

THE UNIVERSITY OF MANITOBA

STRUCTURE OF AN OPERANT

by

Brian L. Rector

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF ARTS

DEPARTMENT OF PSYCHOLOGY

WINNIPEG, MANITOBA

October, 1977

STRUCTURE OF AN OPERANT

BY

BRIAN L. RECTOR

A dissertation submitted to the Faculty of Graduate Studies of  
the University of Manitoba in partial fulfillment of the requirements  
of the degree of

MASTER OF ARTS

© 1977

Permission has been granted to the LIBRARY OF THE UNIVERSITY OF MANITOBA to lend or sell copies of this dissertation, to the NATIONAL LIBRARY OF CANADA to microfilm this dissertation and to lend or sell copies of the film, and UNIVERSITY MICROFILMS to publish an abstract of this dissertation.

The author reserves other publication rights, and neither the dissertation nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

## TABLE OF CONTENTS

CHAPTER		PAGE
	ABSTRACT . . . . .	i
	ACKNOWLEDGEMENTS . . . . .	iii
I	INTRODUCTION . . . . .	1
	Statement of the Problem . . . . .	11
II	FIXED-INTERVAL BEHAVIOR . . . . .	13
	Variables Which Affect Responding . . . . .	16
	1. Response Unit Required for Reinforcement . . . . .	16
	2. Inter-reinforcement Interval . . . . .	19
	3. The Reinforcing Stimulus . . . . .	24
	Summary . . . . .	27
III	METHOD . . . . .	29
	Subjects . . . . .	29
	Apparatus . . . . .	29
	Procedure . . . . .	33
IV	RESULTS . . . . .	36
	Phase I . . . . .	36
	Phase II . . . . .	72
	Phase III . . . . .	83
V	GENERAL DISCUSSION . . . . .	93
	REFERENCES . . . . .	105

LIST OF FIGURES

FIGURE		PAGE
1	Diagram of the experimental environment . . . . .	30
2	Cumulative record of early FI 1-min performance for P10 .	37
3	Cumulative record of early FI 1-min performance for P30 .	39
4	Cumulative record of early FI 1-min performance for P31 .	41
5	Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval during early FI 1-min performance for all birds. .	43
6	Total photocell time across successive thirds of the inter-reinforcement interval during early FI 1-min performance for all birds. . . . .	46
7	Cumulative record of scallop response pattern during FI 1-min for P10. . . . .	49
8	Cumulative record of scallop response pattern during FI 1-min for P30 . . . . .	51
9	Cumulative record of scallop response pattern during FI 1-min for P31 . . . . .	53
10	Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval from a session demonstrating a scallop response pattern during FI 1-min for each bird. . . . .	55
11	Total photocell time and response rate across successive thirds of the inter-reinforcement interval from a session demonstrating a scallop response pattern during FI 1-min for each bird . . . . .	58
12	Cumulative record of break-run response pattern during FI 1-min for P30 . . . . .	61
13	Cumulative record of break-run response pattern during FI 1-min for P31 . . . . .	63
14	Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval for sessions demonstrating scallop and break-run response patterns for P30 and P31 . . . . .	65

LIST OF FIGURES (CONTINUED)

FIGURE		PAGE
15	Total photocell time and response rate across successive thirds of the inter-reinforcement interval for P30 and P31 . . . . .	63
16	Total photocell time and overall response rate for each session of Phase II for P10 and P31 . . . . .	73
17	Percentage of time photocells 1, 2, and/or 3 were operated across successive thirds of the inter-reinforcement interval for each session of Phase II for P10 and P31 . . . . .	75
18	Cumulative record of Session 1 of Phase II for P10 . . .	78
19	Cumulative record of Session 1 of Phase II for P31 . . .	81
20	Cumulative record of break-run response pattern during FI 1-min for P10 during Phase III . . . . .	85
21	Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval over the last 5 sessions of Phases I and III for P10 and P31 . . . . .	87
22	Total photocell time and response rate across successive thirds of the inter-reinforcement interval averaged across the last 5 sessions of Phase III for P10 . . .	89

## STRUCTURE OF AN OPERANT

by

Brian L. Rector

### ABSTRACT

Key pecking was maintained on a FI 1-min schedule of food presentation for three pigeons. Head movements related to the key-pecking operant were recorded by ten photocells which extended outward from the response key. The amount of time the bird was in front of each photocell was recorded across successive thirds of the inter-reinforcement interval. For all three birds the structure of the key-pecking operant changed systematically throughout the development of FI behavior. During early FI performance structure remained constant across the inter-reinforcement interval. Cumulative records during this time demonstrated linear response patterns. During intermediate FI performance head movements moved relatively closer to the response key as the inter-reinforcement interval progressed. These structural changes were associated with a scallop response pattern. By steady-state FI performance the entire activity had shifted proportionally closer to the response key relative to earlier performances. Head movements, however, still moved proportionally closer to the response key as the inter-reinforcement interval progressed. Cumulative records demonstrated a break-run response pattern.

An extinction procedure was implemented during Phase II of the experiment for two of the birds. The structure of the operant remained

constant for one bird as response rate decreased. For the other bird, systematic structural changes occurred in the operant as response rate decreased.

The above findings have implications for many areas of behavior theory.

## ACKNOWLEDGEMENTS

I wish to thank my advisor, Dr. J.J. Pear, for his valuable assistance and comments throughout this investigation. His patience was greatly appreciated. I also thank the other members of my committee, Dr. D. Dyck and Dr. E. Boldt, for their comments. The interesting comments of Dr. R. Tait are also acknowledged.

This investigation was supported by National Research Council of Canada grant number A7461 to Dr. J.J. Pear. The author was also supported by a National Research Council scholarship.

I wish to thank my parents for their constant encouragement and assistance with the figures. The comments of Debby Olenick on earlier drafts of the thesis was appreciated.



## CHAPTER I

### INTRODUCTION

The experimental analysis of behavior has emerged only recently as an area of investigation among the sciences. Numerous approaches and diverse verbal repertoires have developed within the area. Despite these differences, however, the common goal of the behavioral scientist is to precisely describe and control behavioral phenomena. To achieve precise description and control the area must analyze its techniques critically and devise new methodologies to overcome identified problems. In some cases, this new technology may introduce the scientist to new behavioral phenomena.

One area of the experimental analysis of behavior has used response rate (number of responses per unit of time) as a dependent variable in the investigation of behavioral phenomena (Skinner, 1938; Ferster & Skinner, 1957; Honig, 1966; Honig & Staddon, 1977). Typically a response is defined as an instantaneous element in the behavior of the organism (e.g., a bar press or a key peck). Rate of this response is examined as a function of variables manipulated by the experimenter. This approach to the analysis of behavior has a number of advantages (Skinner, 1953a) and has resulted in the establishment of functional relationships between environment and behavior. A number of problems have arisen, however, with the examination of behavior as an instantaneous event, and with the use of rate as a dependent variable:

- 1) The rate of an instantaneous event may not adequately

represent the frequency of occurrence of an operant. The operant is a behavioral unit of analysis defined in terms of three components: a response, consequences which affect the probability of that response, and stimuli which precede and affect the probability of the response. These three components taken together form a contingency which specifies an operant. If the response component of the operant is defined as a behavioral pattern such as a scallop -- i.e., reinforcement is contingent upon a constantly increasing rate of key pecking within a time interval -- mean response rate will not measure the strength of this operant (Hawkes & Shimp, 1975). An alternative measure is required to determine the strength of this behavior pattern.

2) Rate may be the product of two independent variables. For example, the rate of key pecking is calculated as the number of key pecks emitted per unit of observation time which is typically session length. However, if one considers that a pigeon can engage in activities other than key pecking (e.g., preening, scratching, etc.), then rate of key pecking is a function of two variables: (i) the relative amount of time the subject engages in key pecking and (ii) the number of key pecks emitted per unit of key-pecking time. These variables are the perseverance and tempo, respectively, of behavior (Gilbert, 1958), or the propensity and speed of an activity (Pear, 1977). How do these two variables change when rate changes? For example, when response rate increases on a given occasion does speed increase, decrease, or remain constant? The same questions can be asked of propensity. It

would appear that greater control and prediction of behavior would be accomplished if the functional relationships developed in studying behavior included speed and propensity measures rather than simple overall rate measures.

3) Rate as a measure of response strength is further complicated when the experimenter is examining topographically different responses. For example, the rate of bar pressing versus the rate of wheel turning or chain pulling in rats cannot be compared in terms of which response is more likely to occur. The unit of measurement for each of the above responses differs. When comparing the strength of various behaviors a common unit of observation is necessary. Rate of responding does not have this quality.

4) Certain fundamental characteristics of behavior may not be derivable from an analysis of behavior based on the rate of instantaneous units. Behavior can be considered to be a continuous stream of events (Schoenfeld & Farmer, 1969). Presently much of the experimental analysis of behavior has dealt with this behavioral stream by dividing it into units. These units, with few exceptions, have been discrete points in time. An experimental analysis which examines the more continuous aspects of behavior may produce functional relationships which only continuous measurements of behavior could produce.

Many problems involved with rate as a dependent variable center around one basic question. How should one record behavior? As stated earlier, the "response" in the experimental analysis of behavior has

typically been measured as an instantaneous event. Upon closer examination, however, even the comparatively simple key peck consists of a complex sequence of behavior. The pigeon moves its head back and forth with respect to the key and occasionally its beak closes the microswitch. At this point a reinforcer may or may not be presented. Although reinforcer presentation is dependent upon only one component of this behavior sequence, the frequency of occurrence of the entire sequence is affected.

Behavior can therefore be analyzed in terms of different sequences or different activities. An activity will be defined as a continuous sequence of behavior emitted as a result of exposure to a particular set of contingencies. Different activities are behavior sequences emitted as a result of exposure to different contingencies. Thus, an activity is an operant comprised of behavioral sequences.

The concept of activities, as an approach to behavior, has a number of advantages:

- 1) Activities are sequences of behavior comprised of behavioral elements. Determining how these elements are integrated and how they change over time may produce for the experimental analysis of behavior a unit of analysis more fundamental than the instantaneous operant presently examined. That is, this type of analysis may lead to functional relationships which more clearly reflect the continuous nature of behavior (Skinner, 1953b).

- 2) Research examining transitions or interactions between and

within activities, in terms of a fine grained analysis, becomes possible.

3) The classification of reinforcement schedules can be integrated to some extent. The distinction between simple and concurrent schedules of reinforcement, for example, becomes no longer necessary. In the standard two-key concurrent schedule the experimenter is comparing the activity of pecking on one key versus the other. Rate of pecking on either key is determined by the schedule of reinforcement for each key. In a simple reinforcement schedule the experimenter is reinforcing and recording pecks to only one key. However, other activities such as preening, wing flapping, etc., also occur. The rate of key pecking as well as the rate of the other activities are affected by the different schedules of reinforcement associated with each activity. Thus, the distinction between concurrent and simple schedules in our present classification system lies only in the number of activities the experimenter is explicitly reinforcing and recording.

4) If the operant under experimental analysis consists of a behavior sequence which has duration, then time spent responding can be examined as a dependent variable. Time may prove to be an important variable because its units of observation are invariant from one behavior to the next. Time therefore enables the experimenter to make comparisons between topographically diverse behavior sequences with respect to probability of occurrence (Premack, 1965).

The concept of activities and their duration may overcome some of the problems related to response rate described earlier. The concept of

activities, however, has been associated with a particular measurement problem. If activities and time spent responding are to be used, the experimenter must distinguish between the various activities a subject engages in. A number of indirect procedures have been used to record the duration of key pecking and bar pressing activities.

Gilbert (1958), using rats, and Catania (1961), using pigeons, attempted to measure the propensity of bar pressing and key pecking, respectively, by excluding inter-response times (IRTs) longer than a given duration from the session time. Two problems arise with this approach: 1) The subject may engage in the experimentally reinforced activity but not operate the manipulandum frequently enough such that this time would be included as part of the experimental activity. 2) The subject may engage in other activities during IRTs the experimenter has arbitrarily included as time spent in the experimental activity.

Baum (1976) recorded the duration of time subjects held a response bar down as a time measure of the activity of bar pressing with rats. This procedure, however, records the duration of only one component of the behavior sequence involved with bar pressing. A procedure which records the duration of the entire sequence would be more desirable.

Catania (1963), using a Findley concurrent procedure, recorded the length of time each component of the concurrent schedule was presented as a measure of time subjects allocated to key pecking in each component. LaBounty and Reynolds (1973), with a standard two-key concurrent procedure, assessed time spent responding during each

schedule by recording the cumulative times between a response on one of the keys and a subsequent response on the other. Both the Catania (1963) and the LaBounty and Reynolds' (1973) experiments examined the proportional relationship between times devoted to the recorded alternatives. This approach assumes, however, that the proportion of time spent engaging in non-pecking behaviors remains constant across each schedule examined. With this assumption the inclusion of non-pecking activity time would not affect the proportional relationships examined. The assumption of constant proportional bias across conditions is not based on experimental data. An analysis of LaBounty and Reynolds' data by Baum (1974) suggests that the constant proportional bias assumption was violated.

One experiment attempted to directly measure the duration of key pecking maintained on a VI schedule of reinforcement (Rand, 1977). Time engaging in the activity of key pecking was measured by an observer. When the pigeons emitted back and forth head movements with respect to the key, the observer closed a continuous switch. The duration of time this switch was closed was the measure of the activities duration. The validity and reliability of this technique, however, has to be questioned. During VI schedules complex response chains are adventitiously developed and form, in part, the elements of the pecking activity. These elements would not have been measured by Rand as part of the key-pecking activity.

Some experimenters have looked at activities other than key pecking or bar pressing in order to measure the duration of an activity

directly. Direct measures of duration are desirable since they bypass those problems associated with the indirect measures described above. Baum and Rachlin (1969) measured time engaging in an activity by defining two activities as standing on one side of a chamber or the other. The amount of time two sets of floor switches were closed measured the duration of these two activities. Baum and Rachlin found that, in general, time engaging in these activities was directly proportional to the rate of positive reinforcement produced by each activity. Similar findings were also reported by Baum (1973) when platform standing behavior was maintained by negative reinforcement. Bouzas and Baum (1976) reinforced platform standing with pigeons on a multiple variable-interval (VI-VI) schedule. That is, two reinforcement components with correlated stimuli were alternated in time. Standing on the platform in either component was reinforced at varying time intervals (VI schedule). Later reinforcement was withheld for one component (extinction). The amount of platform time in the extinction component decreased while platform time in the remaining reinforcement component increased (i.e., positive behavioral contrast).

To develop techniques that would directly and precisely measure time spent key pecking would be desirable for a number of reasons:

- 1) Numerous experiments have been conducted with key pecking as the observed response. Data from these experiments could be more easily integrated with data obtained from time allocation experiments if the activities examined were similar.

- 2) The suggestion (Baum & Rachlin, 1969) that time as a



dependent variable will lead to more generalized laws than response rate, could be empirically examined.

3) The separation of overall rate into its components of speed and propensity becomes possible. The functional relationships exhibited by these variables could therefore be analyzed.

Some unpublished research has recorded time spent key pecking using experimental control techniques (Pear, 1977). This experiment consisted of the following procedure. A platform was situated on the floor of a pigeon chamber. Directly in front of and above the platform was a standard pigeon response key. A key peck was reinforced if (1) the subject, a pigeon, was standing on the platform for a minimum of eight consecutive seconds and (2) a reinforcer had been made available by the schedule of reinforcement. Time spent engaging in the activity of key pecking was recorded as the duration of time the bird stood on the platform.

Four basic schedules of reinforcement were examined: fixed-interval (FI), -- a key peck is reinforced after a fixed period of time has elapsed, fixed-ratio (FR) -- every  $n$ th key peck is reinforced, variable-ratio (VR) -- a key peck is reinforced after a variable number of pecks have been emitted, and VI schedules. Pear found that for all four schedules of reinforcement, relative time spent key pecking, or propensity, decreased when the reinforcement frequency for key pecking was sufficiently decreased. Rate of responding did not show consistent functional relationships, either between or within subjects, as had propensity. Speed functions, in most cases, tracked rate

functions -- i.e., when rate increased speed increased, etc.

In addition to the above findings, behavioral phenomena related specifically to the continuous aspects of behavior became available for observation. For example, during FI 1-min the birds vacillated on and off the platform during the early portions of the inter-reinforcement interval (the interval of time between reinforcer presentations). Visual observations also indicated that the key-pecking activity changed across the inter-reinforcement interval. Head movements at the beginning of an interval tended to be further away from the response key than head movements towards the end of an interval. This pattern of behavior was not observed with the VI schedules of reinforcement studied.

Thus moment to moment changes in head-movement patterns, related to the key-pecking activity, occurred throughout the inter-reinforcement interval of the FI 1-min schedule. From these observations it would appear that the structure of the key-pecking activity or operant is not fixed or stereotyped during FI schedules. Rather, the observations suggest that the structure of the operant changes in an orderly fashion related to the changing temporal parameters of the FI schedule.

A more quantitative analysis of the above observations related to the structure of the key-pecking operant would be desirable. Experiments and experimental techniques examining the structure of an operant, however, are limited (Hawkes & Shimp, 1975). Shimp (1976) proposed that structural changes in the operant could be examined in terms of the temporal spacing of responses or their inter-response

times (IRTs). A number of problems are associated with this approach to the structural analysis of an operant. First, differences in IRTs alone do not necessarily indicate a change in the structure of the operant examined. The structure of the operant may remain constant while IRTs are varying as a result of (a) the organism emitting other operants of various durations between recordings of the experimental operant, and/or (b) the subject emitting faster or slower motions while engaging in the experimental operant. Second, IRT distributions represent possible systematic changes of only one component of the experimental operant. No information is available with respect to: (a) the topography of the other components of the unit or (b) how these other components combine to form the structure of the experimental operant.

#### Statement of the Problem

In light of the observations made by Pear related to the structural changes of an operant during FI 1-min, and those problems related to an IRT analysis of structure, the objectives of the present experiment can be summarized as follows:

- 1) Directly replicate the findings observed by Pear during the FI 1-min schedule of reinforcement.
- 2) Directly and quantitatively record the elements which form, in part, the structure of the key-pecking operant.
- 3) Determine to what extent the structure of the operant changes across the inter-reinforcement interval of the FI schedule employed.

4) Determine to what extent the structure of the operant changes during extinction.

To accomplish these ends the following procedure was utilized. The key-pecking of pigeons was reinforced on a FI 1-min schedule of reinforcement according to the procedure used by Pear described earlier. In addition a row of ten photocells, extending outwards from the response key, recorded the head movements of the bird during the key-pecking activity. The amount of time a bird was in front of each photocell was recorded across successive thirds of the inter-reinforcement interval. In addition to directly measuring the structure of the key-pecking operant, any orderly functional relationships obtained with this data would further support the position that the duration of a behavioral element or sequence can be a valuable dependent variable.

