AN EXPERIMENTAL OUTLINE FOR BUILDING AND EXPLORING MULTI-OPERANT BEHAVIOR REPERTOIRES

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Although theorists may be found in frequent controversy, experimenters differ in their approach to behavior, and data are sometimes ambiguous or subject to debate, the experimental organism is always right. His behavior is real, lawful, and always appropriate to the instantaneous conditions of his internal and external environments. It is basically the experimenter's job to gain control over those environmental conditions.

In the laboratory, the experimenter emits a variety of behavior and then attempts to relate changes in his behavior with changes in the behavior of the organism under study. The ideal result of such interactions is the statement of definitive relationships which ultimately give rise to what is called "understanding of behavior." Unfortunately, however, we do not have definitive statements or relationships giving us an understanding of what behavior on the part of the experimenter most effectively generates relationships acceptable to the body of behavioral science. Although they are not observed under controlled conditions, variations in behavior from one experimenter to another, or within a given experimenter, suggest that he can state definitive relationships between himself and his organism only insofar as he is able to control and manipulate the relevant environmental conditions. Yet, only occasionally is the experimenter's primary effort to gain control and to manipulate. To do so, in fact, is often punished by other experimenters and theorists. The occasion for punishment would seem particularly strong when the gains in control are substantial and when the interaction between the experimenter and his organism does not immediately result in definitive relationships, but only suggests feasible ones in terms inadequate for conventional language and conceptual analysis. In spite of the occasional punishment for efforts primarily directed at bringing more of an organism's behavior under experimental control and subject to manipulation, we know that such efforts always set the occasion for the obtaining of definitive relationships; and, moreover, that somehow this behavior is maintained.

The material to follow represents, in part, the results of several years of laboratory effort in which the pursuit of behavioral control progressively took precedence over the statement of problems and answers, and in which it was often pursued in their absence. The major result of this effort has been a demonstration that it is feasible to build, describe, and manipulate complex samples of behavior under controlled conditions, on a scale limited only by our individual laboratory behavior. It has been the argument of this section that to do so is in many ways basic to the building of a science of behavior. The following sections are concerned with: first, the nature of multi-operant behavior and general problems of its establishment and analysis; second, the conceptual and notational description of multi-operant behavior; and, finally, the reporting of the laboratory story which largely generated the notions and points of view presented below.

PART I: THE NATURE OF MULTI-OPERANT BEHAVIOR AND PROBLEMS OF ITS ESTABLISHMENT AND ANALYSIS

The continuous nature of an organism's behavior has long been recognized; yet, equally well acknowledged is the argument that behavior can not be studied experimentally in its entirety, but must be broken into units of special attention. These analytical activities are ultimately justified in that the process occasionally results in useful suggestions relevant to the control of particular behaviors, and, also, that it aids in the formulation of a more sophisticated picture of the entire behavioral process.

Current experimental analyses of operant behavior suggest a view of the behavior process in which specific operants under the control of numerous classes of variables are emitted one after another. Thus, one sort of behavior is followed by another in a continuous and flowing manner due to the consequences of each segment giving rise to the special conditions controlling the next. A more specific picture of the overall behavioral process is, for the most part, unavailable. This "conceptual vacuum" is perhaps most readily accounted for by our failure to establish larger samples of behavior in the laboratory under well-controlled conditions. Thus, our history of behavioral science reflects, on the one hand, rather casual observation of extensive and naturalistic samples of behavior, and, on the other, the careful experimental analysis of limited and specific operants. Fortunately,

work of the latter type by Watson, Thorndike, Skinner, and many others has generated the basic technology and conceptual language for the extension of experimental analysis to larger samples of behavior composed of many explicit operants. Although this work is partially at hand, it progresses slowly and against considerable resistance. For example, in the situation in which a rat presses a lever and is reinforced with food on some intermittent schedule, it has long been suggested that not only is lever behavior established and maintained, but that an observable and a sizable sequence of behaviors has been controlled as well. Only occasionally is effort directed towards making that sequence explicit. More frequently, attention is directed at manipulating the variables controlling the lever behavior and then explaining those effects in terms of hypotheses about the existence and importance of other unspecified behavior in the sequence. An alternative approach is to build larger samples of behavior, bringing each under explicit control, and to then proceed with analytical manipulations. The point of view here, then, is that the way to increase our understanding of behavior is not to analyze a particular bit of behavior exhaustively, but rather to complicate the sample of behavior under question as rapidly as good experimental procedure and technology permit.

