failure to observe such an effect can be explained only by making special assumptions about stimulus saliences, acquisition rates, and extinction rates. However, the stimulus - R-R interval account requires no special assumptions to account for this finding. The development of a signalling stimulus is assumed to follow from stimulus-reinforcer pairings occurring in the context of long R-R intervals. The introduction of extra reinforcers is expected to slow acquisition to some extent, because of the resulting reduction in the R-R interval; however, the placement of the extra reinforcers is held to be unimportant.

The assumption that situational stimuli are associated with R-R intervals is also consistent with the results of experiments concerning the characteristics of effective waiting periods. Experiments VI and VII concerned the effects of varying the number and position of waiting periods. In Experiment VI, trials were presented closely spaced in blocks within a long experimental session. As predicted by the present account, this arrangement does not slow the rate of peck acquisition, presumably because the R-R interval is still much longer than in the short ITI condition. However, when all trials occur closely spaced at the end of a long experimental session, peck acquisition is slow. Earlier discussions of this finding suggested that rapid peck acquisition requires an alternation between trials or reinforcers and waiting periods. In an account emphasizing the importance of long reinforcer-reinforcer intervals, it is therefore necessary to argue that experience with several long R-R intervals is required in order to establish conditions which favor rapid development of the key light as a signalling stimulus.

Finally, results from experiments concerning boundary events and stimulus context are quite readily interpreted in terms of associations between situational stimuli and R-R intervals. When a single key-light-food pairing occurs in the middle of a long series of reinforcer presentations, one would clearly expect the spacing of the unsignalled reinforcers to have a large effect on peck acquisition. This prediction is supported by data from Experiment VIII: long R-R intervals lead to rapid peck acquisition, while short R-R intervals lead to slow peck acquisition during the single daily trial. Since R-R intervals are assumed to be associated with situational stimuli, it follows that situational stimuli would have to be present in at least some of the waiting periods which separate experimental events. As predicted by this assumption, the results of Experiment IX show that when the situational stimuli are substantially altered during all waiting periods, the development of pecking during the trial is slow. Conversely, when situational stimuli are present during some or all waiting periods, the development of pecking is rapid. In summary, then, the data from the present series of experiments can be adequately explained in terms of associations between situational stimuli and reinforcer-reinforcer intervals.

Concluding Comments

The preceding discussions conclude that either competition or R-R interval accounts are adequate to explain what is presently known about the trial spacing effect in autoshaping. It is now appropriate to consider differences between these theoretical viewpoints. A major point of contrast between the two types of accounts concerns the temporal relation between waiting periods and trials. Competition models assume that potentially interfering behaviors or stimuli must be present just prior to the occurrence of the reinforcer in order to form competing associations. Rapid peck acquisition therefore requires that waiting periods occur before trials so that potentially interfering behaviors or stimuli are, by virtue of extinction, weak at the time of the key-light - reinforcer pairing. In contrast, the R-R interval account argues that acquisition depends on the duration of the R-R interval. It is presumably unimportant whether waits occur before or after trials, since rapid peck acquisition requires only that key-light -

reinforcer pairings occur in the context of long R-R intervals.