An analysis of the structure of the key-pecking operant during a FI schedule was one of the objectives of this experiment. To familiarize the reader with FI behavior in general, and to better integrate the data from the present experiment with previous research, Chapter II describes the response rate patterns that have been observed with FI schedules as well as those variables found to affect these patterns.

## CHAPTER II

### FIXED-INTERVAL BEHAVIOR

#### INTRODUCTION

With FI schedules, reinforcement is contingent upon the first response occurring after a fixed period of time. Generally this interval is timed from the previous reinforcer presentation. The number of responses emitted per reinforcement has been found to greatly exceed one. Generally, two basic patterns of responding have been reported for behavior maintained under FI schedules. One is the "scallop" pattern where a pause in responding occurs after reinforcement (termed the post-reinforcement pause or PRP) followed by a gradual increase in response rate. A steady rate is eventually achieved and maintained until reinforcer delivery. This pattern has been reported by Ferster and Skinner (1957), Cumming and Schoenfeld (1958), and Dews (1962; 1965a, b; 1966). The other commonly observed pattern has been described as a "break-run" pattern. This pattern consists of a pause after reinforcement followed by a rapid transition to a high response rate. This rate is maintained throughout the remainder of the interval. This pattern has been reported by Ferster and Skinner (1957), Cumming and Schoenfeld (1958), and Schneider (1969).

Skinner (1953a) reported that the scallop pattern was frequent with high valued FI schedules, and the break-run pattern was frequent with short inter-reinforcement intervals. However, Cumming and Schoenfeld (1958) found that with FI 30-min the scallop pattern was

actually a transitional stage followed by a steady-state break-run pattern.

Although the scallop and break-run patterns are the two patterns most frequently reported in the literature, other patterns have also been noted. Many of these patterns appear to be transitional (Ferster & Skinner, 1957; Skinner & Morse, 1958). One other pattern has been reported which may be representative of steady-state responding in some situations. This pattern, which resembles the break-run pattern, consists of a pause after reinforcement followed by a rapid transition to a high response rate. However, response rate then declines just prior to reinforcement. This pattern has been reported both with pigeons' key pecking (Cumming & Schoenfeld, 1958) and with rats running in a wheel (Skinner & Morse, 1958). Skinner and Morse suggested that the decline in responding towards the end of an interval might be the result of the subject engaging in approach responses towards the food magazine.

A number of investigators have proposed various processes or variables to account for the behavior patterns generated by FI schedules. Skinner (1953a) and Ferster and Skinner (1957) suggested that a pause occurs after reinforcement since a response is never reinforced immediately after a feeder operation during FI schedules. The organism eventually develops a behavioral discrimination based upon stimuli generated from the act of consuming food. So long as this stimulation is effective, response rate remains low. Ferster and Skinner also suggested that the unreinforced responses within an interval occur because the stimulus conditions during the latter portions of the interval are

similar to those present when the reinforced response occurs. Thus, responding occurs prior to reinforcement set up because the subject cannot discriminate exactly when the interval terminates.

Dews (1962, 1966b, 1969) and Catania (1969) suggested that the scallop pattern found during FI schedules was based on a declining retroactive rate-enhancing effect of the reinforcing stimulus. That is, one response is followed promptly by the reinforcing stimulus, but the preceding responses are also followed by the stimulus and are therefore strengthened as well. The degree to which each response in the sequence is strengthened would depend inversely on the time separating that response from the reinforcer. According to this interpretation, the entire pattern of FI responding is maintained by the reinforcing stimulus. Dews (1966b) suggested that schedules of reinforcement in general can be regarded in this manner; i.e., as reinforcing entire patterns of responding.

Schneider (1969) suggested a two state analysis of FI responding based on the break-run pattern found with FI schedules. Schneider argued that the FI schedule can be characterized as a multiple extinction-VI schedule. The first state (the pause) is considered to be a temporally discriminated post-reinforcement extinction period followed by a second component (the run or work state) that terminates with reinforcement. Since the transition from one component to the next is variable (Schneider, 1969), the duration of the second component is also variable. Responding in the second component is therefore reinforced on a VI schedule whose parameters are determined by the point of

transition from the first component to the second. Schneider demonstrated that the function relating response rate to reinforcement frequency in the second component of FI schedules was similar to the function reported by Catania and Reynolds (1968) between response rate and reinforcement frequency for standard VI schedules. Response rate showed an increasing, negatively accelerated function as reinforcement rate increased.

#### Variables Which Affect Responding

Numerous experiments have been conducted to determine those variables which control the patterns of responding observed with FI schedules. Some of the variables examined have been: 1) the response unit required for reinforcement, 2) the inter-reinforcement interval, and 3) the reinforcing stimulus.

##### 1. The Response Unit Required for Reinforcement

Skinner (1953a) stated, "the effects of a schedule are due to the contingencies which prevail at the moment of reinforcement (p. 105)." However, a number of studies have shown that some of the general characteristics of FI behavior, such as the duration of the PRP, are not affected by the particular conditions present at the moment of reinforcement.

Farmer and Schoenfeld (1964), using rats, examined the effects of a differential reinforcement for low rates schedule (DRL) superimposed on a FI 30-sec schedule. The DRL contingency specified a minimal IRT for a reinforced response. They observed that when DRL values ranged from one to four seconds, mean PRP length remained constant while terminal response rates decreased. In a similar study, Elmore (1971) restricted the upper limit as well as the lower limit on the IRT that



qualified a response to be reinforced on a FI 30 or 60-sec schedule. In agreement with Farmer et al. (1964), Elmore found no systematic difference in PRP duration that was related to the reinforced IRT.

Shull, Guilkey, and Witty (1972), using pigeons, manipulated the response unit required for reinforcement while maintaining inter-reinforcement time constant. They employed the use of second-order schedules to accomplish this. With the second-order schedule, FI 3-min (FR 10), the first FR 10 ratio completed after three minutes was reinforced. The completion of each ratio was followed by a brief darkening of the response key. The authors varied this ratio requirement from 10 to 20 responses and compared the behavior generated with these schedules to that found with a standard FI schedule with an equivalent inter-reinforcement interval. Shull et al. found that with the second-order schedules completion of each ratio was followed by a short pause in key pecking and response rate increased as the fixed ratio increased. However, despite the large differences in response rate and response patterning between the schedules examined, PRP length remained fairly constant across the schedules.

Shull (1970), using pigeons, Staddon and Frank (1975), using pigeons, and Morgan (1970), using rats, examined various conjunctive FT-FR schedules to determine the independence of PRP duration and response-reinforcer contiguity. After a certain number of pecks specified by the FR was emitted, food was presented at the end of the fixed-time (FT) interval regardless of the subject's behavior at that time. Although both the FT component and the FR component had to be

completed, there was no specification as to which component should be completed first. All three experiments showed that, in comparison with simple FI schedules with the same inter-reinforcement intervals, PRP length was equal between the conjunctive and simple FI schedules even though terminal component rates differed.

All of the previous data indicate that the allocation of time between the PRP and work state is relatively independent of the actual rate and topography of responding after the pause. Dews (1969) examined response rate changes throughout an inter-reinforcement interval as a function of different contingencies present at the moment of reinforcement. He compared a standard FI 180-sec schedule with either a tandem FI 180-sec/FR 2 schedule (the second key peck was reinforced after 180 seconds from the last reinforcer presentation) or with a tandem FI 180-sec/FR 10 schedule (the tenth key peck was reinforced after 180 seconds from the last reinforcer presentation). The tandem schedules increased the frequency of short IRTs relative to the standard FI 180-sec schedule. With all three schedules, however, a progressive increase in the average rate of responding throughout the inter-reinforcement interval occurred. In addition, the relative increase in response rate was similar under all schedules.

To summarize the articles for this section, it would appear that the conditions which prevail at the moment of reinforcement determine the rate and topography of the reinforced operant, but not the duration of the PRP.

## 2. Inter-reinforcement Interval

a) PRP length. Ferster and Skinner (1957) reported data on a variety of inter-reinforcement intervals ranging from FI 1-min to FI 45 minutes. Their general finding was that PRP duration increased with increases in inter-reinforcement time. Chung and Neuringer (1967), Schneider (1969), Shull (1970, 1971), Elsmore (1971), Starr and Staddon (1974), and Staddon and Frank (1975) have all confirmed the finding that PRP length increases with increases in the inter-reinforcement interval. Schneider (1969), and Shull (1971) reported that the functional relationship between PRP length and FI duration was approximately linear in form.

b) Response rate. Ferster and Skinner (1957) noted that, with long inter-reinforcement intervals, irregular patterns of responding occurred unless a time out (chamber not illuminated for a fixed period of time) followed each reinforcement. Catania and Reynolds (1968) found no systematic relationship between overall response rate and inter-reinforcement duration with FI schedules. They did find, however, that the terminal rate of responding increased as the overall rate of reinforcement increased. This latter finding was also reported by Schneider (1969).

Research outlined previously which utilized conjunctive FT-FR schedules indicated that PRP length remains constant when reinforcer presentation is no longer contiguous with the experimental operant. However, can the response pattern of increasing rate throughout an interval be developed or maintained when the experimental response is no longer contiguous with reinforcer presentation? In other words, what

effect, if any, does a constant inter-reinforcement interval have on response patterning?

Zeiler (1968) established key pecking on an FI 5-min or a VI 5-min schedule of reinforcement. For some subjects the schedule was changed to a FT 5-min schedule of reinforcement. That is, after five minutes from the last reinforcer the feeder would again operate independently of the subject's behavior. The FT schedule produced positively accelerated responding between reinforcers. This pattern developed independently of the distribution of responses existing prior to when the schedule was first imposed. For example, those subjects showing a steady rate of responding during the initial VI schedule developed positively accelerated responding between reinforcer presentations on the FT schedule. For all subjects, rate of responding decreased below the level maintained by the previous response dependent reinforcement schedule. Therefore, although the rate of responding was affected primarily by the events contiguous with reinforcement, the pattern of responding appeared to be determined by the presentation of reinforcers in relation to time. It should be noted, however, that the FT schedule does not necessarily prevent key peck -- reinforcer contiguity from occurring.

Marr and Zeiler (1971) examined FT and FI presentations of a conditioned reinforcer (key light changes paired with grain) superimposed on a FI schedule of food presentation. Patterns of positively accelerated responding occurred between stimulus presentations for both the FT and FI schedules of conditioned reinforcement. The FT schedule of

conditioned reinforcement, however, produced substantially lower rates than the FI schedule of conditioned reinforcement. These authors concluded, in support of Zeiler (1968) and Dews (1969), that the precise behavior occurring at the moment of reinforcement determined the rate of responding, and the temporal location of reinforcement determined the pattern of responding.

The previous two studies both showed that FT schedules produced positively accelerated responding within the inter-reinforcement interval. Alleman and Zeiler (1974) demonstrated, however, that two types of patterns could be produced with FT schedules. When subjects were previously exposed to a DRL schedule of reinforcement, responses typically occurred at a steady rate in the period between successive food presentations on a FT schedule. If the subjects were exposed to a high FR schedule, rate under the FT schedule was positively accelerated between food presentations. Thus, the pattern of responding during FT schedules may depend, in part, on the previous history of the subject. However, two patterns of responding (steady rate and scalloping) were consistently maintained during the FT schedule. Alleman and Zeiler argued that only an unchanging variable could maintain this consistency. During the FT schedule response-reinforcer relations would be changing over time, but the temporal presentation of food would always remain constant. They concluded, as did Zeiler (1968) and Dews (1969), that the temporal location of reinforcers affects the pattern of responding developed and maintained during interval schedules.

c) PRT length and response rate interactions. The data presented

thus far in this chapter support Schneider's two state analysis of FI behavior. It appears that one set of factors (e.g., inter-reinforcement time) determines how the animal allocates its time between the two states, and another set of factors (e.g., reinforced IRT) determines the rate and topography of behavior in the terminal workstate. Additional data indicates, however, that the PRP and workstate of FI schedules are not independent components.

Skinner (1938) and Ferster and Skinner (1957) reported "second-order" effects during large FI schedules. These authors noted that successive PRPs tended to alternate between long and short durations. They suggested that when many responses occur within an interval, responding will occur relatively late in the following interval. However, when few responses occur within an interval, responding will begin relatively early in the following interval.

Shull (1971) controlled the alternating pattern of long and short PRP durations by manipulating the minimal amount of time between the first response emitted and the following reinforcer presentation. He found that the shorter the work time within an interval, the longer the work time in the following interval. At present, no studies have established whether the alternating pattern of long and short PRP durations is controlled by the duration of time in the work state, or by the number of responses emitted in the workstate.

Buchman and Zeiler (1975) examined response number as a discriminative stimulus for subsequent responding within the context of FI behavior. They utilized a two component chained schedule. The number

of responses emitted during the initial FI 3-min component determined whether a VI food schedule or extinction schedule prevailed in the second or terminal component. In one condition, the VI schedule was in effect if the number of responses during the FI was less than a specified number. In another condition, the number of responses had to exceed a specified number. Buchman and Zeiler found that responses emitted during the initial FI component did not shift in the direction required for the VI schedule to be presented. Instead, responding tended to shift in the opposite direction. This result supports Ferster and Skinner's analysis that a low response number per reinforcer will subsequently generate high response rates, and many responses per reinforcer will subsequently generate low rates (also see Herrnstein & Morse, 1958; Shull, 1971).

Buchman and Zeiler also found that response rate in the terminal component was a function of how close response number in the FI component approached those limits required for the VI schedule to be presented. Thus, response number in the initial component served as a discriminative stimulus for responding in the terminal component. Buchman and Zeiler questioned, however, the function of response number as a discriminative stimulus during standard FI schedules. They argued that stimulus control requires differential reinforcement with respect to a subset of values. With FI schedules the number of responses emitted in successive intervals varies widely (Dews, 1970). Thus, many response numbers are correlated with reinforcement. Past research has shown (Reynolds, 1961; Zeiler, 1969) that when a large number of values of an exteroceptive stimulus dimension are correlated with reinforcement, stimulus control is

not obtained.

In summary, the number of responses emitted in an FI schedule can have a discriminative function when there is explicit differential reinforcement, but it may not characterize response number in the ordinary FI schedule. However, even if response number is not a discriminative stimulus during standard FI schedules, the number of responses per reinforcer may still affect subsequent responding.

### 3. The Reinforcing Stimulus

The delivery of a reinforcer following a single response is an important determinant of the tendency to respond, but the schedule of reinforcement appears to modulate the rate of responding and how successive occurrences of the response are distributed in time. Therefore one cannot examine the effects of a reinforcing stimulus per se out of the context of its schedule of presentation. What follows is a review of some of the literature where researchers have demonstrated or postulated the effects of the reinforcer within the context of FI schedules.

Stebbins, Mead, and Martin (1959) varied the concentration of a sucrose solution when bar pressing was maintained with rats on a FI 2-min schedule of reinforcement. They found that as sucrose solution increased in concentration, overall response rate increased exponentially. Staddon (1970) varied feeder duration while key pecking was maintained on a FI 1-min schedule with pigeons. He found that PRP length increased and running rate (rate after the first response in an interval) decreased as feeder duration increased.



One method used extensively to determine the effects of the reinforcing stimulus has been the reinforcement-omission procedure (Staddon & Innis, 1966; Staddon & Innis, 1969). With this procedure a reinforcer is occasionally omitted and replaced with a chamber blackout of a specific duration. The pattern of responding in the following interval is then examined in terms of pause length after the blackout and the subsequent rate of responding.

Staddon and Innis (1969) showed that during a FI 2-min schedule presentation of a brief timeout in lieu of reinforcement increased response rate in the following two-minute interval. This increase in overall rate resulted from shorter post-blackout pauses relative to the post-reinforcement pauses. Similar findings were also obtained by Staddon and Innis (1966), and Innis and Staddon (1969).

Data discrepant with this literature are the results reported by Chung and Neuringer (1967) and Neuringer and Chung (1967). Chung and Neuringer (1967) compared response-initiated FI schedules (tandem FI 1 FR) ranging from FI 1-sec to FI 15-sec with a condition whereby some of the response-initiated FI intervals were followed by a one-second blackout instead of food. In contrast with Staddon and Innis (1969), Chung et al. found that post-blackout pauses were of the same duration as post-reinforcement pauses.

In a further investigation, Starr and Staddon (1974) demonstrated that the length of the post-blackout pause was determined principally by the amount of time to the next reinforcement opportunity. This was true provided that the absolute times of the FI schedule were short in

duration. With FI schedules less than 20 sec (as in the Chung and Neuringer study) post-blackout pauses were of the same duration as the post-reinforcement pauses. With longer FI schedules the reinforcement omission effect reported by Staddon and Innis (1969) occurred.

Data obtained from reinforcement-omission experiments (e.g., Staddon and Innis, 1969) and feeder duration studies (e.g., Staddon, 1970) with FI schedules have been interpreted in terms of the reinforcer having inhibitory effects on responding for a period of time following its offset. Staddon (1969) suggested that if a stimulus generalization test was conducted during an inter-reinforcement interval, one would obtain an inhibitory gradient early in the interval, but an excitatory gradient later in the interval.

A number of studies have been conducted which have manipulated key color throughout the inter-reinforcement interval of a FI schedule in an attempt to assess the stimulus control properties of this schedule.

Flanagan and Webb (1964) and Henrichs (1968) demonstrated dishinhibition effects during FI schedules. When novel stimuli were presented at the beginning of an interval, response rate increased relative to baseline conditions. In an attempt to establish stimulus generalization gradients, Malone (1971) conducted stimulus generalization tests with novel stimuli presented throughout the inter-reinforcement interval. Malone found that responding increased for all testing intervals and for all stimuli. These studies suggest that the introduction of a salient stimulus during a FI schedule will always increase response rate. Wilkie (1974) demonstrated otherwise. Key pecking on a response key

illuminated by a vertical line was maintained on a FI 3-min or FI 6-min schedule of reinforcement. Following training generalization tests were conducted in which the orientation of the line varied. Responses were recorded across successive thirds of the inter-reinforcement interval. Excitatory gradients of responding were obtained for the terminal portion of the interval. Inhibitory gradients of responding were obtained during the early portion of the inter-reinforcement interval, when the preceding interval had terminated with reinforcement. On occasions when a blackout was presented in lieu of a reinforcer (reinforcement-omission procedure), inhibitory gradients were not obtained following the blackout. Thus, the data support Staddon's claim that reinforcer presentation during FI schedules has subsequent inhibitory effects on responding.

#### Summary

The data presented in this chapter generally support Schneider's two state analysis of FI behavior. The characteristic patterns obtained with FI schedules are affected by a number of different variables. Some of these variables appear to affect only certain aspects or components of the pattern and not others. For example, the conditions which prevail at the moment of reinforcement appear to affect only local response rate and not the duration of the PRP.