The ultimate nature of multi-operant behavior, then, is largely experimental. It is defined by the experimental demonstration of several related operants, where each operant is defined in terms of explicit operations and experimental control. The problems in establishing and analyzing multi-operant behavior are therefore largely ones of definition, conceptualization, description, and experimental control.

The Problem of Definition and Units

A persistent problem in the experimental analysis of behavior has been the selection of units. Historically, behavior has been fractionated into many terms and concepts suggesting fundamental properties. A partial list would include traits, feelings, perceptions, habits, acts, responses, and reflexes. Although the problem of finding definitive units of analysis does not pose itself as a major one for the experimenter facing practical or strictly empirical questions, serious difficulties arise when the interest turns to a more general account of behavior. The presence of these difficulties is best evidenced by the number of theoretical systems which often develop independently with untranslatable terms and concepts. Moreover, these independent systems grow to elaborate proportions only to disappear, except for perhaps helpful biases which are sometimes carried over to new systems. To the extent that the individual laboratory behavior of an experimenter is materially effected by the presence or absence of sound analytical units, then they become his problems as well. A more cumulative analysis of behavior would hopefully follow the introduction of less evasive units.

A promising unit of behavior suggested by Skinner (1953, p. 64-65), and by Ferster and Skinner (1957, p. 730), and now commonly employed, is the concept of an operant. Briefly, an operant is a class of behavior in which the emission of a response of this class may be followed by specified consequences. Usually, the contingencies between the behavior and the consequences define the formal properties of the operant.

The use of the term operant as a unit of behavior, however, does not follow from its formal properties alone, but it is also dependent upon the empirical success with which the experimenter can demonstrate its functional properties (Skinner, 1938). Thus, ideally, a class of behavior is referred to as an operant only after the given class of behavior is found to vary in a unitary fashion with manipulations of given variables.

One difficulty with the operant when used as a building block for systematic analysis is its sometimes wide applicability, since an almost unlimited number of operants may be operationally defined and demonstrated to embrace workable unitary properties. Generally, this problem is of little consequence when simply describing the variables of which a single operant is a function. On the other hand, when the contingencies and consequences under which a single operant is examined become highly complex, or when several interconnected operants are involved, the freedom in the usual definition of an operant creates problems in delineating the levels of analysis and in the translatability of procedures. Thus, with basic units highly flexible, the analytical reduction of complex samples of behavior to special combinations and arrangements of more elemental units becomes extremely difficult. Moreover, it becomes all but impossible to show definitively that one procedure is simply an abbreviated or expanded part of another.

A more adequate basic unit less subject to the above sorts of criticism may result in time from further work directly upon the problem of units. Recent work by Gilbert,[3] Notterman (1960), and Mechner[4] show hopeful developments in this direction. In the absence, however, of a more fundamental unit of behavior than that suggested by the operant, one reasonable approach would be that of a more restrictive definition of the term when referring to units of behavior.

Current usage of the term operant as a unit of behavior largely emphasizes the manipulation of the organism. Thus, we speak of bar pressing, key pecking, wheel turning, etc., as the unit of behavior under analysis, then frequently proceed to describe the prevailing stimulus conditions, the contingencies for reinforcement, and the nature of reinforcement simply as conditions rather than as defining properties of the behavior under question. This often results in some confusion. For example, in a simple discrimination procedure in which lever presses in the presence of a

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[3] Personal communication, 1961.

[4] Personal communication, 1961.

light are followed by food and those in darkness are not followed by food, are we dealing with one operant (lever presses, under two conditions)? Or, would a more preferable description of units be that of two operant: one operant being that of lever pressing in light followed by certain consequences, and the second, lever pressing in darkness followed again by certain consequences? In the latter case, two operants would be recognized, one perhaps increasing in strength and the other declining in strength. With simple procedures, such distinctions are usually trivial. However, the problem becomes somewhat less than trivial once the situation embraces several different manipulations by the organism, a variety of stimulus conditions, complex contingencies for reinforcement, and several types of reinforcement.