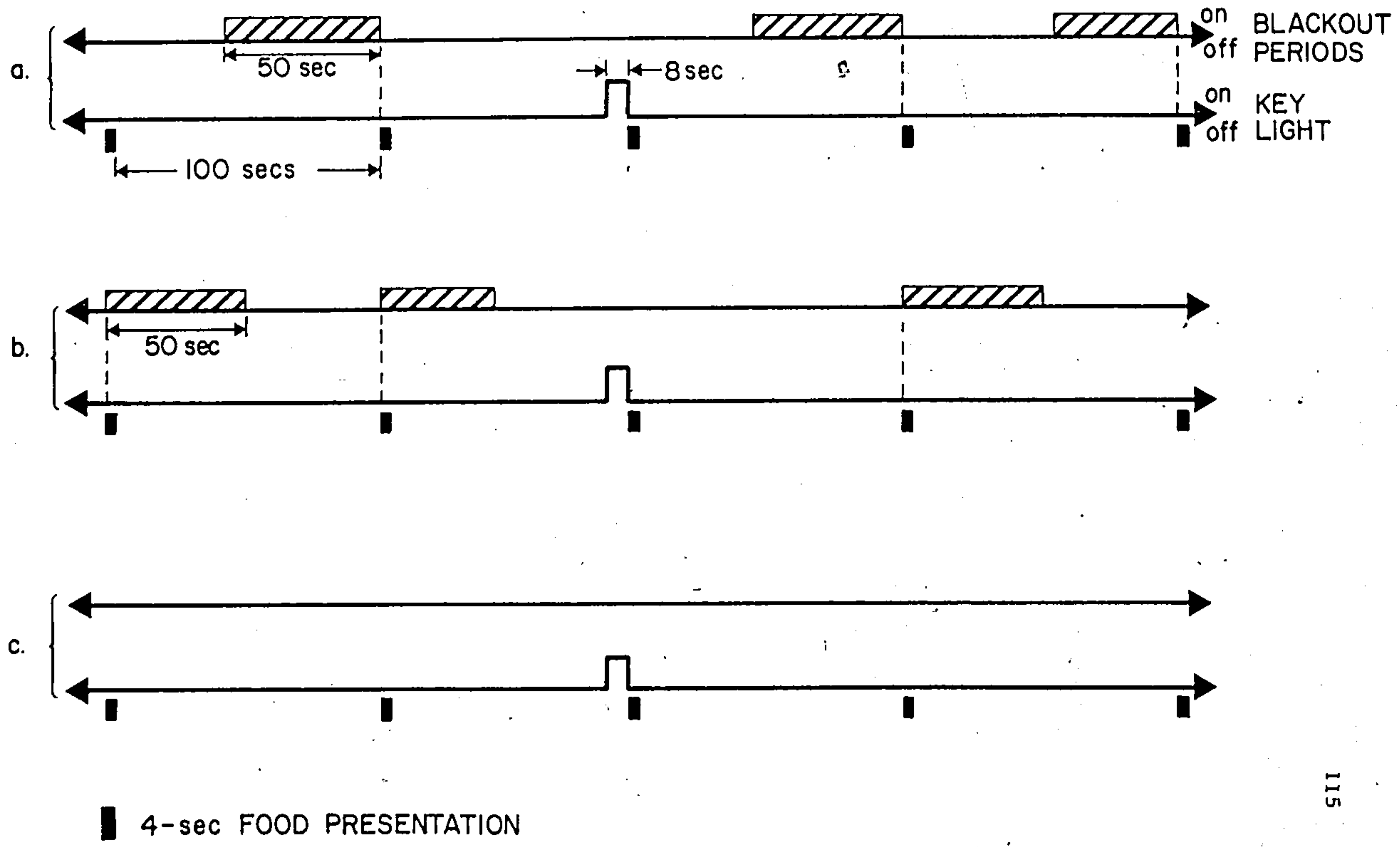
This theoretical discussion suggests that the two types of accounts could be experimentally tested in an arrangement where the location of waits is manipulated in relation to trial presentations. The design shown diagrammatically in Figure 18 gives one example of such a test. For each of three groups, a daily autoshaping session consists of a long series of uniformly spaced reinforcer presentations. A brief key-light illumination precedes one reinforcer presentation in the middle of each session. For one group (Figure 18a.), the remaining reinforcer presentations are preceded by a blackout period which occupies the second half of the R-R interval and ends at the onset of the reinforcer; the houselight and white noise operate during the reinforcer presentation and the first half of the next R-R interval. For a second group (Figure 18b.), the remaining reinforcers (excluding the stimulus-reinforcer pairing) are followed by a blackout period; the houselight and white noise operate in the second half of the R-R interval until the offset of the reinforcer presentation. For a third, reference group, (Figure 18c.), no blackout periods occur at any time during autoshaping.

In Figure 18, a 100-second R-R interval is suggested to separate all reinforcer presentations. On the basis of previously reported experimental results, one would expect that this reinforcer spacing would lead to a moderate rate of peck acquisition during trials for the reference group. If the assumptions of competition models are correct, the group

Figure 18

Diagram of autoshaping conditions for experiment discussed in the final section of the General Discussion.