Although research conducted with FI schedules has resulted in the establishment of important functional relationships, the analysis has been limited to some extent by the dependent variables examined. The patterns exhibited by a cumulative record represent a highly complex

summary of events over time. The event recorded represents only one element of a complex activity which is occurring. As proposed in Chapter I, the purpose of the present experiment was to empirically measure a number of behavioral elements that comprise the key-pecking operant during a FI schedule. This additional data should provide more information related to the behavioral processes which occur during this schedule. For example, one question the present experiment attempted to answer was -- do head movements related to the key-pecking activity differ between the traditional scallop and break-run response patterns? If differences do exist, this may eventually lead to a more precise specification of those variables which control these patterns, and possibly response patterns in general.

The analysis of the behavioral elements which comprise the experimental operant may also aid our integration of those variables which affect schedule performance. For example, when a variable has been manipulated such that the experimental activity changes, does the entire activity change or only some of its elements? Do some elements change during one set of manipulations, but not during another? The answers to these questions can be determined by measuring the various elements which comprise the operant examined. Presently those variables which affect response patterns have been classified in terms of their affects on PRP length and overall response rate. A classification system integrating more molecular measures of behavior may prove to be more useful.

## CHAPTER III

### METHOD

#### Subjects

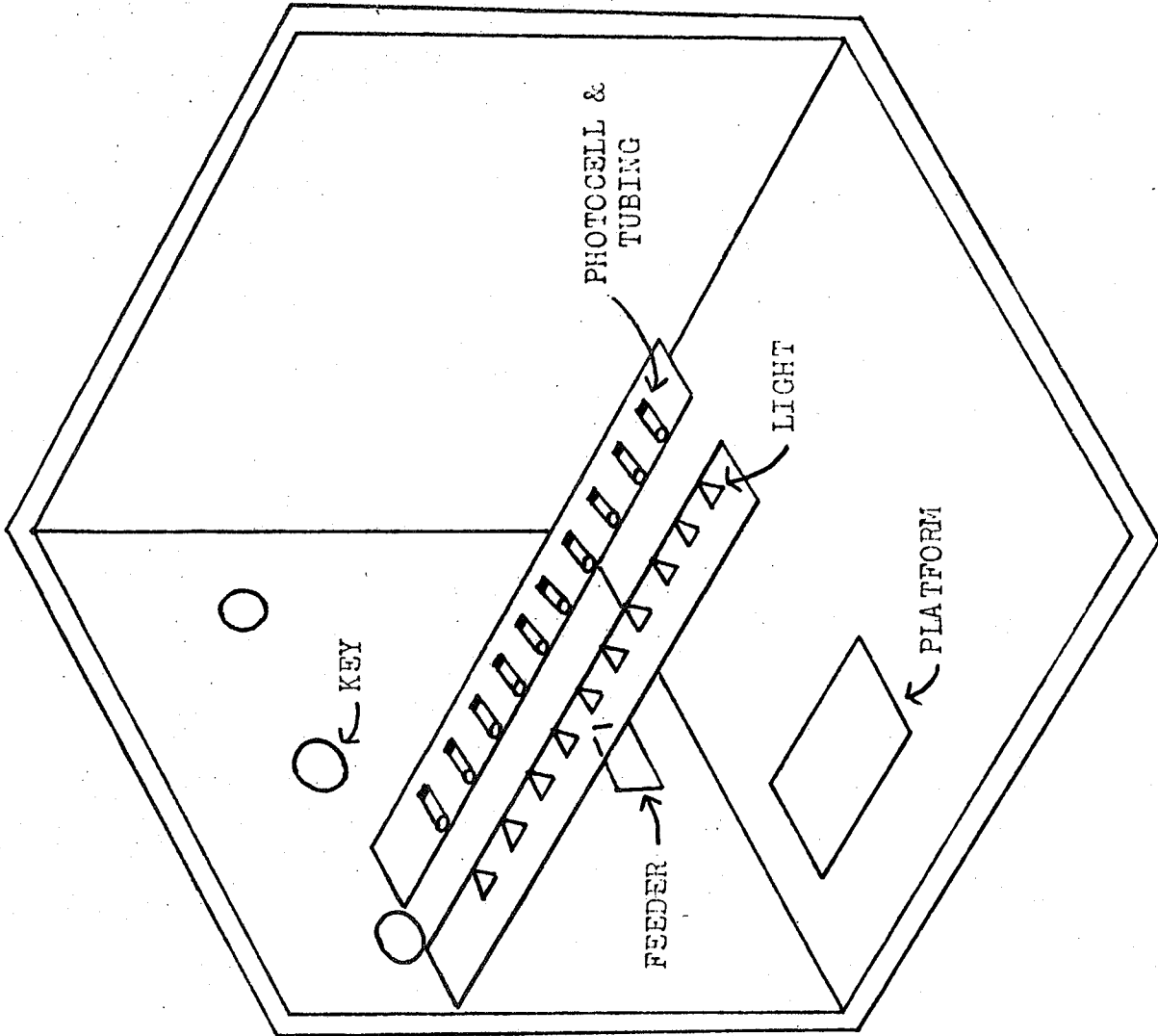
Three experimentally naive male White Garneaux pigeons were used. All birds (P10, P30, P31) were maintained at 80% of their free-feeding weights throughout the experiment.

#### Apparatus

Figure 1 shows a diagram (not to scale) of the experimental environment. A standard three-key pigeon chamber with interior dimensions 31 x 35 x 35 cm was used. The center key was removed from the chamber and the right key was inoperative. The left key was operative, and was activated when a minimal force of .08N was applied to the key. This key was 2.5 cm in diameter and could be illuminated either red or green.

Attached to the front panel, approximately 5 cm on each side of the left key, were two parallel bars. They extended directly outwards into the chamber and were parallel to the floor. The dimensions of these bars were 23 by 5 by 4 cm. Situated along the right hand bar was a row of ten photocell sensors. Each photocell was fitted with a black rubber tubing which extended 2 cm from the sensor. The tubing was 0.6 cm in diameter. Only a light source directly in front of the photocell would activate the sensor. The first photocell was 3.5 cm from the front key panel and all photocells were 1.25 cm apart. A strip of clear Plexiglass covered the top and front of each photocell to protect them from the pigeon, the accumulation of dust, etc. Situated on the left bar was a row of ten

Figure 1. Diagram of the experimental environment.



bulbs (Spectro no. 222 with lens), each directly opposite one of the photocells. The bulbs, with their narrow light beams, were directed at corresponding photocell sensors on the opposite bar. Like the photocells, the bulbs were protected by a strip of clear Plexiglass. The actual distance between the light and photocell bars was the diameter of the response key, i.e., 2.5 cm.

A platform 0.2 cm above the grid floor was placed directly below the light and photocell bars. The platform was 4 cm from the front panel and measured 11 by 9.5 cm. Microswitches located beneath the platform were activated when a minimal force of .55N was applied to the surface of the platform.

Situated near the middle of the front panel, 8 cm above the floor, was an opening for presenting a food hopper containing Purina Racing Pigeon Checkers. A feeder light could be illuminated when the feeder operated. A speaker was located directly behind the food hopper. A houselight was continuously on during the session. An exhaust fan ran continuously providing air and a partial masking noise to the chamber. White noise was also presented through a speaker to the room where the chamber was located.

Solid state and relay equipment were located in an adjacent room. This equipment recorded and programmed events in the chamber. The solid state equipment had a time base of 0.1 sec from which the duration of events was recorded. During the latter portion of the experiment (Phase III) a microprocessor was used. This equipment had a time base of 0.01 sec from which the duration of events was recorded.



## Procedure

Preliminary training. Birds were magazine trained by first continuously operating the food hopper until the bird approached and consumed grain from the hopper. The feeder light, at this stage, was illuminated when the hopper operated. The speaker behind the food hopper would also emit a tone during the operation of the feeder. The duration of each hopper operation was gradually reduced until the bird would approach and consume grain from the hopper within three seconds of its presentation. The intensity of the feeder light was then gradually decreased to zero. By the end of magazine training the birds would approach and consume grain within the 3-sec hopper presentations with no feeder light present. Throughout magazine training no specific response was reinforced and no key light was present.

After magazine training was completed the left response key was continuously illuminated red. The birds were trained to peck this key by the method of successive approximations (shaping). After shaping procedures key pecking was maintained for one session on a continuous reinforcement schedule (CRF). After the CRF session the schedule of reinforcement was changed to VI 30-sec. That is, key pecking was reinforced on the average once every 30 secs. After two sessions of VI 30-sec the schedule was changed to VI 60-sec. The birds were on VI 60-sec for approximately four sessions. All sessions during preliminary training terminated after 60 feeder presentations.

Platform training. After key pecking was maintained on VI 60-sec, platform training was initiated. The platform, situated on the floor below the light and photocell bars and directly in front of the left key,

was made operative. When the bird was off this platform the left key light was green. When the bird stood on the platform, such that its weight activated the microswitches underneath, the left key light changed to red. The first peck to the red key after the bird had stood on the platform for a minimum of eight consecutive seconds (change over delay; COD = 8 sec) was reinforced. This COD was initiated each time the bird stepped on the platform. During feeder operations the key light always remained red. After the operation of the food hopper the key light would either be red or green depending on whether the bird was on or off the platform, respectively. As outlined in Chapter I, this key light-platform procedure was successfully used by Pear (1977) to distinguish key-pecking from non-key pecking activities. The birds would only stand on the platform while engaging in the key-pecking activity. Platform training terminated after approximately four sessions. Each session terminated after 60 feeder operations.

Phase I - FI 1-min. After platform training, the birds were introduced to a FI 1-min schedule of reinforcement. The operating characteristics of the COD and key lights were the same as that during platform training. Now, however, a reinforcer was only made available 60 sec after the previous reinforcer (or from the start of the session). After reinforcement set up a key peck would be reinforced provided the COD requirement had been satisfied.

While key pecking the position of the bird's head was recorded by the photocells. The photocells would operate if: 1) the bird's head was within the 2.5 cm corridor (bounded by the photocell lights and sensors)

which extended outwards from the key, and 2) the bird was standing on the platform. Head movements were only recorded during the time between the termination of the previous reinforcer and the availability of the next reinforcer (60 sec). The distance between the photocell sensors was such that the pigeon's head would always be in front of at least one photocell sensor. If the bird was in front of two or more photocells simultaneously, of these photocells only that one closest to the response key would operate. The amount of time each photocell was operated was recorded across successive thirds of the inter-reinforcement interval. Key pecks, while the bird was standing on the platform, were also recorded for successive thirds of the inter-reinforcement interval. Each session terminated after 60 feeder operations. Phase I terminated when visual inspection of the cumulative records and head-movement data showed no systematic trends across 5 consecutive sessions.

Phase II - FI 1-min -- empty feeder. Subjects P10 and P31 served in Phase II. During Phase II the food hopper was empty. Presentations of the hopper, however, still occurred on a FI 1-min schedule. Head movements and key pecks were recorded as they were in Phase I. Each session lasted 60 min. This phase terminated when no head movements were recorded for a session.

Phase III - FI 1-min. Phase III was a reversal to conditions present during Phase I, i.e., FI 1-min. During Phases I and II a time base of 0.1 sec was used to record photocell time. During Phase III, in addition to the 0.1 sec time base, a microprocessor recorded photocell activations from a time base of 0.01 sec. Differences in relative photocell time between the two time bases were minimal (< 1%).

## CHAPTER IV

### RESULTS

#### Phase I

Early FI 1-min performance. During the first few sessions of FI 1-min all birds generally demonstrated a linear pattern of responding with minimal post-reinforcement pauses. This behavior is typical of early FI performance (Ferster & Skinner, 1957). Figures 2, 3, and 4 show cumulative records of this key pecking performance for Session 1 for P10 and P30 and Session 2 for P31, respectively. (No cumulative record is available for Session 1 for P31). As with all the cumulative records shown for this study, session time proceeded along the horizontal axis. The response pen moved a constant vertical distance with each key peck. Thus, the slope of the line indicates overall rate. The cumulative response pen deflected upward when the bird stood on the platform, and deflected downward when the bird stood off the platform. Feeder operations are indicated by the slash marks created by the event pen proceeding along the horizontal axis of the figure. The above records indicate that when the birds stopped key pecking they stepped off the platform, and when on the platform they pecked the response key. This indicates that the head movements recorded were related to the key pecking activities of the birds, since the photocells operated only when the bird was on the platform.

Figure 5 shows the percentage of time the birds were in front of a given photocell across successive thirds of the inter-reinforcement

Figure 2. Cumulative record of early FI 1-min performance  
for P10.

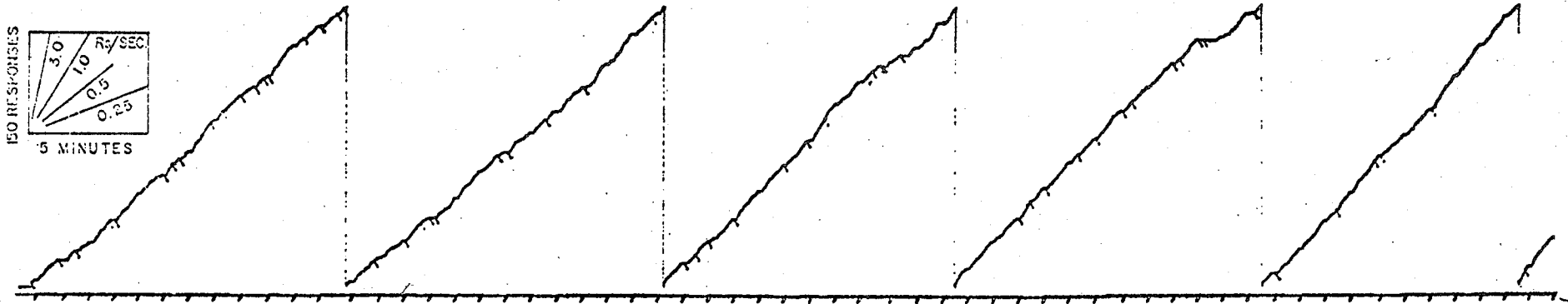


Figure 3. Cumulative record of early FI 1-min performance for P30.

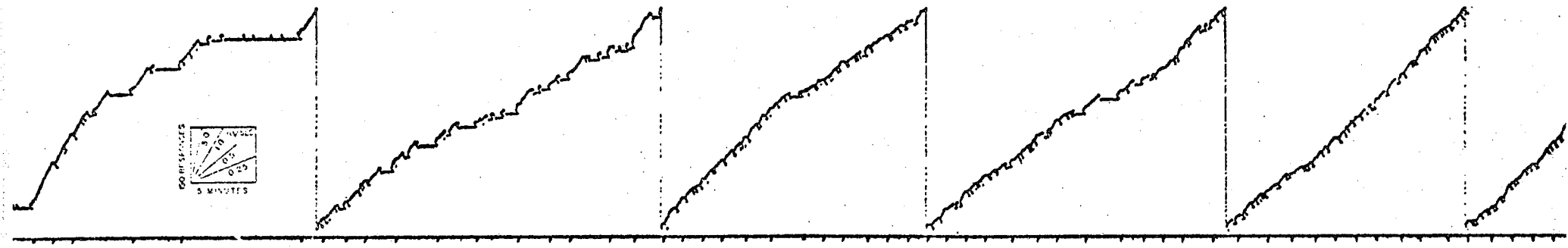




Figure 4. Cumulative record of early FI 1-min performance for P31.

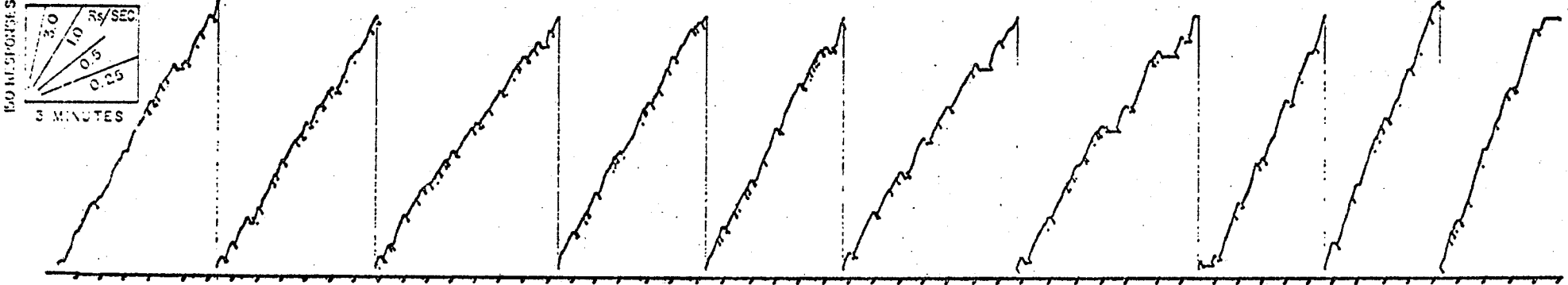
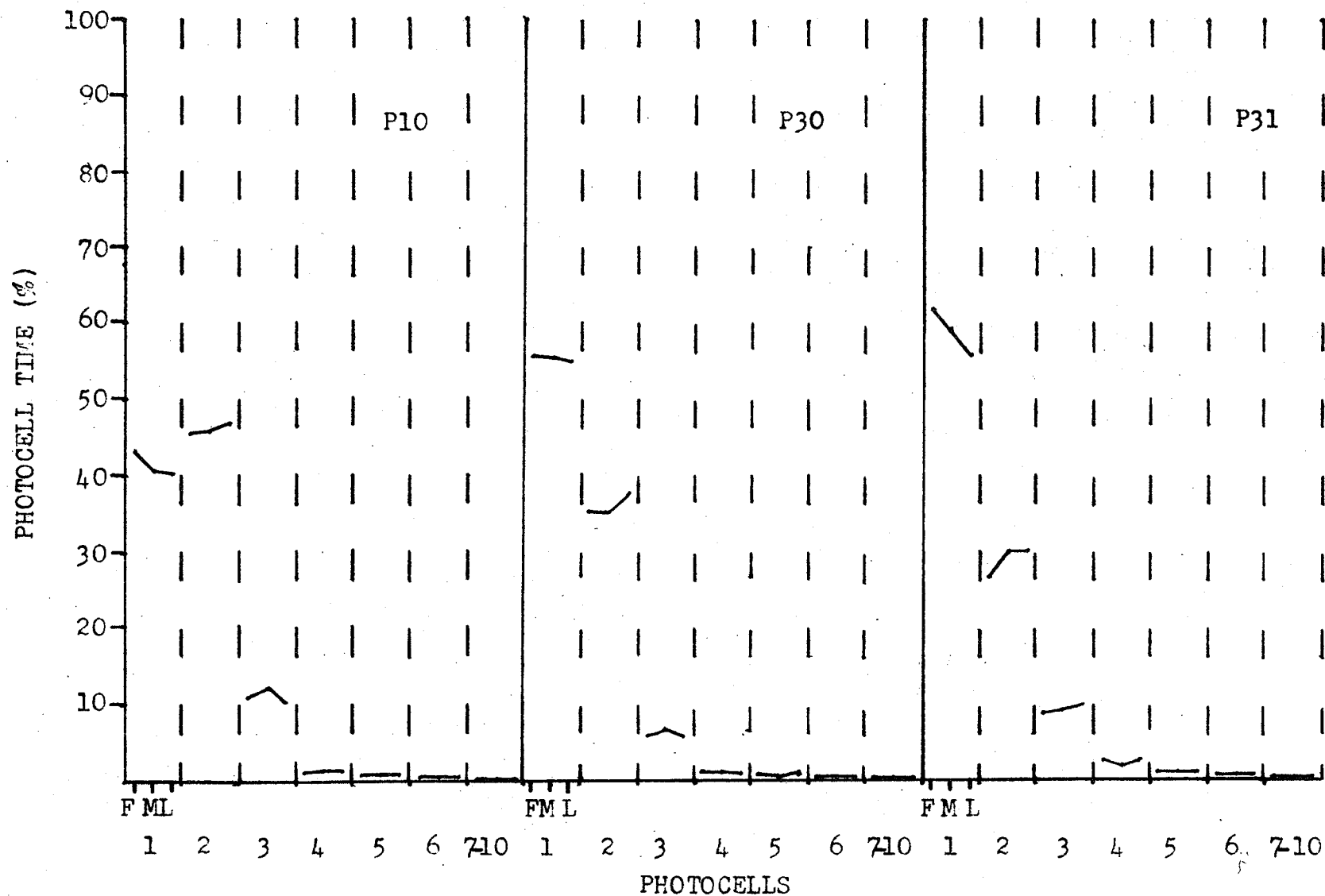


Figure 5. Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval during early FI 1-min performance for all birds. The letters F, M, and L indicate the first, middle, and last thirds of the inter-reinforcement interval, respectively.



interval for Session 1 for P10 and P30 and Session 2 for P31. Due to equipment limitations and the small amounts of time involved, time allocated to the four photocells furthest away from the response key (Photocells 7-10) were combined. The amount of time in front of the remaining six photocells were recorded separately. Photocell 1 was closest to the response key, Photocell 2 second closest, etc. The figure indicates that:

1. Relative time in front of each photocell changed only slightly across the inter-reinforcement interval for all three birds. Thus, the structure of the key-pecking activity remained constant across the inter-reinforcement interval for these sessions.

2. Generally for all three birds, the closer a photocell was to the response key, the higher the percentage of time that photocell was operated.

Figure 6 shows the total amount of photocell time across successive thirds of the inter-reinforcement interval for Session 1 for P10 and P30 and Session 2 for P31. Photocell time remained fairly constant across the interval except for P31 which showed an increase in photocell time from the first to the second third of the inter-reinforcement interval. This difference was due to the short post-reinforcement pauses that had already developed in P31's performance by Session 2. Thus, Figure 6 indicates that a linear pattern of key pecking, with minimal post-reinforcement pauses, was associated with a constant duration in photocell time across the reinforcement interval.

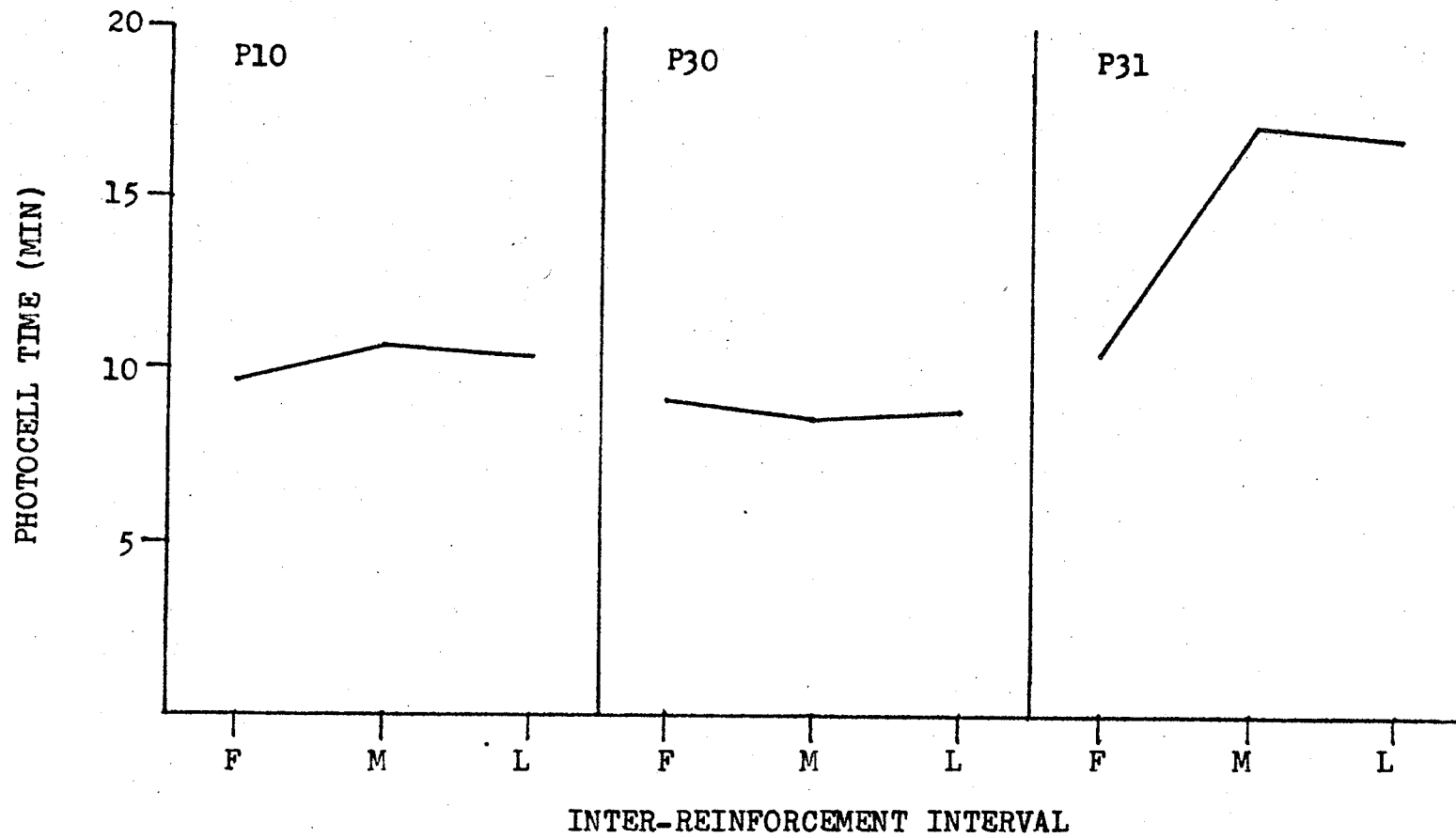
Intermediate FI 1-min performance. For all three birds typical scallop response patterns (Ferster & Skinner, 1957) soon developed.

Figure 6. Total photocell time across successive thirds of the inter-reinforcement interval during early FI 1-min performance for all birds.

F-- FIRST THIRD

M-- MIDDLE THIRD

L-- LAST THIRD



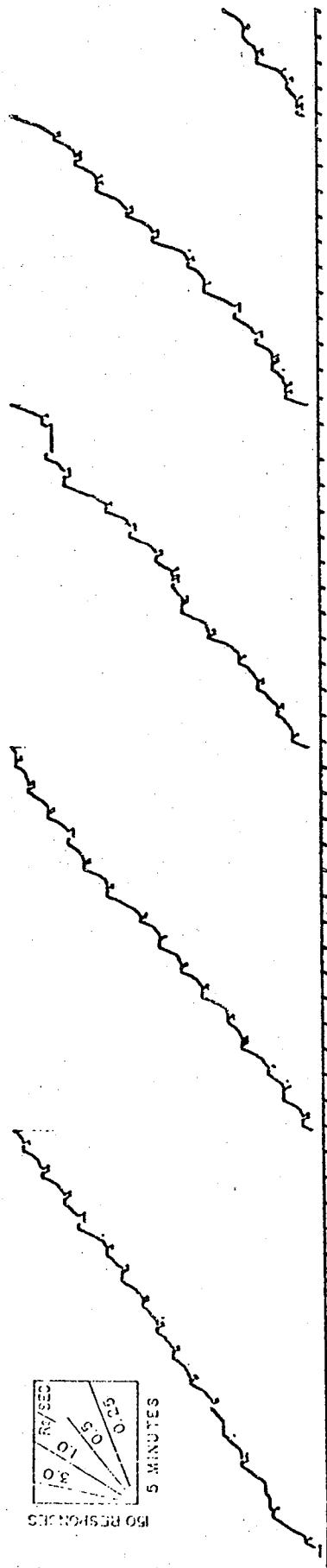
Figures 7, 8, and 9 are cumulative records of scallop response patterns from Session 35 for P10 and Session 17 for P30 and P31, respectively. The records show that the degree of scalloping and the frequency of its occurrence differed both between intervals and between birds. The cumulative records also indicate that the birds tended to stand on the platform and not peck the response key during the PRP. Visual observations indicated that on those occasions on which this occurred, the birds were well below the photocell sensors. The activity of key pecking was always observed when the bird was within the narrow 2.5 cm photocell corridor. The actual amount of photocell time recorded for P31 supports these visual observations. This bird tended to remain on the platform during the PRP for most of Session 17 (see Figure 9). However, total photocell time for the first third of the inter-reinforcement interval for this session was only 19 sec out of a possible 20 min. Approximately 73% of this time was accumulated by Photocell 1, the photocell closest to the response key.

Figure 10 shows the percentage of time the birds were in front of a given photocell across successive thirds of the inter-reinforcement interval for the above session demonstrating scalloped response patterns. The figure indicates that:

1. For all three birds, structural changes in the key-pecking activity occurred across the inter-reinforcement interval. For all birds the percentage of time Photocell 1 was operated increased across the inter-reinforcement interval while the percentage of time for Photocells 2 through 10 decreased across the interval. That is, the

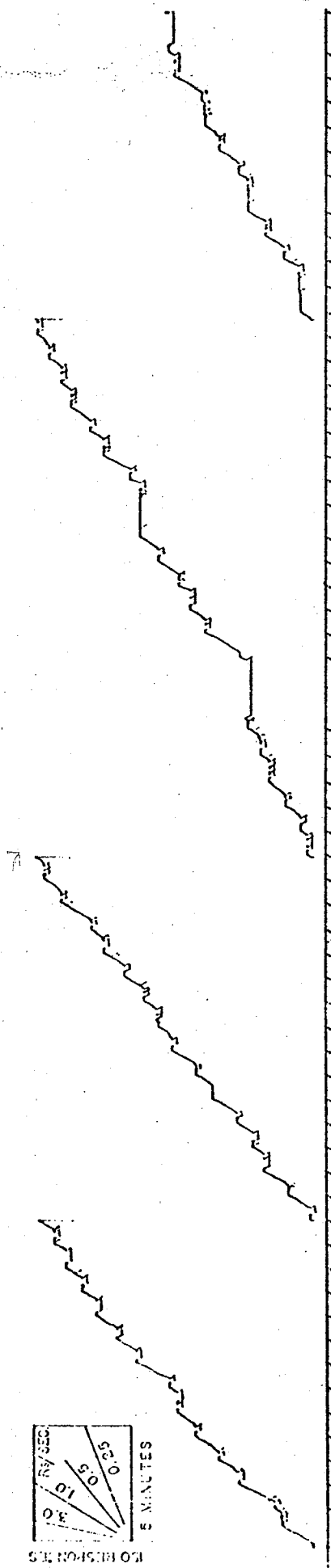


Figure 7. Cumulative record of scallop response pattern during FI  
1-min for P10.



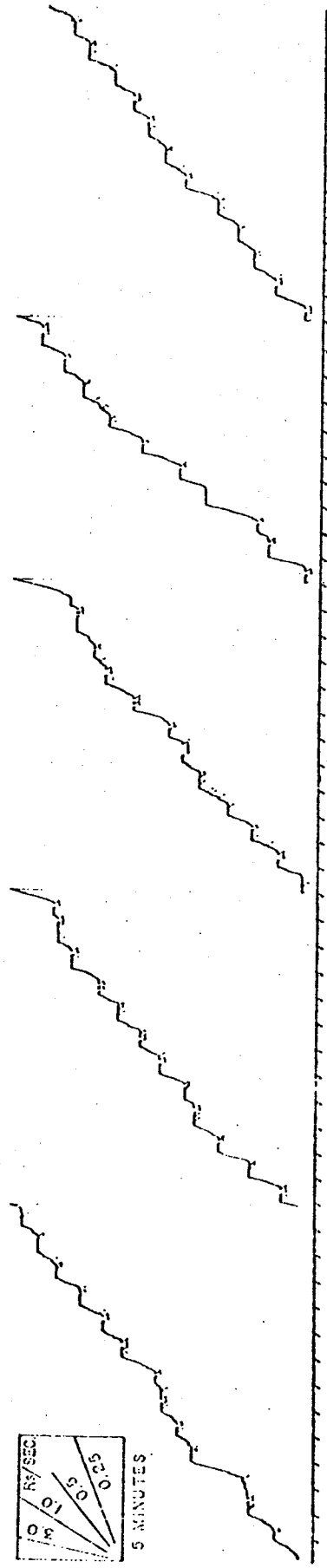
ISO RESPONSES  
5 MINUTES  
3.0  
1.0  
0.5  
0.25  
R/SEC

Figure 8. Cumulative record of scallop response pattern during  
FI 1-min for P30.



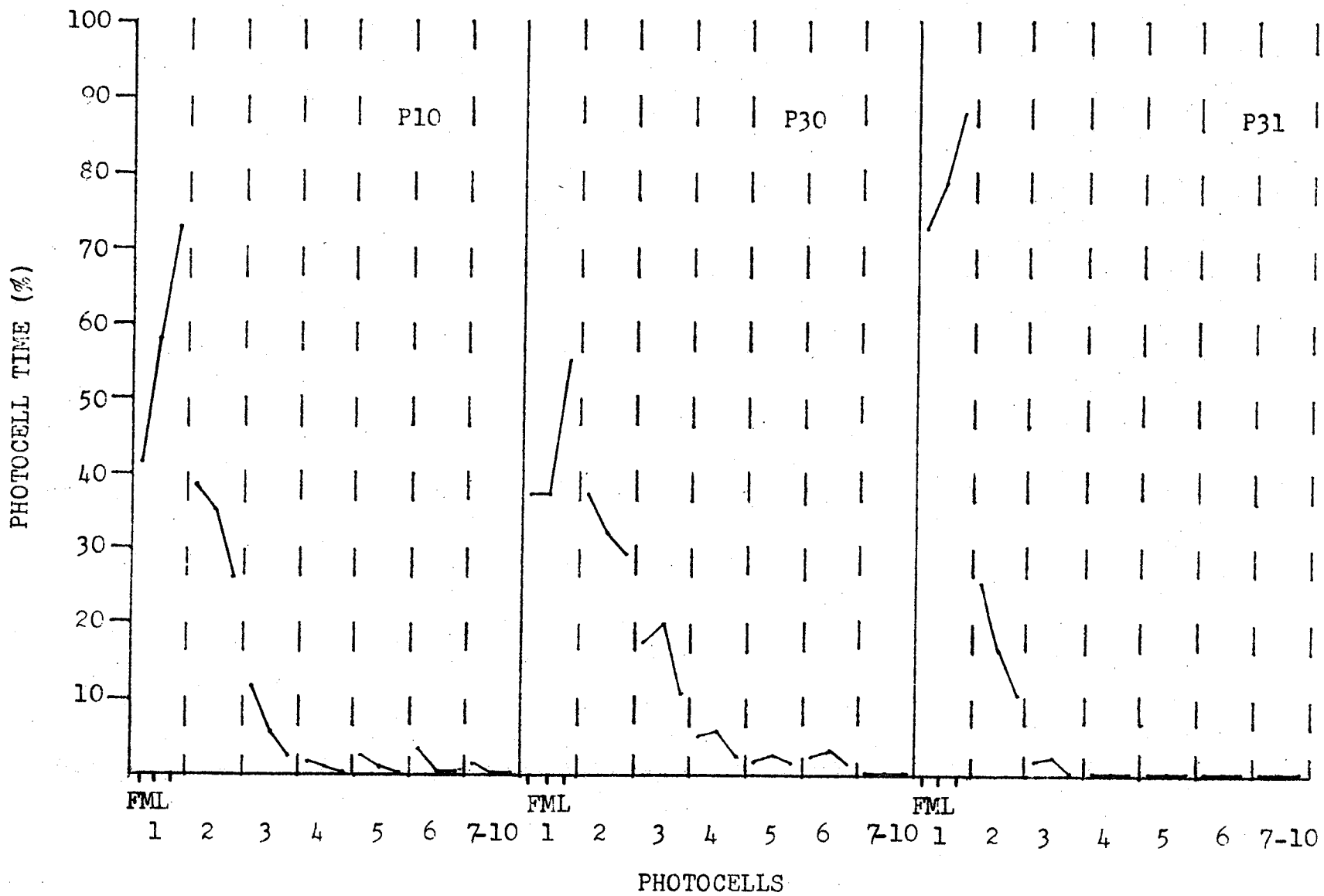
100 INCHES  
R/SEC  
3.0  
1.0  
0.5  
0.25  
5 MINUTES

Figure 9. Cumulative record of scallop response pattern during  
FI 1-min for P31.



1.00 IN. 50 DIVS  
RS/SEC  
0.5  
0.1  
0.05  
0.025  
5 MINUTES

Figure 10. Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval from a session demonstrating a scallop response pattern during FI 1-min for all birds. The letters F, M, and L indicate the first, middle and last thirds of the inter-reinforcement interval, respectively.





key-pecking activity moved proportionally closer to the response key as the inter-reinforcement interval progressed.

2. For all three birds, the structural changes in the key-pecking activity associated with scalloped patterns of responding were clearly larger than those structural changes (if any) associated with early FI performance (Figure 5).

3. The scalloped pattern appears to be associated with head movements relatively far from the key. P31, which showed the least degree of scalloping (see Figure 4), also spent proportionally more time in front of Photocell 1 than any of the other birds. That is, the key-pecking activity of P31 was proportionally closer to the response key relative to the key-pecking activities of the other birds for those sessions compared in Figure 10. Additional support for this inferred relation between scalloping and the structure of the activity will be presented below, when terminal performance is described.