AUTOSHAPING CONDITIONS



experiencing blackout periods just before reinforcer presentations should show more rapid peck acquisition than the reference group because the blackout reduces the likelihood that situational stimuli or non-pecking behaviors are associated with reinforcers. The group experiencing blackouts just after reinforcer presentations should show less rapid peck acquisition than the reference group because the time available for extinction of competing associations is reduced. If, on the other hand, the R-R interval account is correct, both blackout groups should show slightly slower acquisition than the reference group. While the temporal location of waiting periods is not expected to have any effect, the reduction of waiting time in the presence of appropriate situational stimuli might be expected to slow the rate of peck acquisition in both blackout groups.

In conclusion, the present series of experiments provide considerable information about how the temporal spacing of trials influences the development of a signalling stimulus. In general, the results are consistent with theoretical interpretations which attribute the spacing effect to differential interference from competing stimulus or response associations. However, a more general issue, which requires further investigation, is the nature of conditioning to situational stimuli and the relation of such conditioning to the signalling stimulus. While competition models provide one perspective on this problem, the present data are not sufficient to reject alternative formulations. One alternative account has been discussed here in some detail. However, a final judgement will require more rigorous analysis of the role of situational stimuli in the control of behavior.

FOOTNOTES

[1] While the present analysis emphasizes the number of trials required to initiate pecking, it should be noted that trial spacing also affects the likelihood that key pecking will occur at all within the course of the experiment. In the reference groups described in Experiments I-V, the proportion of birds reaching the five-trial acquisition criterion within 240 trials (12 autoshaping sessions) was 0.93 in Group L but 0.70 in Group S.

Despite the fact that the majority of birds in Group S never initiated persistent key pecking, observation of individual animals showed that a bird invariably changed its pattern of behavior at the onset of the key-light stimulus. The behavioral changes included approach and orientation to the key, stereotyped patterns of head bobbing in front of the key, and pecks directed to, but not contacting the key. Thus, the key light exerted some control over behavior for all subjects in Group S, even though most birds rarely contacted the key. Since the observed non-pecking behaviors closely resemble the pre-pecking behaviors described by Wessells (1974), it seems reasonable to argue that such behaviors reflect weak stimulus-reinforcer associations. It appears that the key light does become a signal for behavioral change when trials are closely spaced, but not so strong a signal as when trials are widely spaced.

[2] The results of an unpublished experiment conducted by Dr. H. M. Jenkins provide further support for this conclusion. Two groups of naive pigeons were trained to eat from the food hopper and then exposed to the following autoshaping conditions. For both groups, one trial (key-light - food pairing) occurred in the middle of each daily, 12-minute experimental session. One group received only the single trial presentation, while another group received an additional food presentation which terminated immediately prior to the occurrence of the single trial. The results of this experiment showed that peck acquisition was rapid for both autoshaping groups. Thus, even when no delay separates a reinforcer from the subsequent trial presentation, there is no substantial interference with the development of autoshaped key pecking.

[3] McAllister, McAllister, Weldin, and Cohen (1974) have reported an experiment which attempts to test the discrimination learning account of the spacing effect. Rats were first exposed to pairings of a light presentation (CS) and shock; the interval between pairings varied from 15 to 225 seconds for six independent groups. The strength of conditioning was tested by measuring the latency to escape from the gray conditioning chamber to an adjoining white chamber where the animals had never received shocks. For half of the animals in each group, the CS was present from the onset of the test trial to the completion of the escape response. For the remaining

animals, the CS was not presented during test trials. Responding in the latter groups presumably reflects the strength of association between situational stimuli and shock. For the groups where the CS was present during test trials, the latency of the escape response decreased as a function of training ITI values between 15 and 105 seconds, and was stable at training ITI values between 105 and 225 seconds. For groups where the CS was absent during test trials, the latency of the escape response decreased as a function of training ITI values up to 165 seconds and increased at the training ITI value of 225 seconds.

Although these data demonstrate that animals may form associations between situational stimuli and reinforcer presentations, the results provide little support for an account of the spacing effect in terms of the differential extinction of such associations. The theoretical account outlined previously predicts that the strength of conditioning to situational stimuli should decline as the strength of conditioning to the CS increases across ITI values. However, McAllister, et al. report that responding to situational stimuli decreases at a point where responding to the CS no longer shows the effect of changes in the ITI value during training.

Some aspects of the procedure used in this experiment suggest that the results cannot be taken as a disconfirmation of the present theoretical account. One difficulty is that the validity of the results depend on the animal's ability to distinguish between the gray conditioning chamber and the white "safe" chamber. Since the CS was presentation of a light which greatly increased the brightness of the gray conditioning chamber, the contrast between the two chambers may not have been very great for groups tested with the CS present until the completion of the escape response. This aspect of the procedure may have made the testing arrangement less sensitive to the effects of the ITI value present during training.