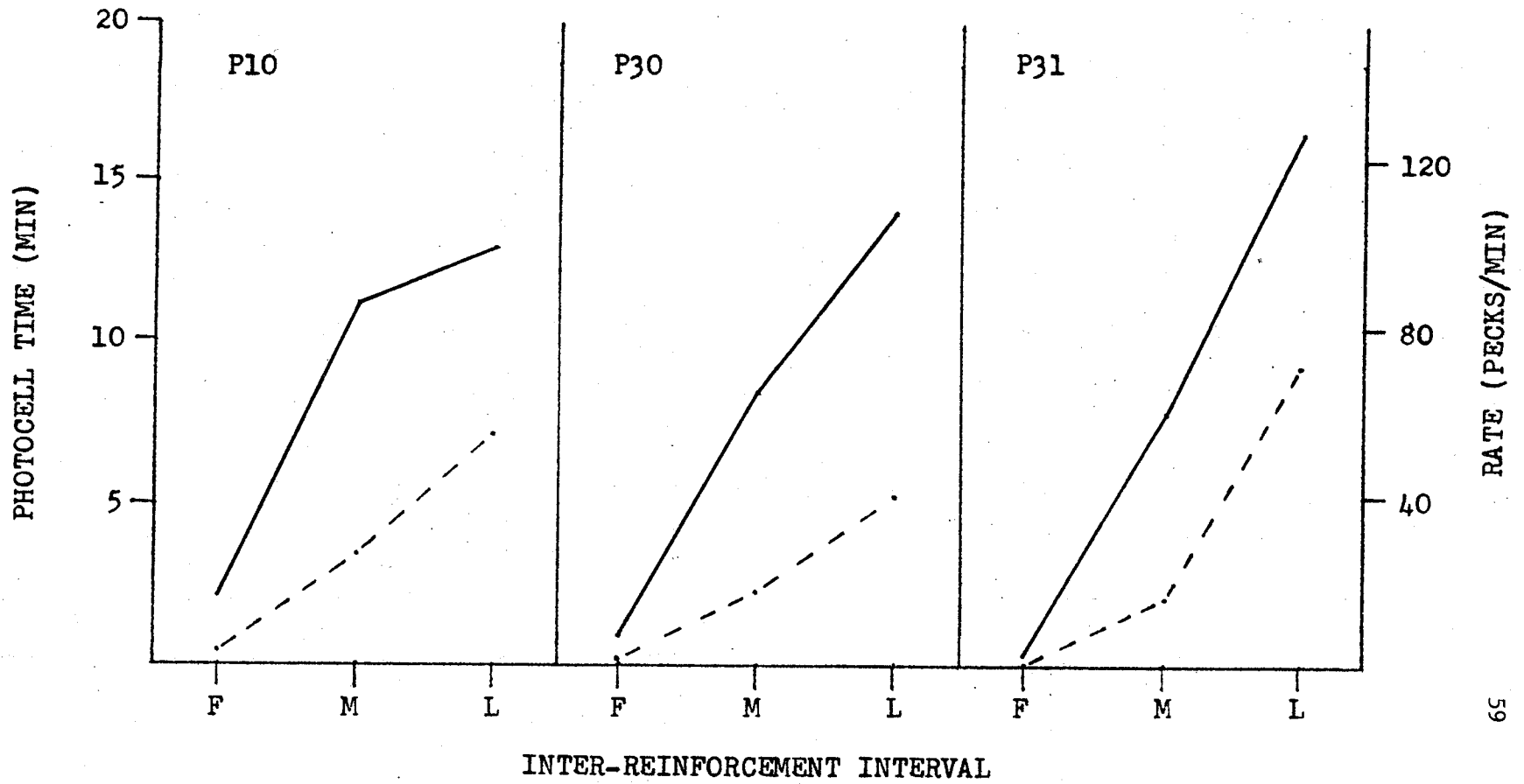
Figure 11 shows total photocell time and response rate across successive thirds of the inter-reinforcement interval for each bird for those sessions shown in Figure 10. With the development of the scallop pattern of responding, all photocell time functions now show an increasing trend across the reinforcement interval. Two of the time functions (those for P10 and P30) show negative acceleration. All response rate functions show positive acceleration.

Terminal FI performance. Terminal or stable performance was considered to have been reached when visual inspection of the cumulative records and head-movement data showed no systematic trends across 5 consecutive sessions.

Figure 11. Total photocell time and response rate across successive thirds of the inter-reinforcement interval from a session demonstrating a scallop response pattern during FI 1-min for each bird.

— TIME  
- - - RATE

F-- FIRST THIRD  
M-- MIDDLE THIRD  
L-- LAST THIRD



Terminal performance in cumulative response patterns and photocell time distributions have already been presented for P10 in Figures 7 and 10, respectively. These data were taken from the last session of Phase I for P10 and are representative of the last 5 sessions of Phase I. As has been seen, this bird demonstrated large structural changes in its key-pecking activity across the inter-reinforcement interval. Associated with these structural changes were cumulative records which demonstrated pronounced scalloped patterns across the inter-reinforcement interval. Although this behavior was considered to be stable-state FI 1-min performance for P10 during Phase I, Phase III later demonstrated that this scallop pattern would eventually change into a break-run pattern. Thus, the scallop pattern for P10 is more appropriately categorized as an intermediate performance.

For P30 and P31, the scallop patterns of responding shown earlier eventually developed into a break-run pattern like that described by Ferster and Skinner (1957). Figures 12 and 13 are cumulative records of this pattern taken from the last session of Phase I for P30 and P31. Thus, for two of three birds in Phase I on FI 1-min, the scallop pattern was a transitional performance prior to a steady-state break-run pattern. These data replicate Cumming and Schoenfeld (1958) who observed this change with behavior maintained under FI 30-min.

Figure 14 shows the relative photocell time distributions of Session 17 for P30 and P31, and compares them with the relative photocell distributions averaged from the last 5 sessions of Phase I for each bird. Figure 14 can be summarized as follows:

Figure 12. Cumulative record of break-run response pattern during  
FI 1-min for P30.

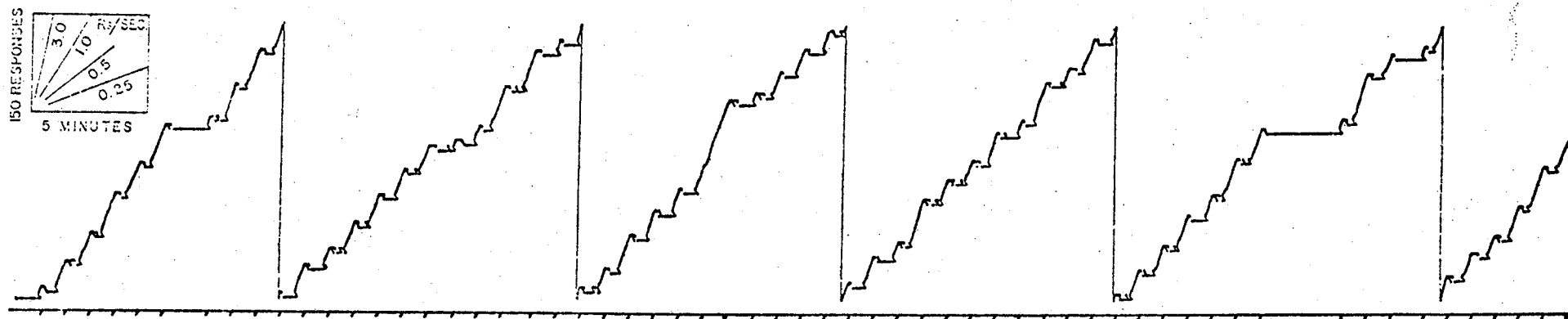
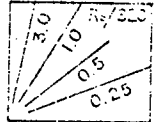


Figure 13. Cumulative record of break-run response pattern during  
FI 1-min for P31.

150 REVISIONS



5 MINUTES

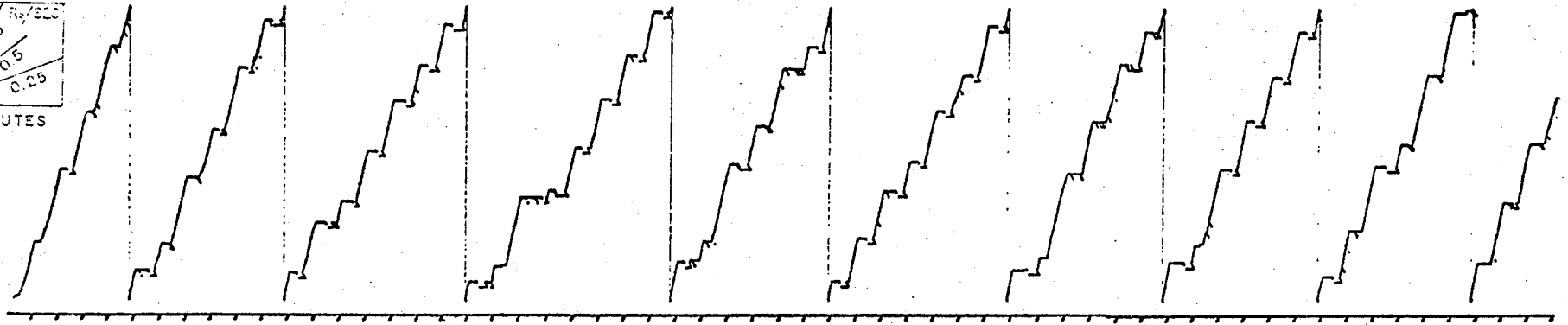
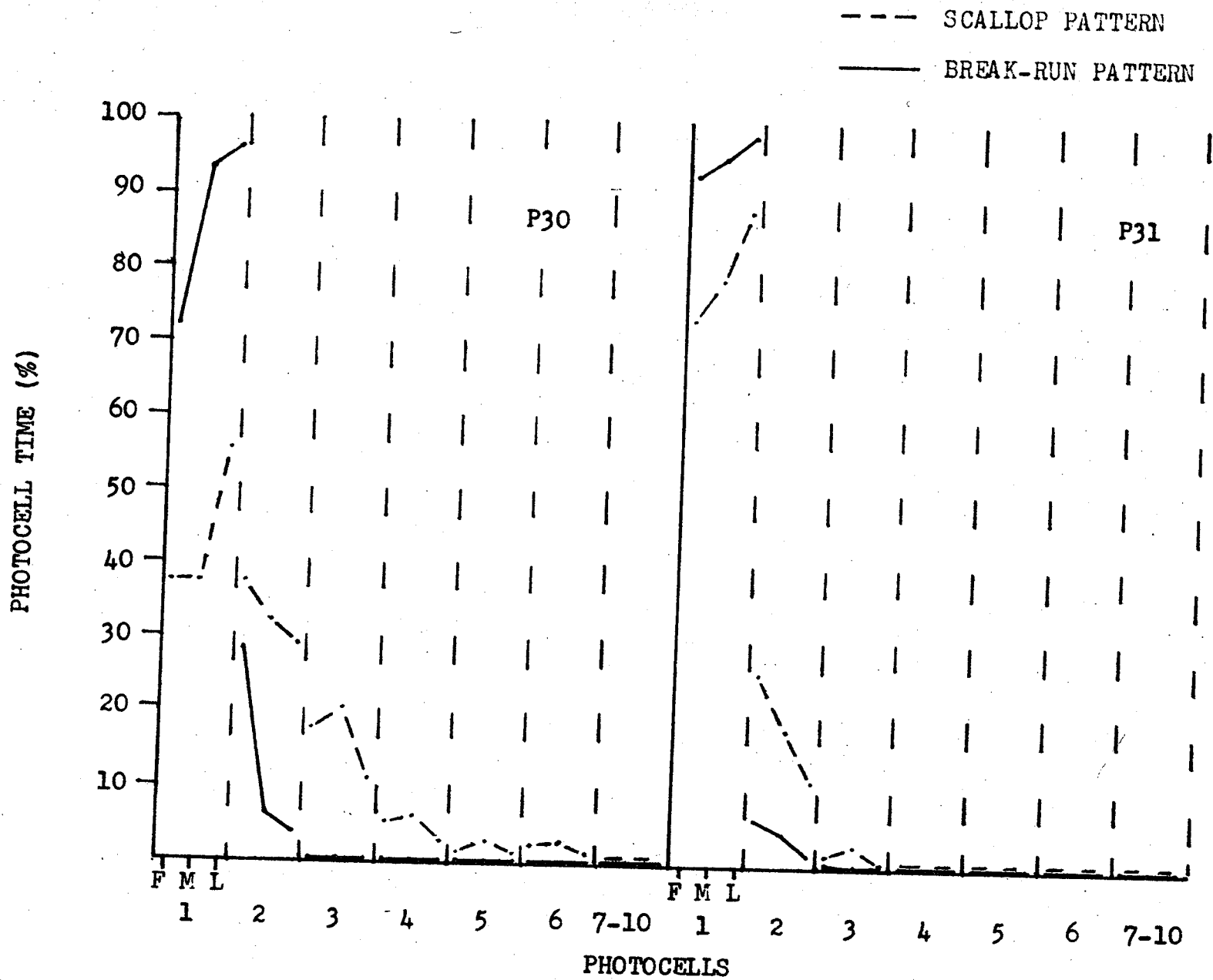




Figure 14. Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval for sessions demonstrating scallop and break-run response patterns for P30 and P31. The letters F, M, and L indicate the first, middle, and last thirds of the inter-reinforcement interval, respectively.



1. In association with a change from a scallop to a break-run pattern of responding, the key-pecking activities of both P30 and P31 had shifted proportionally closer to the response key relative to earlier behavior.

2. As with the scallop pattern, head movements during the break-run pattern tended to become closer to the response key as the inter-reinforcement progressed.

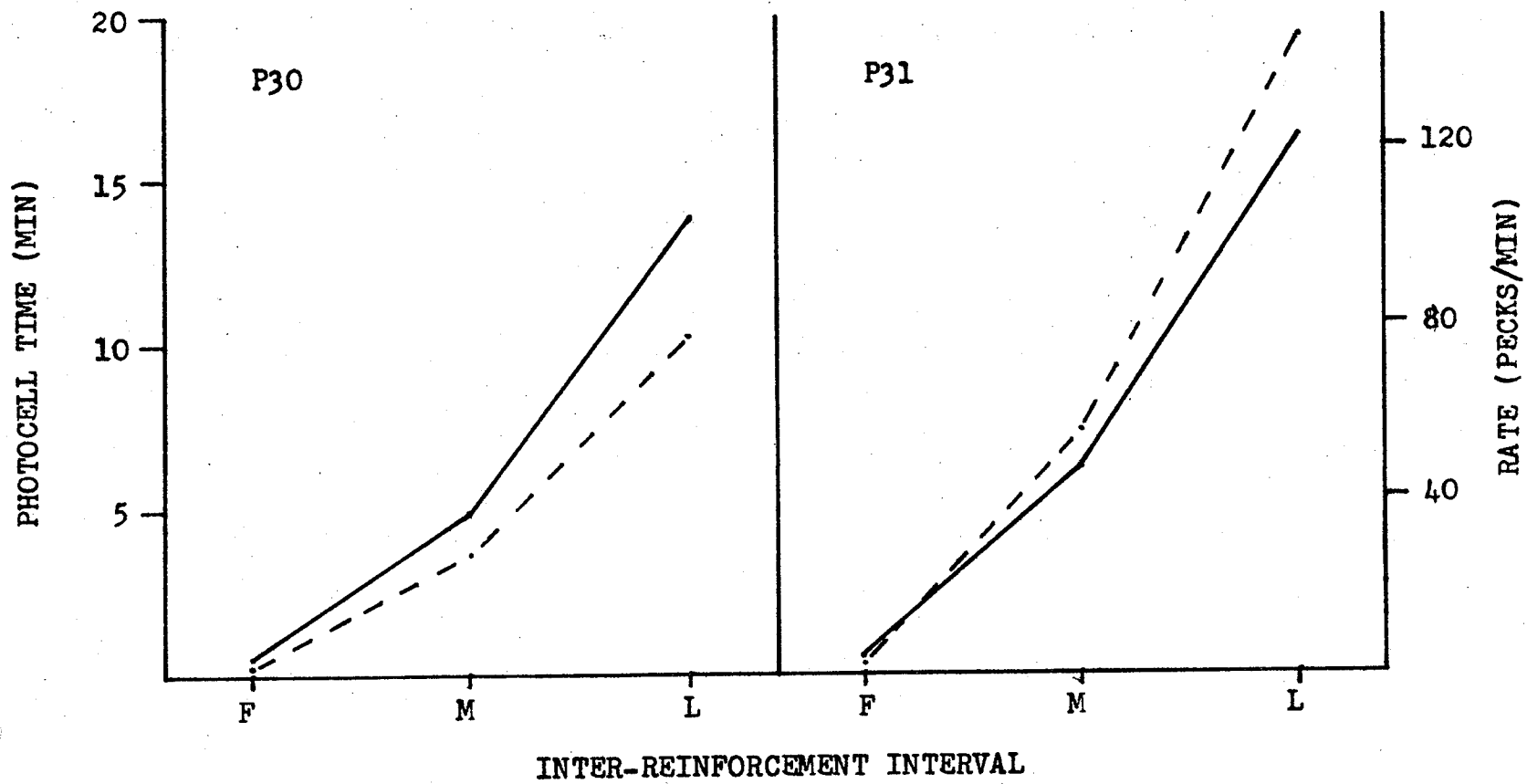
Figure 15 shows average photocell time and response rate across successive thirds of the inter-reinforcement interval for P30 and P31. The data was averaged over the last 5 sessions of Phase I and is representative of the individual sessions. For both birds, photocell time and response rate show positive acceleration across the inter-reinforcement interval. Figures 12 and 15, therefore, indicate that photocell time shows either negative or constant acceleration across the inter-reinforcement interval when scalloping occurs, but pronounced positive acceleration when the break-run pattern occurs. Overall response rate, on the other hand, shows positive acceleration when both patterns occur.

The cumulative records in Figures 12 and 13 indicate that the break-run pattern of key-pecking for P30 and P31 are similar in appearance. The photocell time distributions for both birds are similar for the last two-thirds of the inter-reinforcement interval (see Figure 14). However, Figure 14 also indicates that, for the first third of the inter-reinforcement interval, head movements tended to be proportionally further away from the response key for P30 than for P31. This presents

Figure 15. Total photocell time and response rate across successive thirds of the inter-reinforcement interval during steady-state FI 1-min performance for P30 and P31. The data was averaged over the last 5 sessions of Phase I.

— TIME  
- - - RATE

F-- FIRST THIRD  
M-- MIDDLE THIRD  
L-- LAST THIRD



an interesting question: If the structure of the key-pecking activity is related to the type of cumulative response pattern generated, how can the structure between two activities be different yet show the same cumulative response pattern? The answer may be found in Figure 15. Figure 15 shows that photocell time for the first third of the reinforcement interval averaged less than 30 sec per session for both birds. Due to the short duration of the two activities during this portion of the reinforcement interval, differences in structure at this time would have had little effect on producing different types of cumulative response patterns.