However, another difficulty is more serious. McAllister et al. assume that the same response may be used as an index of conditioning to both the CS and the situational stimuli. If this assumption is taken to be correct, then the Rescorla and Wagner model cannot account for the spacing effect. Since situational stimuli and the temporally discrete CS occur simultaneously, the total amount of excitation present during a trial is assumed to be the same for all groups. In a short ITI group, much of the available excitation is assumed to be associated with situational stimuli and less excitation is associated with the CS. In a long ITI group, less excitation is associated with situational stimuli, and much is associated with the CS. What then distinguishes short from long ITI groups is the division of excitation between situational stimuli and the CS. However, if both sets of associations control the same pattern of behavior, the spacing effect should never be observed; since the total amount of excitation available during a trial is the same for both groups.

the strength of responding should be likewise identical for both groups.

If the spacing effect is due to differential opportunity for extinction of conditioning to situational stimuli, then one must assume that situational stimuli and the CS control different patterns of behavior. Because McAllister, et al. use the same response as an index of conditioning to both sets of stimuli, their study does not provide an appropriate test of this theoretical account of the spacing effect. However, the discussion of this problem does raise the question of whether the situational stimuli and the key light can be assumed to control different patterns of behavior in the autoshaping situation.

One available study suggests that conditioning to stimuli such as a diffuse light does indeed lead to behavioral patterns other than key pecking. Wasserman (1973) exposed pigeons to pairings of a key light and food in a chamber which was not illuminated by a houselight. In the absence of a houselight, key light presentation had the effect of providing diffuse illumination in the chamber. Under these conditions, pigeons developed distinctive patterns of behavior in the presence of key light illumination, but rarely pecked the key. In contrast, when the chamber was continuously illuminated by a houselight, key-light - food pairings produced strong key pecking. These results suggest that in an autoshaping arrangement with pigeons, spatially localized visual stimuli lead to pecking while diffuse visual stimuli lead to other patterns of behavior.

APPENDIX

Hopper Training Procedure for Experiment VI

For the purposes of another experiment, the hopper training procedure was arranged to train the birds on a discrimination between two colors of houselight illumination. At any particular time during a session, the chamber was illuminated by one of three houselight colors: white, red, or blue. The colors perceived as red and blue by human observers are associated with wavelengths which seem to be maximally discriminable to pigeons (Wright and Cumming, 1971). The white houselight consisted of an 1820 lamp, operated at 32 volts DC. The red and blue houselights consisted of 313 lamps, operated at 32 volts DC, and colored appropriately with DriMark waterproof marking pens. The lamps were washed and recolored as often as necessary to maintain the designated color of chamber illumination. The intensity of light produced by 313 lamps is much greater than that produced by 1820 lamps. Thus, the brightness of chamber illumination was about the same for all three houselight conditions, since the intensity of the 313 lamps was diminished when the bulbs were colored.

During discrimination training, the food hopper was presented in the presence of one houselight color (S+) and never presented during a second houselight color (S-). The third houselight color (S_o) was used only during the autoshaping phase of the experiment. The colors and positions of houselights associated with S +, S-, and S_o conditions were counterbalanced for all groups. In Session 1, all birds were placed in the experimental chamber for 50 minutes during which only the S- houselight and the white noise were operative. In Sessions 2-11, the birds were exposed to alternating presentations of S+ and S- houselight illumination. The durations of S+ and S- periods were determined by a geometric distribution of 30-second intervals where the probability of a stimulus change was 0.33. During each 30-second S+ interval, the probability of a hopper presentation was 0.57; approximately 30 4-second hopper presentations occurred in each session. The mean duration of S + and S- periods was 90 seconds and sessions were about 70 minutes in duration. All birds were observed during Session 4 to see that they were eating from the food hopper. Two birds were not eating during hopper presentations; one bird started eating after receiving manual hopper training (as described in the General Method, Experiments I-V) and the other bird was replaced after failing to begin eating during manual training.

When this discrimination procedure failed to produce behavioral differences between stimulus conditions, discrimination training was continued for another ten sessions with some procedural changes. S+ periods were reduced so that the mean duration was 45 seconds; the probability of hopper presentation was 0.57 for every 15-second S +

interval. S- periods were lengthened so that the mean duration was 225 seconds.

Throughout hopper training, the birds were run daily and fed whatever necessary to maintain their weight immediately after each session.

BIBLIOGRAPHY

Bilbrey, J. and Winokur, S. Controls for and constraints on autoshaping. Journal of the Experimental Analysis of Behavior, 1973, 20, 323-332.

Blanchard, R. and Honig, W. K. Surprise value of food determines its effectiveness as a reinforcer. Journal of Experimental Psychology: Animal Behavior Processes, 1976, 2, 67-74.

Brown, P. L. and Jenkins, H. M. Auto-shaping of the pigeon's key peck. Journal of the Experimental Analysis of Behavior, 1968, 11, 1-8.

Catania, A. C. Self-inhibiting effects of reinforcement. Journal of the Experimental Analysis of Behavior, 1973, 19, 517-526.

Davis, M. Effects of interstimulus interval length and variability on startle-response habituation in the rat. Journal of Comparative and Physiological Psychology, 1970, 72, 177-192.

Dweck, C. S. and Wagner, A. R. Situational cues and correlation between CS and US as determinants of the conditioned emotional response. Psychonomic Science, 1970, 18, 145-147.

Egger, M. D. and Miller, N. E. When is a reward reinforcing?: An experimental study of the information hypothesis. Journal of Comparative and Physiological Psychology, 1963, 56, 132-137.

Estes, W. K. Toward a statistical theory of learning. Psychological Review, 1950, 57, 94-107.

Estes, W. K. Statistical theory of distributional phenomena in learning. Psychological Review, 1955, 62, 369-377.

Farrell, L. The role of partial reinforcement in the acquisition of an autoshaped response. Paper read at the Eastern Psychological Association meeting, New York, New York, 1974.

Gamzu, E. and Williams, D. R. Classical conditioning of a complex skeletal response. Science,. 1971, 171, 923-925.

Glickman, S. E. Perseverative neural traces and consolidation of the memory trace. *Psychological Bulletin*, 1961, *58*, 218-233.

Gonzalez, F. A. Effects of varying the percentage of key illuminations paired with food in a positive automaintenance procedure. *Journal of the Experimental Analysis of Behavior*, 1974, *22*, 483-489.

Gormezano, I. and Moore, J. W. Empirical relationships. In M. H. Marx (Ed.), *Learning: Processes*. Toronto: Collier-Macmillan Canada, Ltd., 1969., Pp. 133-168.

Griffin, R. W. Classical conditioning of directed motor behavior in pigeons and rats: Effects of intertrial interval duration and variation. Paper presented at the Eastern Psychological Association Meeting, New York, New York, April, 1975.

Hearst, E. and Jenkins, H. M. Sign-tracking: The stimulus-reinforcer relation and directed action. Austin, Texas: The Psychonomic Society, 1974.

Herrnstein, R. J. and Loveland, D. H. Food-avoidance in hungry pigeons, and other perplexities. *Journal of the Experimental Analysis of Behavior*, 1972, *18*, 369-383.

Jenkins, H. M. and Moore, B. R. The form of the auto-shaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior*, 1973, *20*, 163-181.

Kamin, L. J. Predictability, surprise, attention, and conditioning. In B. A. Campbell and R. M. Church (Eds.), *Punishment and Aversive Behavior*. New York: Appleton-Century-Crofts, 1969. Pp. 279-296.

Kettlewell, N. M. and Papsdorf, J. D. The effects of an interpolated ITI stimulus on classical conditioning of the nictitating membrane response of the rabbit. *Psychonomic Science*, 1967, *9*, 257-258.

Krauss, H. H. and Prokasy, W. F. On intertrial interval discrimination in classical conditioning. *Psychological Reports*, 1963, *12*, 138.

Martin, J. M. and Golinko, B. E. Emergence of key pecking under different response-independent interreinforcement times. Submitted to, *Journal of the Experimental Analysis of Behavior*.

McAllister, W. R., McAllister, D. E., and Weldin, G. H. Intertrial interval effects in classically conditioning fear to a discrete conditioned stimulus and to situational cues. Journal of Comparative and Physiological Psychology, 1974, 87, 582-590.