A similar analysis can account for why P10 and P30 earlier showed almost identical relative photocell distributions in Figure 10, but demonstrated different degrees of scalloping as shown in Figures 7 and 8. Although the structure of the activities for P10 and P31 were similar across the inter-reinforcement interval, Figure 11 indicates that the amount of time engaged in these various structural combinations differed between the two birds.

In summary, in addition to structural changes, the amount of time the bird engages in the various key-pecking structures across the inter-reinforcement interval is related to the type of cumulative response pattern generated.

The data for Phase I can be summarized as follows:

1. For all three birds, during early FI behavior the structure of the key-pecking activity changed only slightly across the inter-reinforcement interval. Photocell time remained fairly constant across successive

thirds of the inter-reinforcement interval. Cumulative records of key pecking during this time demonstrated linear patterns across the entire inter-reinforcement interval.

2. For all three birds, with continued exposure to FI 1-min structural changes in the key-pecking activity occurred across the inter-reinforcement interval. For all birds, the key-pecking activity tended to move proportionally closer to the response key as the inter-reinforcement interval progressed. Photocell time showed either negative or constant acceleration across the inter-reinforcement interval, while response rate showed positive acceleration. Cumulative records of key pecking during this time generally demonstrated a scalloped pattern across the inter-reinforcement interval.

3. By the end of Phase I, the key-pecking activities of two birds shifted proportionally closer to the response key relative to (2) above. Their head movements, however, still moved closer to the response key across the inter-reinforcement interval. Photocell time and response rate both showed positive acceleration across the inter-reinforcement interval. For these birds, cumulative records of key pecking now showed a break-run pattern of responding.

4. Three aspects of the key-pecking activity appear to be related to the generation of various cumulative response patterns: a) The distance of the majority of the activity from the response key; i.e., how close or far away from the key most of the activity is. b) The types of structural changes which occur in the activity over time. c) The proportion of time the bird engages in the key-pecking activity

relative to other activities.

### Phase II

During Phase II the food hopper was empty. Presentations of the food hopper, however, still occurred on a FI 1-min schedule. Sessions terminated after 60 min. Two birds (P10 and P31) served in Phase II. Upon termination of Phase I, P10 and P31 had demonstrated the largest and smallest structural changes, respectively, in their key-pecking activities across the inter-reinforcement interval. P10 and P31 had also demonstrated pronounced scallop and break-run patterns, respectively, by the end of Phase I.

Figure 16 shows total photocell time and overall response rate for each session of Phase II for each bird. Both birds show a drop in photocell time and response rate across Phase II.

Figure 17 shows the relative photocell time distributions for each session of Phase II for each bird. Only Photocells 1, 2, and 3 are presented for P10, and only Photocells 1 and 2 are presented for P31. These photocells comprised approximately 98% of the total photocell time. For comparison purposes, Figure 17 also includes the average percentage of time these photocells were operated across the inter-reinforcement interval over the last 5 sessions of Phase I. The data from Figure 17 will be discussed for each bird individually.

P10. The photocell distributions for P10 can be summarized as follows:

1. Relative time in front of each photocell, and therefore the structure of the key-pecking activity, became more constant across the





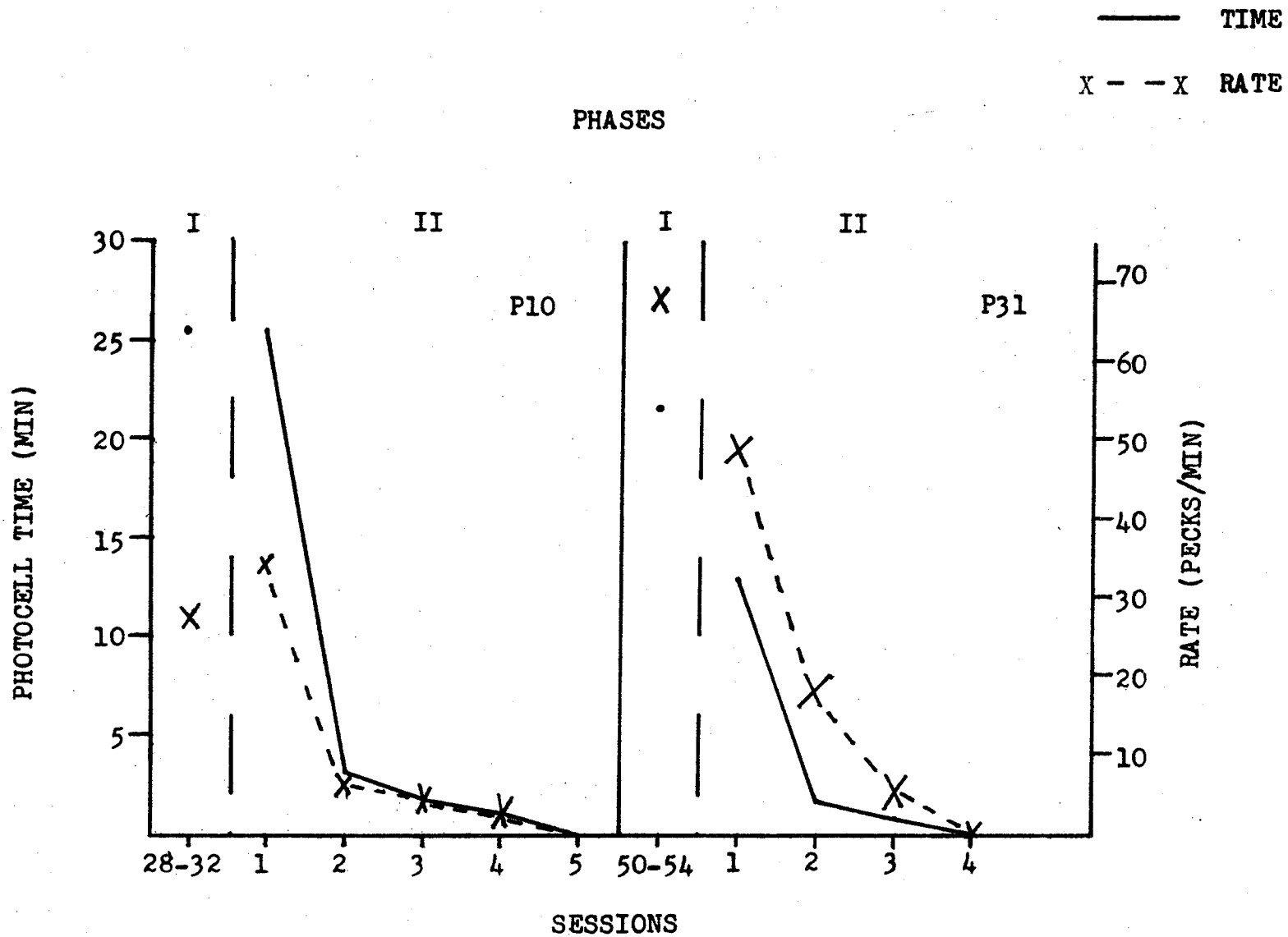
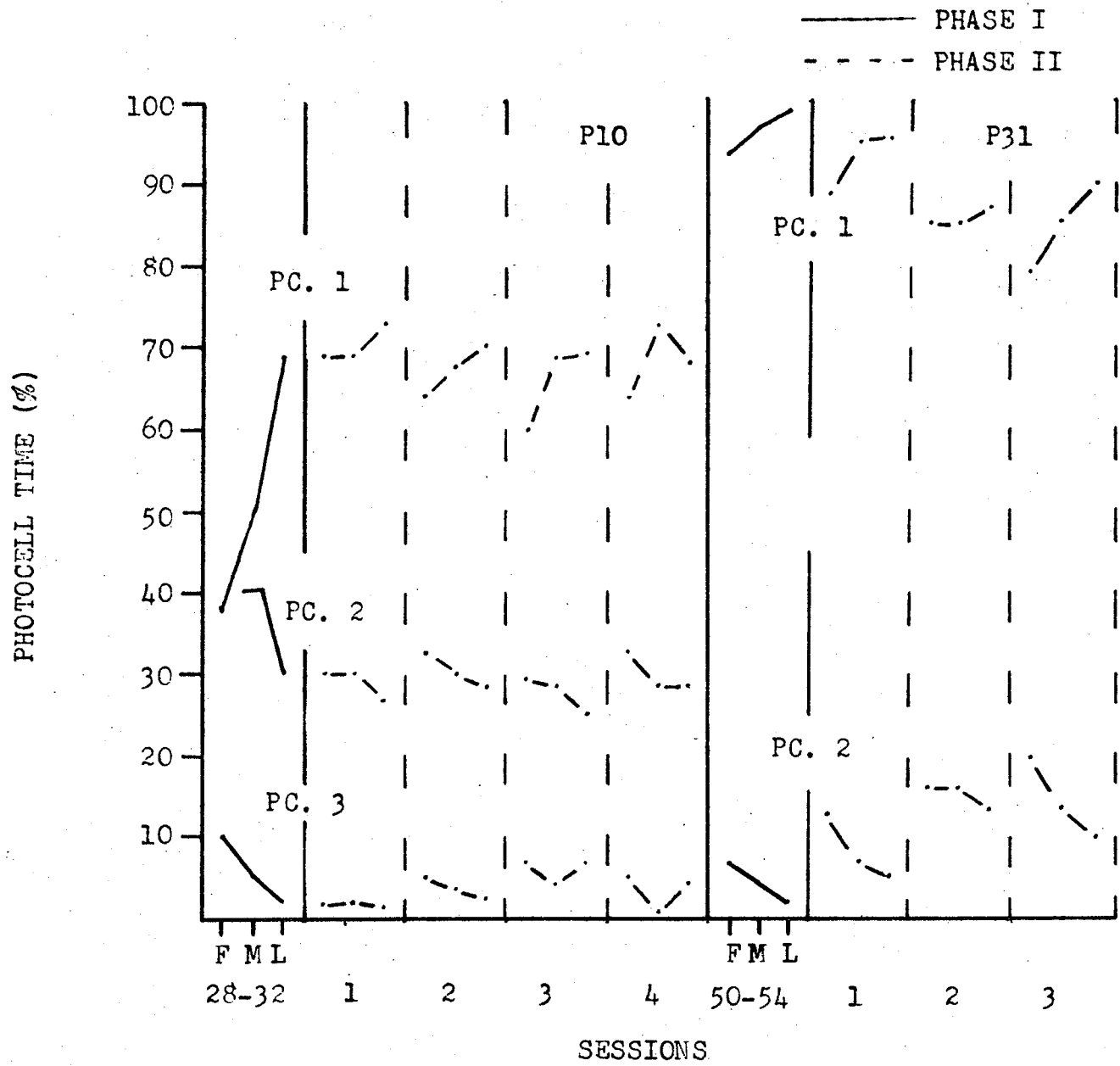


Figure 17. Percentage of time photocells 1, 2, and/or 3 were operated across successive thirds of the inter-reinforcement interval for each session of Phase II for P10 and P31. The average percentage of time each photocell was operated across the inter-reinforcement interval over the last 5 sessions of Phase I is also presented. F, M, and L indicate the first, middle, and last thirds of the inter-reinforcement interval, respectively. PC. 1, 2, and 3 indicates Photocell 1, 2, and 3, respectively.



inter-feeder interval relative to Phase I.

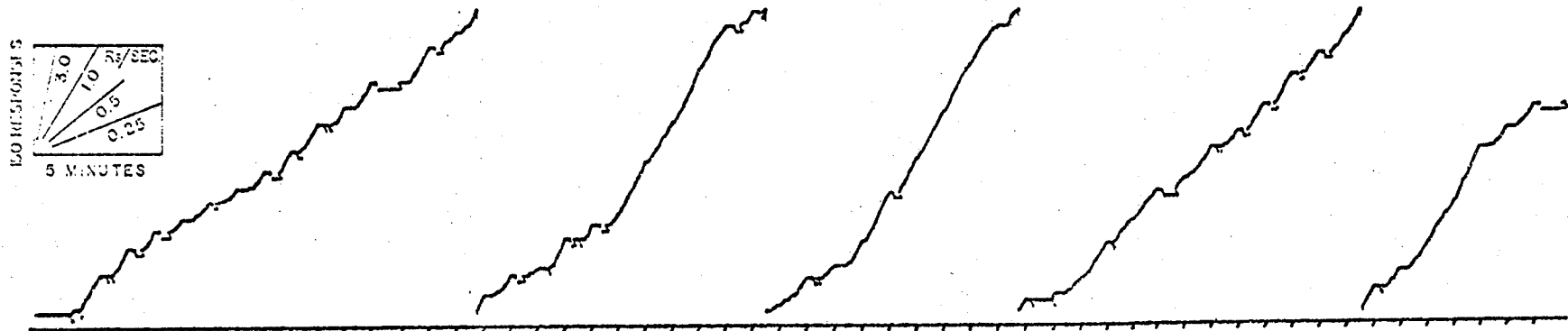
2. The percentage of time each photocell was operated throughout the inter-feeder interval in Phase II was similar to that observed during the latter third of the inter-reinforcement interval of Phase I. Therefore, the structure of the operant throughout the inter-feeder interval of Phase II was similar to the structure of the operant which occurred just prior to a feeder operation in Phase I.

3. The relative photocell time distribution remained fairly constant throughout Phase II despite a large drop in absolute photocell time across the phase. This indicates that, although the key-pecking unit was being emitted less often across Phase II, the structure of the operant nevertheless remained fairly constant within the phase.

Changes in the cumulative records of key pecking accompanied the structural changes in the activity reported above. Figure 18 shows the cumulative record for Session 1 of Phase II for P10. The record shows that, relative to the scalloped performance by the end of Phase I (see Figure 7), a more steady rate of responding developed with "run-throughs" (key pecking which continued immediately after a feeder operation) occurring for many of the inter-feeder intervals. Thus, as was found during Phase I, when the structure of the key-pecking activity becomes more constant across the inter-feeder interval, cumulative response patterns become more linear.

P31. The relative photocell distributions for P31 across Phase II are presented in Figure 17. These distributions can be summarized as follows:

Figure 18. Cumulative record of Session 1 of Phase II for P10.



1. Structural changes in the operant across the inter-feeder interval became larger. Whereas head movements changed about 5% across the inter-reinforcement interval in Phase I, they changed by 10-12% across the inter-feeder interval in Phase II by Session 3.

2. The total proportion of time comprised by Photocell 1 systematically decreased across Phase II, while the total proportion of time comprised by Photocell 2 systematically increased.

3. Despite the above two types of structural changes across Phase II, the key-pecking activity always moved proportionally closer to the response key as the inter-feeder interval progressed.

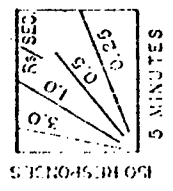
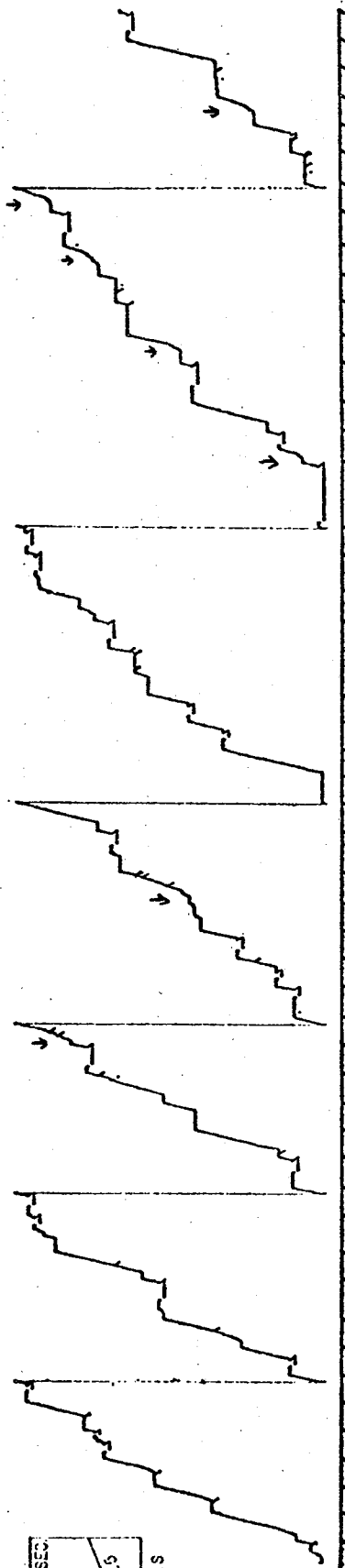
Thus across Phase II as photocell time and response rate decreased, the key-pecking activity for P31 demonstrated larger and larger structural changes across the inter-feeder interval. In addition, the activity occurred proportionally further and further away from the response key across the phase. Within the inter-feeder interval, however, the key-pecking activity always moved proportionally closer to the response key as the interval progressed.

Figure 19 shows the cumulative record for Session 1 of Phase II for P31. The record indicates that along with the structural changes reported above, scalloping which was absent during terminal performance in Phase I (see Figure 12), now occurred to some extent during Phase II. The above structural changes and the accompanying increase in scalloped responding is consistent with the data reported earlier on the development of scalloped response patterns in Phase I.

The data for Phase II can be summarized as follows:



Figure 19. Cumulative record of Session 1 of Phase II for P31.  
Arrows indicate scallop pattern.



1. For the two birds which served in Phase II, response rate and absolute photocell time decreased across Phase II.
2. Both birds demonstrated immediate changes in the structure of their key-pecking activities upon the introduction of Phase II. For one bird, the structure of the activity became more constant across the inter-feeder interval relative to Phase I, and the majority of the activity was relatively closer to the response key. For the other bird structural changes in the activity became larger, and the activity moved further away from the key relative to Phase I.
3. For one bird, a decrease in response rate across Phase II occurred only as a function of the key-pecking unit being emitted less frequently across the phase. For the other bird, response rate also decreased across Phase II as a function of the key-pecking unit being emitted less frequently. In addition, structural changes occurring within the unit may also have contributed to the decrease in response rate.
4. As was shown in Phase I, systematic changes in the relative photocell time distributions were accompanied by systematic changes in cumulative response patterns. A more consistent structure in the key-pecking activity across the inter-feeder interval was accompanied by a more linear response pattern. When structural changes in the activity became larger, and the activity shifted proportionally further away from the response key, more curvilinear response patterns were observed.

### Phase III

Phase III was a reversal to conditions present during Phase I;

i.e., FI 1-min. The data from Phase III will be discussed for each bird individually.

P10. By the end of Phase I P10 had demonstrated pronounced scallop patterns (see Figure 7). However, after approximately 150 sessions on FI 1-min in Phase III the steady-state performance for this bird demonstrated a more consistent break-run pattern (see Figure 20). Thus, for all three birds in this study, the scallop pattern of responding was an intermediate pattern prior to a steady-state break-run pattern.

The left side of Figure 21 compares the relative photocell time distribution for P10 for Phase I and III. The distributions are averaged over the last 5 sessions of each phase. Relative time in the first third of the inter-reinforcement interval for Phase III is not presented because total time for a session averaged less than 0.5 sec for this interval. Figure 21 indicates that the key-pecking activity of P10 occurred proportionally closer to the response key relative to Phase I. P30 and P31 had also demonstrated this effect in Phase I when a scallop pattern of responding developed into a break-run pattern (see Figure 14).

Figure 22 shows total photocell time and response rate across successive thirds of the inter-reinforcement interval for P10. The data was averaged over the last 5 sessions of Phase III. Positive acceleration in photocell time and response rate occurred across the inter-reinforcement interval. The change to pronounced positive acceleration in photocell time was also demonstrated by P30 and P31 when a scallop pattern of responding developed into a break-run pattern in Phase I (see Figures 11 and 15).

Figure 20. Cumulative record of break-run response pattern during  
FI 1-min for P10 during Phase III.

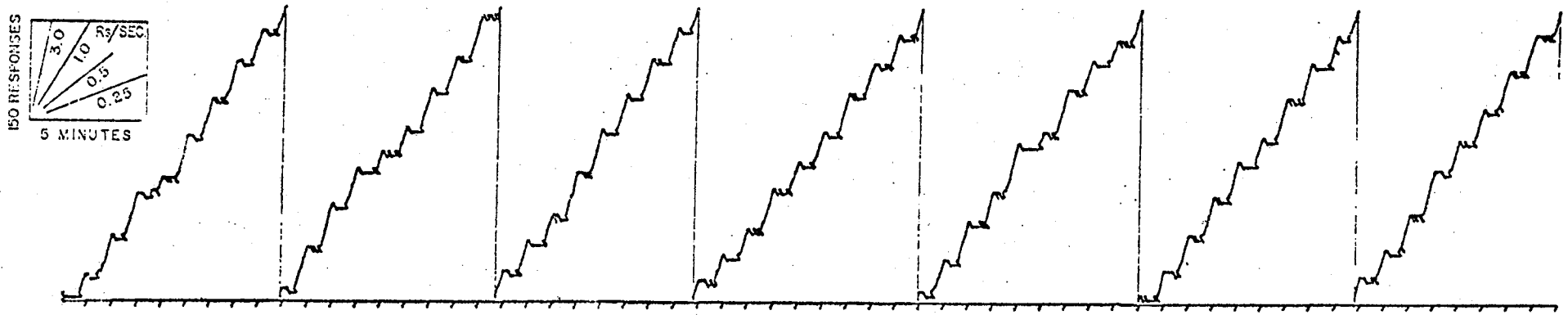


Figure 21. Percentage of time each photocell was operated across successive thirds of the inter-reinforcement interval over the last 5 sessions of Phases I and II for P10 and P31. The letters F, M, and L, indicate the first, middle, and last thirds of the inter-reinforcement interval, respectively.

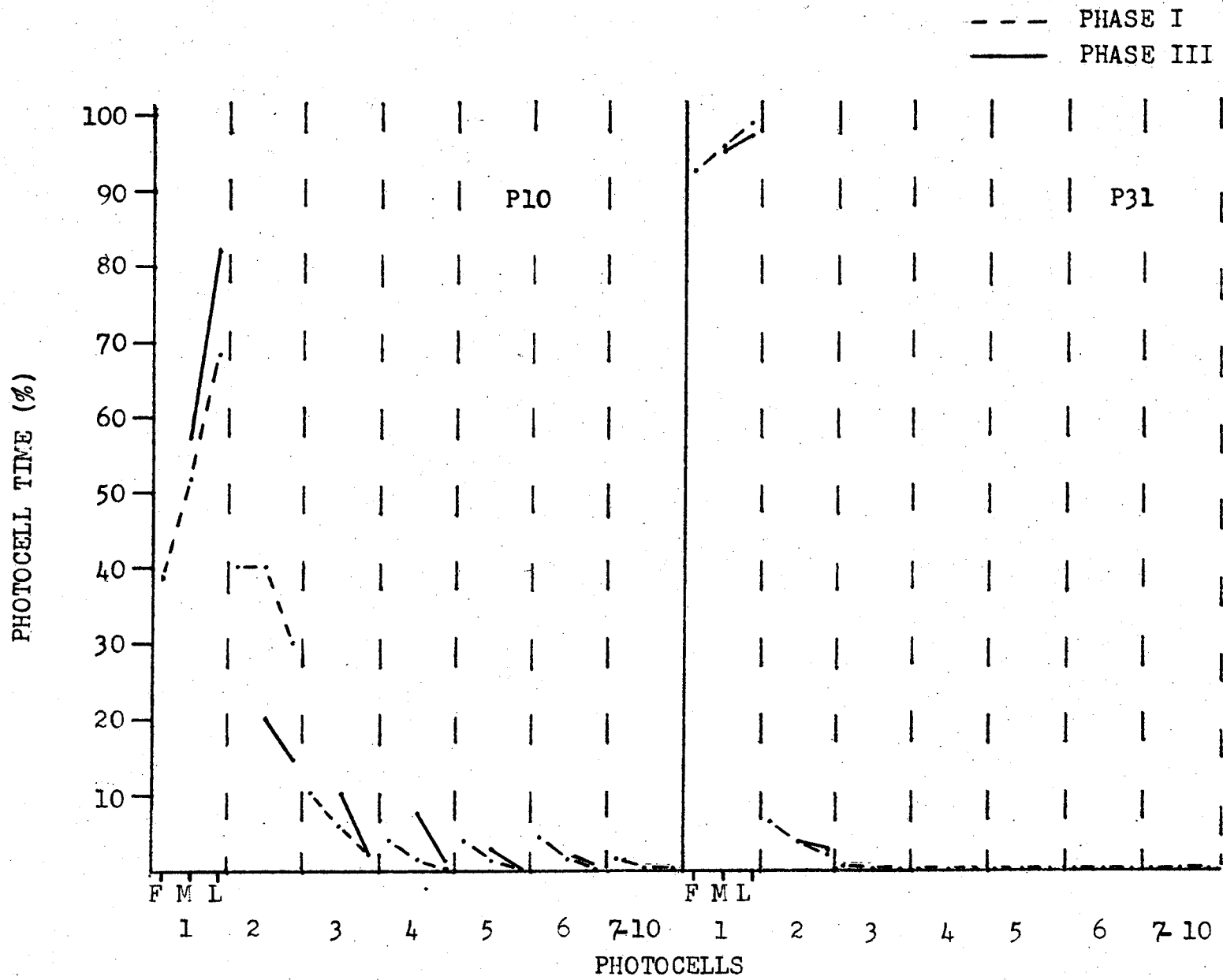
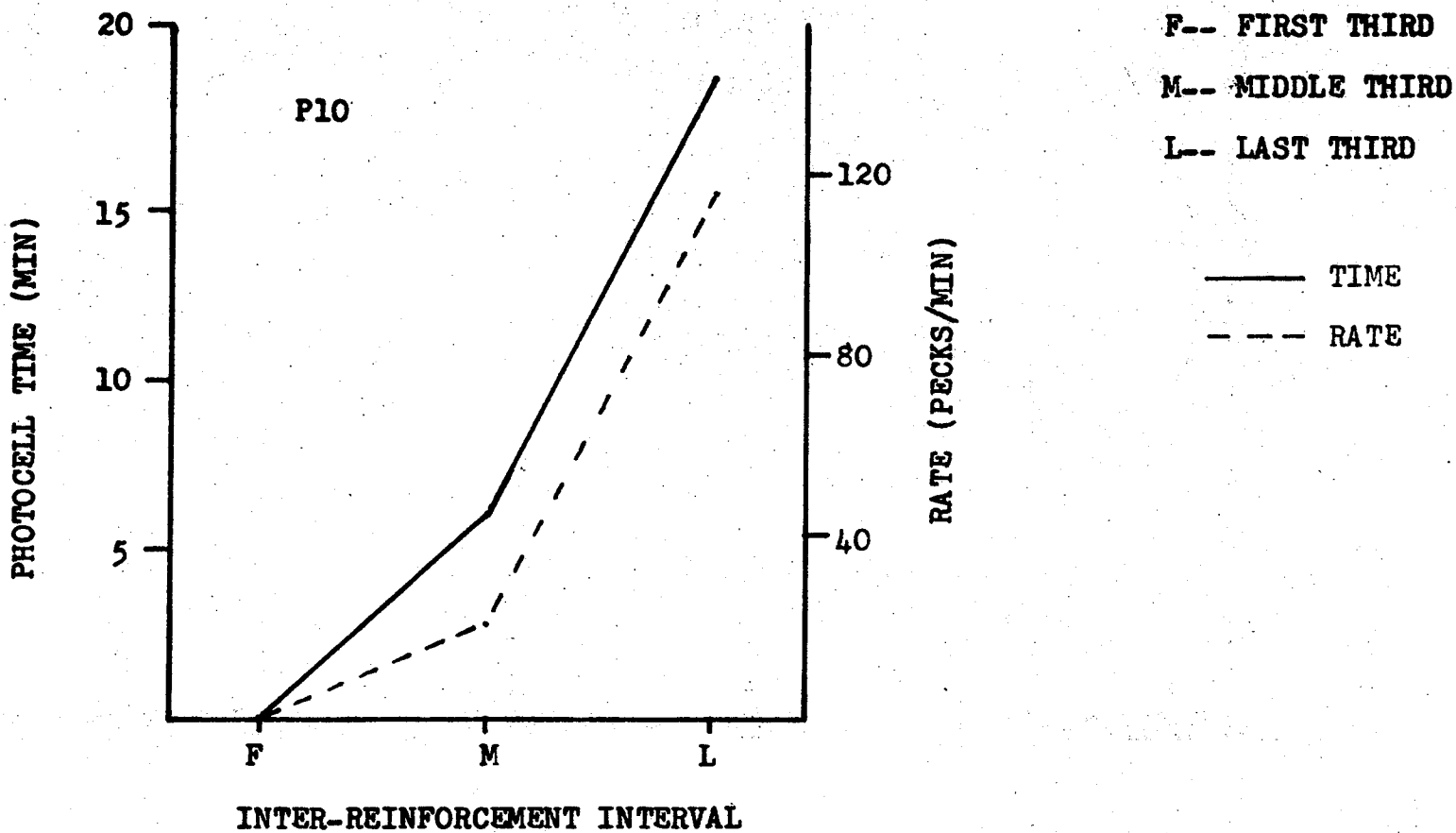




Figure 22. Total photocell time and response rate across successive thirds of the inter-reinforcement interval averaged across the last 5 sessions of Phase III for P10.



P31. The right side of Figure 21 presents the relative photocell time distributions for P31 for Phases I and III. The distributions were averaged over the last 5 sessions of each phase. Since the first third of the inter-reinforcement interval for Phase III only accumulated on the average 1 sec of time for a session, percentage time for this interval is not presented. Figure 21 indicates that the photocell distributions for P31 in Phase III were very similar to those of terminal performance in Phase I. except for an increase in PRP length in Phase III, the cumulative records for P31 demonstrated the same break-run pattern that was observed for terminal performance in Phase I.

Both birds occasionally stood on the platform during the PRP. It is important to note, however, that very little photocell time was accumulated for either bird during the first third of the inter-reinforcement interval. This is consistent with the earlier observation that when the birds were standing on the platform and not pecking, they were well below the photocell sensors.

The data for Phase III can be summarized as follows:

1. With extended exposure to FI 1-min, the key-pecking activity of P10 shifted proportionally closer to the response key relative to Phase I. Whereas negative acceleration in photocell time occurred across the inter-reinforcement interval in Phase I for P10, positive acceleration occurred in Phase III. The cumulative records demonstrated that a scallop pattern of responding, which was present in Phase I for this bird, changed to a break-run pattern in Phase III. All these effects had previously been shown for P30 and P31 within Phase I.

2. The key-pecking activity of P30 demonstrated the same structure in Phase III as in Phase I. The break-run pattern was present for both steady-state performance for each phase.

## CHAPTER V

### GENERAL DISCUSSION

From the results of the present experiment it appears that the following generalizations can be made.

#### Summary of Behavioral Developments Under FI 1-min

Upon the introduction of FI 1-min, the structure of the key-pecking activity remains constant across the inter-reinforcement interval. The amount of time the bird engages in the operant is also constant across the interval. Constant structure and constant time allocation of the operant is associated with a linear response pattern across the entire inter-reinforcement interval.

With continued exposure to FI 1-min, structural changes in the operant occur across the inter-reinforcement interval. Head movements now move proportionally closer to the response key as the interval progresses. A PRP is present but of relatively short duration. Time allocation of the operant is a negative accelerating function across the inter-reinforcement interval. These structural changes and changes in time allocation of the operant across the inter-reinforcement interval are associated with scalloped response patterns.

Eventually, the entire key-pecking activity shifts proportionally closer to the response key relative to previous observations. Head movements, however, still move proportionally closer to the response key as the inter-reinforcement interval progresses. The PRP has increased in length. Time allocation of the operant at this stage is a positive accelerating function across the inter-reinforcement interval. These

structural changes and the times allotted to these structures is associated with a break-run cumulative response pattern.

#### Summary of Behavioral Developments During Extinction

As response rate decreases across extinction, the amount of time the bird engages in the key-pecking operant decreases. When behavior has been maintained on FI 1-min immediate changes in the structure of the operant occur upon the introduction of an extinction procedure. As response rate decreases across extinction, the structure of the operant may remain constant or systematically change.

#### Variables Correlated with Response Patterns

Three aspects of the key-pecking activity appear to have been related to the generation of various cumulative response patterns: a) the distance of the majority of the activity from the response key, i.e., how close or far away from the key most of the activity was; b) the types of structural changes which occurred for the activity over time; and c) the proportion of time the bird engaged in the key-pecking activity relative to other activities.

The concept of a key-pecking activity and the use of photocells to measure certain elements of that activity has produced some orderly data. A number of basic theoretical questions and areas for future research have been suggested by this data.

The fundamental unit of analysis. Most established sciences have adopted basic units of analysis. For example, in chemistry the elements form the minimal units of analysis. Chemical phenomena are investigated in terms of these elements or units. In the experimental analysis of

behavior the operant has been considered to be the basic unit of analysis. In general, the occurrence of an operant has been recorded as an instantaneous point in time. It was suggested in the introduction of this thesis, however, that the presentation of a reinforcer increases the frequency of occurrence of an entire sequence of behavior. If key pecking is the operant examined, some of the elements involved in this unit would be head positions near the response key. How these elements change over time is the structure of the key-pecking unit or operant. Schoenfeld (1976) and Shimp (1976) have argued that the basic behavioral unit has a constant or stereotyped structure. Thus, the rate of the unit increases or decreases as a function of the basic behavioral sequence being emitted more or less often, respectively, per unit of time.

The concept of the basic unit of behavior as having a constant or stereotyped structure has to be critically analyzed in light of the present experiment. If the basic unit has a constant structure one would expect the pattern of head movements across the inter-reinforcement interval of a FI schedule to remain constant. In the present experiment this was true when key pecking demonstrated a linear pattern. However, when scalloped patterns of key pecking were obtained head movements changed systematically across the entire inter-reinforcement interval. In this latter situation, in order for the basic unit to be defined as having a constant structure the unit would have to be the entire behavior pattern; i.e., the scallop. Two major problems also arise with this interpretation, however. First, variations in the structure of the key-pecking activity occur between inter-reinforcement intervals. Overall

rate and head movement graphs may show systematic changes across the inter-reinforcement interval, but these graphs represent data that has been averaged over many intervals. They do not necessarily represent the specific events for each and every interval. Upon close examination of any cumulative record one can see many deviations between intervals at the molecular level. Second, continuous and systematic changes in the structure of the key-pecking operant occur throughout the development of FI behavior.

An alternative to the stereotyped behavioral unit appears to be required if one considers the behavior generated during FI schedules at a molecular level. The data from the present experiment suggest that three types or levels of structural changes can occur in the operant over time:

1. The first structural level describes the actual elements which form the operant. A complete structural change at this level would occur only if the entire operant shifted from one location in space to another.

2. The second structural level describes how the elements form the operant. Those structural patterns observed across the inter-reinforcement interval of a FI schedule represent this level.

3. The third structural level describes how the same behavioral elements change in probability over long periods of time. The relative photocell time distributions changing systematically over sessions represents this level.

The above observations suggest that the basic behavioral unit is



derived from a set of continuous elements. The probability of occurrence of any element, and thus the unit's structure, can change over time. In terms of this analysis a fixed or stereotyped unit may occur in limited situations. However, systematic changes in the structure of the behavioral sequences which comprise the unit can also occur.

The long term usefulness of our present "basic behavioral unit" should also be questioned. Much of the experimental analysis of behavior has observed behavior as a discrete event. Hopefully, the experimental analysis of behavior will progress towards the development of laws involved with the more continuous aspects of behavior. A problem that arises is that terminology useful at one level of analysis may be inappropriate at another. A complete description and analysis of the continuous aspects of behavior may not be possible with a technology and a terminology based on discrete units of observation. As the science develops some type of basic unit will probably be maintained. However, the present author doubts such a unit will have discrete boundaries.

In terms of future research, the ability to record head movements associated with the key-pecking operant of pigeons should lead to more control over the structure of this operant. To date, studies concerned with control over the structure of the operant have been minimal and have dealt with reinforcing specific IRTs. However, only one behavioral element of the operant is recorded and directly controlled in these experiments. The combined duration of the other behavioral elements have been specified but not their actual topographies. (In some situations, such as with long IRTs, these other elements may actually be from activities other

than the experimental operant such as preening, wing flapping, etc. The photocell apparatus of the present experiment will allow the experimenter to specify more precisely the structure of an operant.

Time as a dependent variable. The present experiment supports the position that examining the duration of behavior can lead to the establishment of both structural and functional relationships at either the molecular or molar levels of analysis. A question that some researchers dwell upon is whether the duration of behavior is a more fundamental dependent variable than response rate, or vice versa. However, the seeming importance of this question is related only to the confines of our present technology. Upon closer examination of the issues, one can see that the relative duration of a behavioral element and its rate of occurrence are the same dependent variables. The activity of key pecking consists of an infinite number of behavioral elements. If we record the frequency of each behavioral element and we do so with inter-observation times approaching zero (i.e., continuously), the rate of occurrence of each element and the relative duration of each element become identical variables. Summing the frequencies of all the behavioral elements would give us the total duration of the activity or operant. Present day distinctions between time and response rate lie only in the number of behavioral elements examined, or time between experimenter observations.