Miller, R. R. and Springer, A. D. Amnesia, consolidation, and retrieval. Psychological Review, 1973, 80, 69-79.

Mitchell, D. S. Conditional responding and intertrial-interval variability in classical conditioning in the rabbit (Oryctolagus cuniculus). Journal of Comparative and Physiological Psychology, 1974, 87, 73-79.

Moore, B. R. The role of directed Pavlovian reactions in simple instrumental learning in the pigeon. In R. A. Hinde and J. Stevenson-Hinde (Eds.), Constraints on Learning. New York: Academic Press, 1973, Pp. 159-188.

Ost, J. W. P. Consolidation disruption and inhibition in classical conditioning. Psychological Bulletin, 1969, 72, 379-383.

Papsdorf, J. D. and Kettlewell, N. M. The effects of different interpolated ITI stimulus-conditioned stimulus intervals on the acquisition of the classically conditioned nictitating membrane response of the rabbit. Psychonomic Science, 1968, 10, 171-172.

Perkins, C. C., Jr., Beavers, W. O., Hancock, R. A., Jr., Hemmendinger, P. C., Hemmendinger, D. and Ricci, J. A. Some variables affecting the rate of key pecking during response independent procedures (autoshaping). Journal of the Experimental Analysis of Behavior, 1975, 24, 59-72.

Prokasy, W. F. Stimulus fluctuation, reactive inhibition, and time between trials in classical eyelid conditioning. Journal of Experimental Psychology, 1965, 70, 464-472.

Prokasy, W. F. and Whaley, F. L. The intertrial interval in classical conditioning. Journal of Experimental Psychology, 1961, 62, 560-564.

Rescorla, R. A. and Wagner, A. R. A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black and W. F. Prokasy (Eds.), Classical Conditioning II: Current Theory and Research. New York: Appleton-Century-Crofts, 1972. Pp. 64-99.

Ryan, T. A. Significance tests for multiple comparison of proportions, variances, and other statistics. Psychological Bulletin, 1960, 57, 318-328.

Skinner, B. F. "Superstition" in the pigeon. Journal of Experimental Psychology, 1948, 38, 168-172.

Sokolov, Y. N. Perception and the Conditioned Reflex. (Translated by S. W. Waydenfeld) New York: The MacMillan Company, 1963.

Synder, R. E. and Papsdorf, J. D. The interaction of ITI interpolated stimuli and ISI on classical conditioning of the nictitating membrane membrane response of the rabbit. Psychonomic Science, 1968, 12, 191-192.

Terrace, H. S., Gibbon, J., Farrell, L. and Baldock, M. D. Temporal factors influencing the acquisition of an auto-shaped response. Animal Learning and Behavior, 1975, 3, 53-62.

Thompson, R. F. and Spencer, W. A. Habituation: A model phenomenon for the study of the neuronal substrates of behavior. Psychological Review, 1966, 73, 16-43.

Wagner, A. R. Stimulus validity and stimulus selection. In W. K. Honig and N. J. Mackintosh (Eds.), Fundamental Issues in Associative Learning. Halifax: Dalhousie Press, 1969.

Wagner, A. R. and Rescorla, R. A. Inhibition in Pavlovian conditioning: Application of a theory. In R. A. Boakes and M. S. Halliday (Eds.), Inhibition and Learning. London: Academic Press, 1972. Pp. 301-336.

Wagner, A. R., Rudy, J. W., and Whitlow, J. W. Rehearsal in animal conditioning. Journal of Experimental Psychology, 1973, 97, 407-426.

Wasserman, E. A. The effect of redundant contextual stimuli on autoshaping the pigeon's keypeck. Animal Learning and Behavior, 1973, 1, 198-206.

Wessells, M. G. The effects of reinforcement upon the prepecking behaviors of pigeons in the autoshaping experiment. Journal of the Experimental Analysis of Behavior, 1974, 21, 125-144.

Williams, D. R. Biconditional behavior: Conditioning without constraint. Personal communication, September, 1974.

Williams, D. R. and Williams, Harriet. Auto-maintenance in the pigeon: sustained pecking despite contingent non-reinforcement. Journal of the Experimental Analysis of Behavior, 1969, 12, 511-520.

Wright, A. A. and Cumming, W. W. Color-naming functions for the pigeon. Journal of the Experimental Analysis of Behavior, 1971, 15, 7-17.