Stimulus control. "Stimulus control is observed when a change in a particular property of a stimulus produces a change in some response characteristic (Rilling, 1977, p. 433)." In the experimental analysis

of behavior, stimulus control has typically been measured in terms of: response rate changes (Guttman & Kalish, 1956; Jenkins & Harrison, 1962); inter-response time changes (Blough, 1963, 1969); and changes in the estimated amount of time the organism engages in the experimental operant (Migler & Millenson, 1969; Rand, 1977). The concept of the operant as a unit of behavior that has structure suggests a more molecular dependent variable in the analysis of stimulus control. It is possible that changes in stimulus control may be measured in terms of changes that occur in the structure of the operant studied.

In their analysis of inhibition Hearst, Beasley and Farthing (1970) defined an inhibitory stimulus as "a stimulus that develops during conditioning the capacity to decrease response strength below the level occurring when that stimulus is absent" (p. 376). A number of changes in the behavior of the organism could account for this decrease in response strength (as measured by one element of the activity) when an inhibitory stimulus is presented: 1) the reduction may be the result of an increase in the duration of other operants or activities; 2) the amount of time for completion of each key-peck unit may have increased. (This would occur if the subject moved its head at a slower speed from point to point along the key-pecking activity.); or 3) the structure of the unit may have changed such that some elements increased in frequency of occurrence while others, such as the closure of the microswitch, decreased. A decrease in response strength, as measured in terms of response rate, may represent any one or a combination of the above three possibilities for either inhibitory or excitatory

stimulus control.

In the present experiment, the systematic changes recorded in the structure of the key-pecking operant during a FI schedule suggests that structural changes may be an effect occurring during inhibitory and excitatory control over responding. As described in Chapter II, Wilkie (1974) obtained inhibitory stimulus control gradients during the early portions of an inter-reinforcement interval of a FI schedule, but excitatory gradients during the latter portions of an interval. The results of the present experiment demonstrated that relative head movements of the key-pecking activity at the start of an interval were proportionally further away from the response key than head movements at the end of the interval. This effect, along with the results obtained by Wilkie (1974), suggests that the presentation of an inhibitory or excitatory stimulus changes the structure of the operant such that the frequency of certain elements of the unit decrease or increase, respectively. In other words, a decrease in response rate observed upon the presentation of an inhibitory stimulus may be partially due to a change in the structure of the operant. Similar structural changes may also be occurring during excitatory stimulus control but resulting in increases in response rate.

The data for the present experiment also suggest that structural changes occur in the operant during the formation of a discrimination between a reinforced and non-reinforced component. With FI schedules the break-run pattern of responding can be considered to be the result of a discrimination between an "extinction" component and a "VI" reinforced component (Schneider, 1969). Before this discrimination fully

develops, however, the scallop pattern of responding occurs. During this time large structural changes in the key-pecking activity occur across the inter-reinforcement interval. It is possible that the scallop pattern of responding during FI schedules may be a function of changing degrees of stimulus control across the interval combined with resulting changes in the structure of the operant.

Due to the similarities between FI schedules and multiple VI-EXT schedules, it is possible that during the formation of the discrimination between the components of a multiple VI-EXT schedule, structural changes in the operant occur in the presence of  $S^-$ . It is expected that these changes would resemble those which occurred during the early portions of the inter-reinforcement interval when scalloped responding occurred in the present experiment. The duration of these transitional structural changes may also be related to the length of time required for the discrimination to develop. Along similar lines, those variables related to the increase in response rate during the shift from a scallop to a break-run pattern of responding with FI schedules, may be similar to those variables associated with increased response rate during the reinforcement component of a multiple VI-EXT schedule -- i.e., behavioral contrast phenomena.

Structure of the operant key peck vs. reflexive key peck. Williams (1965), with dogs, concurrently measured salivation and panel pushing. Panel pushing was maintained on a FI schedule of reinforcement. Williams found that within an inter-reinforcement interval, salivation often preceded panel pushing. Schwartz (1977a) examined the duration of key

pecks (i.e., the amount of time the microswitch was closed) across successive fourths of a FI 1-min and FI 2-min schedule of reinforcement. The data demonstrated that peck duration generally became longer as the inter-reinforcement interval progressed. On the basis of Williams data and previous studies which indicated that short key pecks (0-25msec) are insensitive to response-reinforcer relations (Schwartz & Williams, 1972; Schwartz, 1977b), Schwartz suggested that the pecks at the beginning of the inter-reinforcement interval of a FI schedule are reflexive -- i.e., under Pavlovian control.

In the present experiment head movements were found to change systematically across the inter-reinforcement interval of a FI 1-min schedule of reinforcement. The similarities between these data and those of Schwartz (1977a) support an alternative interpretation of short key pecks measured under FI schedules. The switch closure represents one structural element of the key-pecking operant. As the duration of the other elements of the operant change systematically across the inter-reinforcement interval, so does the switch-closure element. The gradual change in the structure of the activity across the inter-reinforcement interval does not support the position that two dichotomous types of key pecks are occurring at different ends of the inter-reinforcement interval. The data suggest a unitary behavioral phenomena occurring under changing values of a controlling parameter. One possible parameter may be changes in stimulus control which are known to occur across the reinforcement interval of a FI schedule (Wilkie, 1974).

Cumulative record. The cumulative record, as a means of analyzing

data, is being used less frequently in the experimental analysis of behavior relative to previous years (Skinner, 1976). Shimp (1976) suggested that the structural complexities presented by a cumulative record, and the difficulty in quantifying the structural changes which occur, accounts for the decrease in its usage. The data from the present experiment suggest that as the experimental analysis of behavior progresses towards quantifying behavior at the molecular level, both the molecular and molar behavior patterns exhibited by a cumulative record will be quantified.

Since the cumulative record at present only records one element of an activity its usefulness is restricted. A standard cumulative record cannot demonstrate structural changes in an activity. As with standard IRT distributions, a standard cumulative record can only suggest the occurrence of structural changes in the experimental operant. What the actual structure of an operant is, and to what extent the structure changes, can only be specified by empirically measuring those behavioral elements which actually define the unit.

In terms of a more precise and informative analysis, a recorder that demonstrates moment-to-moment changes in the structure of an operant needs to be developed. With some minor modifications, it seems possible for the cumulative recorder to accomplish this. While key-pecking the position of the bird's head changes over time. These various positions form, in part, the structure of the key-pecking operant. Suppose the closer the bird moves towards the response key, the faster the cumulative response pen moves in a vertical direction. At

some specified distance away from the key (such as off the platform in the present experiment), the response pen would only move in a horizontal direction as time progressed. The resulting record would demonstrate moment-to-moment changes in the structure of the operant. Changes in the slope of the cumulative line over time would represent changes in the actual structure of the operant over time.

Concluding comment. Over the past 50 years the rate of an instantaneous event has been extensively used in the analysis of behavior. The approach of the present experiment was to analyze the operant as a continuous phenomenon comprised of many elements. The durations of these elements were recorded. The results indicate this approach will clarify some of the behavioral phenomena studied in the past, and introduce the researcher to new behavioral phenomena related to the continuous aspects of behavior.



## References

- Alleman, H.D., & Zeiler, M.D. Patterning with fixed-time schedules of response-independent reinforcement. Journal of the Experimental Analysis of Behavior, 1974, 22, 135-141.
- Baum, W.M. Time allocation and negative reinforcement. Journal of the Experimental Analysis of Behavior, 1973, 20, 313-322.
- Baum, W.M. On two types of deviation from the matching law: Bias and undermatching. Journal of the Experimental Analysis of Behavior, 1974, 22, 231-242.
- Baum, W.M. Time-based and count-based measurement of preference. Journal of the Experimental Analysis of Behavior, 1976, 26, 27-35.
- Baum, W.M., & Rachlin, H.C. Choice as time allocation. Journal of the Experimental Analysis of Behavior, 1969, 12, 861-874.
- Blough, D.S. Interresponse time as a function of continuous variables: A new method and some data. Journal of the Experimental Analysis of Behavior, 1963, 6, 237-246.
- Blough, D.S. Generalization gradient shape and summation in steady-state tests. Journal of the Experimental Analysis of Behavior, 1969, 12, 91-104.
- Bouzas, A., & Baum, W.H. Behavioral contrast of time allocation. Journal of the Experimental Analysis of Behavior, 1976, 25, 179-184.
- Buchman, I.B., & Zeiler, M.D. Stimulus properties of fixed-interval responses. Journal of the Experimental Analysis of Behavior,

- 1975, 24, 369-375.
- Catania, A.C. Behavioral contrast in a multiple and concurrent schedule of reinforcement. Journal of the Experimental Analysis of Behavior, 1961, 4, 335-342.
- Catania, A.C. Concurrent performances: Reinforcement interaction and response independence. Journal of the Experimental Analysis of Behavior, 1963, 6, 253-263.
- Catania, A.C. Reinforcement schedules and psychophysical judgments: A study of some temporal properties of behavior. In W.N. Schoenfeld (Ed.), The theory of reinforcement schedules. New York: Appleton-Century-Crofts, 1970.
- Catania, A.C., & Reynolds, G.S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 1968, 11, 327-383.
- Chung, C., & Neuringer, A.J. Control of responding by a percentage reinforcement schedule. Psychonomic Science, 1967, 8, 25-26.
- Cumming, W.W., & Schoenfeld, W.N. Behavior under extended exposure to a high-value fixed interval reinforcement schedule. Journal of the Experimental Analysis of Behavior, 1958, 1, 245-263.
- Dews, P.B. The effect of multiple  $S^A$  periods on responding on a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 1962, 5, 369-374.
- Dews, P.B. The effect of multiple  $S^A$  periods on responding on a fixed-interval schedule: II. In a primate. Journal of the Experimental Analysis of Behavior, 1965, 8, 53-54. (a)

- Dews, P.B. The effect of multiple  $S^A$  periods on responding on a fixed-interval schedule: III. Effect of change in pattern of interruption, parameters and stimuli. Journal of the Experimental Analysis of Behavior, 1965, 8, 427-435. (b)
- Dews, P.B. The effect of multiple  $S^A$  periods on responding on a fixed-interval schedule: IV. Effect on continuous  $S^A$  with only short  $S^D$  probes. Journal of the Experimental Analysis of Behavior, 1966, 9, 147-151.
- Dews, P.B. Studies on responding under fixed-interval schedules of reinforcement: The effects on the pattern of responding of changes in requirements at reinforcement. Journal of the Experimental Analysis of Behavior, 1969, 12, 191-199.
- Dews, P.B. The theory of fixed-interval responding. In W.N. Schoenfeld (Ed.), The theory of reinforcement schedules. New York: Appleton-Century-Crofts, 1970.
- Elsmore, T.F. Independence of postreinforcement pause length and running rate on fixed-interval pacing reinforcement schedules. Psychonomic Science, 1971, 23, 371-372.
- Farmer, J., & Schoenfeld, W.N. Effects of a DRL contingency added to a fixed-interval reinforcement schedule. Journal of the Experimental Analysis of Behavior, 1964, 7, 391-399.
- Ferster, C.B., & Skinner, B.F. Schedules of reinforcement. New York: Appleton-Century-Crofts, 1957.
- Flanagan, B., & Webb, W.B. Disinhibition in fixed interval operant behavior. Psychonomic Science, 1964, 1, 123-124.
- Gilbert, T.F. Fundamental dimensional properties of the operant.

- Psychological Review, 1958, 65, 272-282.
- Guttman, N., & Kalish, H.I. Discriminability and stimulus generalization. Journal of Experimental Psychology, 1965, 51, 79-88.
- Hawkes, L., & Shimp, C.P. Reinforcement of behavioral patterns: Shaping a scallop. Journal of the Experimental Analysis of Behavior, 1975, 23, 3-16.
- Hearst, E., Besley, S., & Farthing, G.W. Inhibition and the stimulus control of behavior. Journal of the Experimental Analysis of Behavior, 1970, 14, 373-409.
- Henrichs, J.V. Disinhibition of delay in fixed-interval instrumental conditioning. Psychonomic Science, 1968, 12, 313-314.
- Herrnstein, R.J., & Morse, W.H. A conjunctive schedule of reinforcement. Journal of the Experimental Analysis of Behavior, 1958, 1, 15-24.
- Honig, W.K. (Ed.), Operant behavior: Areas of research and application. New York: Appleton-Century-Crofts, 1966.
- Honig, W.K., & Staddon, J.E.R. (Eds.), Handbook of operant behavior. Englewood Cliffs: Prentice-Hall, 1977.
- Innis, N.K., & Staddon, J.E.R. Scopolamine and reinforcement omission on fixed-interval schedules. Psychonomic Science, 1969, 14, 43-45.
- Jenkins, H.M., & Harrison, R.H. Generalization gradients of inhibition following auditory discrimination learning. Journal of the Experimental Analysis of Behavior, 1962, 5, 435-441.
- LaBounty, C.E., & Reynolds, G.S. An analysis of response and time matching to reinforcement in concurrent ratio-interval schedules. Journal of the Experimental Analysis of Behavior, 1973, 19,

- 155-166.
- Malone, J.C. Properties of the fixed-interval  $S^D$ . Psychonomic Science, 1971, 23, 57-59.
- Marr, M.J., & Zeiler, M.D. Schedules of response-independent conditioned reinforcement. Journal of the Experimental Analysis of Behavior, 1971, 21, 433-444.
- Migler, B., & Millenson, J.R. Analysis of response rates during stimulus generalization. Journal of the Experimental Analysis of Behavior, 1969, 12, 81-87.
- Morgan, M.J. Fixed-interval schedules and delay of reinforcement. Quarterly Journal of Experimental Psychology, 1970, 22, 663-673.
- Neuringer, A.J., & Chung, S.H. Quasi-reinforcement: Control of responding by a percentage reinforcement schedule. Journal of the Experimental Analysis of Behavior, 1967, 10, 45-54.
- Pear, J.J. The constituents of response rate. Paper presented at the Midwestern Association of Behavior Analysis, Chicago, May 1977.
- Premack, D. Reinforcement theory. In D. Levine (Ed.), Nebraska symposium on motivation. Lincoln: University of Nebraska Press, 1965.
- Rand, J.F. Behaviors observed during  $S^{\sim}$  in a simple discrimination learning task. Journal of the Experimental Analysis of Behavior, 1977, 27, 103-117.
- Reynolds, G.S. Contrast, generalization, and the process of discrimination. Journal of the Experimental Analysis of Behavior, 1961, 4, 289-294.

- Rilling, M. Stimulus control and inhibitory processes. In W.K. Honig and J.E.R. Staddon (Eds.), Handbook of operant behavior. Englewood Cliffs: Prentice-Hall, 1977.
- Schneider, B.A. A two-state analysis of fixed-interval responding in the pigeon. Journal of the Experimental Analysis of Behavior, 1969, 12, 677-687.
- Schoenfeld, W.N. The "response" in behavior theory. Pavlovian Journal, 1976, 11, 129-149.
- Schoenfeld, W.N., & Farmer, J. Reinforcement schedules and the "Behavior Stream". In W.N. Schoenfeld (Ed.), The theory of reinforcement schedules. New York: Appleton-Century-Crofts, 1970.
- Schwartz, B. Studies of operant and reflexive key pecks in the pigeon. Journal of the Experimental Analysis of Behavior, 1977, 27, 301-313. (a)
- Schwartz, B. Two types of pigeon key pecking: Suppression of long-but not short-duration key pecks by duration dependent shock. Journal of the Experimental Analysis of Behavior, 1977, 27, 393-398. (b)
- Schwartz, B., & Williams, D.R. Two different kinds of key peck in the pigeon: Some properties of responses maintained by negative and positive response-reinforcer contingencies. Journal of the Experimental Analysis of Behavior, 1972, 18, 201-216.
- Shimp, C.P. Organization in memory and behavior. Journal of the Experimental Analysis of Behavior, 1976, 26, 113-130.

- Shull, R.L. A response-initiated fixed-interval schedule of reinforcement. Journal of the Experimental Analysis of Behavior, 1970, 13, 13-15.
- Shull, R.L. Sequential patterns in post-reinforcement pauses on fixed-interval schedules of food. Journal of the Experimental Analysis of Behavior, 1971, 15, 221-231.
- Shull, R.L., Guilkey, M., & Witty, W. Changing the response unit from a single peck to a fixed number of pecks in fixed-interval schedules. Journal of the Experimental Analysis of Behavior, 1972, 17, 193-200.
- Skinner, B.F. The behavior of organisms. New York: Appleton-Century-Crofts, 1938.
- Skinner, B.F. Some contributions of an experimental analysis of behavior to psychology as a whole. American Psychologist, 1953, 8, 69-78. (a)
- Skinner, B.F. Science and human behavior. New York: Free Press, 1953. (b)
- Skinner, B.F. Farewell, my lovely. Journal of the Experimental Analysis of Behavior, 1976, 25, 218.
- Skinner, B.F., & Morse, W.H. Fixed-interval reinforcement of running in a wheel. Journal of the Experimental Analysis of Behavior, 1958, 1, 371-374.
- Staddon, J.E.R. Inhibition and the operant. Journal of the Experimental Analysis of Behavior, 1969, 12, 481-487.
- Staddon, J.E.R. Effect of reinforcement duration on fixed-interval

- responding. Journal of the Experimental Analysis of Behavior, 1970, 13, 9-11.
- Staddon, J.E.R., & Frank, J.A. The role of the peck-food contingency in fixed-interval schedules. Journal of the Experimental Analysis of Behavior, 1975, 23, 17-23.
- Staddon, J.E.R., & Innis, N.K. An effect analogous to "frustration" in interval reinforcement schedules. Psychonomic Science, 1966, 4, 287-288.
- Staddon, J.E.R., & Innis, W.K. Reinforcement omission in fixed-interval schedules. Journal of the Experimental Analysis of Behavior, 1969, 12, 689-700.
- Starr, B.C., & Staddon, J.E.R. Temporal control in periodic schedules: Signal properties of reinforcement and blackout. Journal of the Experimental Analysis of Behavior, 1974, 22, 535-545.
- Stebbins, W.C., Mead, P.B., & Martin, J.M. The relation of amount of reinforcement to performance under a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 1959, 2, 351-355.
- Williams, D.R. Classical conditioning and incentive motivation. In W.F. Prokasy (Ed.), Classical conditioning. New York: Appleton-Century-Crofts, 1965.
- Wilkie, D.M. Stimulus control of responding during a fixed-interval reinforcement schedule. Journal of the Experimental Analysis of Behavior, 1974, 21, 425-432.
- Zeiler, M.D. Fixed and variable schedules of response-independent reinforcement. Journal of the Experimental Analysis of Behavior,



1968, 11, 405-414.

Zeiler, M.D. Repeated measurements of reinforcement schedule effects on gradients of stimulus control. Journal of the Experimental Analysis of Behavior, 1969, 12, 451-461.