One alternative solution to problems of defining the units of analysis would be a partial circumvention of the problem, emphasizing, instead, a notation system which would precisely describe experimental conditions and contingencies regardless of their complexity. Mechner (1959) has suggested such a notation system, worked out in careful detail. Skinner (1958) has also suggested a somewhat less extensive classification system for describing reinforcement schedules; and, in addition, many experimenters have developed and are informally using their own systems to denote procedures. It is suggested here that although the concise notation of procedures is important, it does not resolve the problem of units, and that what is needed for the analysis of multi-operant behavior is a more extensive conceptual system in combination with notations.

In Part II, an approximate system is developed based upon a definition of the operant as a sample of behavior composed of responses of a given class, emitted under given stimulus conditions, and with stated contingencies by which members of that class produce given consequences. In this concept of the operant as a unit, a change in any of the defining properties establishes a different operant. The system elaborates upon this definition and arose, in part, as a necessary "road map" for the description and analysis of multi-operant experiments presented in Part III.

The Problem of Experimental Control

Although frequently discussed under a guise of many theoretical and philosophical concepts, the problem of experimental control is basically one of "how does the experimenter make the organism do what he desires?" This is perhaps most readily accomplished by hastily manipulating many variables, by giving the organism more freedom, or by complicating the experimental situation. Once the experimenter discovers how to get the organism to do what is desired, he may use this behavior as a base line or as a starting point for further demands of performance. The terminal result of such laboratory activities, if faithfully pursued, is the establishment of an extensive sample of the organism's behavior, all under the control of the experimenter. If the individual performances are identifiable, have unitary properties, and are measurable, then one has essentially established a multi-operant sample of behavior to which may be addressed perhaps better and more formal questions. The alternative approach is to establish elaborate and rigorous conditions, require very little behavior from the organism, and then ask, "What will he do?" This latter approach may generate many verbal answers, but usually affords little improvement in experimental control (c.f., Gilbert, 1959; Sidman, 1960).

What type of things, then, does the experimenter do in order to gain control, or to make the organism behave as desired? Typically, the experimenter manipulates deprivation, reinforcement nature and contingencies, prevailing stimulus conditions, and the nature of the past history. Potential gains in experimental control lie within each of these general categories by pushing the variables to greater extremes. For example, with food deprivation, if the organism's body weight is at 80 per cent of its free-feeding weight and yet it fails to work in the experimental situation under given contingencies, the experimenter seldom lets the organism remain unfed for 3 or 4 days until the behavior comes in. Rather, he returns the animal to its cage and reinforces with food, in effect, not working. Concerning the nature of the reinforcement used, if a given behavior is desired and the reinforcement has been found weak, typically we accept this limitation as inevitable rather than altering the nature of the reinforcement or adding additional reinforcers to give an enhanced effect. When contingencies are examined, they are usually varied over a relatively small range. Thus, fixed-interval schedules are varied from 1 minute to 20 minutes, rather than from 1 minute to 4 days; fixed-ratio contingencies are varied from 1 to 200, rather than from 1 to 100,000. Moreover, in the general use of schedules, time-based contingencies seem to be heavily favored although they call attention to what the organism may do, rather than what he must do. In regard to the nature of prevailing stimulus conditions used in many experiments, they tend to be left within the organism, or perhaps within the experimenter, rather than made external and explicit. Although it has been well demonstrated that the capacity of the organisms to form discriminations is all but unlimited, the expansion of simple situations to more complex, yet explicit, ones has proceeded quite slowly. This may be due in part to the changes in the nature of the formal question that may result from such an expansion process, and to the new problems it creates in defining and identifying the explicit behavior. Manipulations of the past history of the experimental organism similarly tend to be weak and limited in scope. Thus, organisms that have an extensive past history from birth—not of the experimenter's design—are generally used. Such organisms are placed under experimental conditions for perhaps a few days

or weeks, with the hope of establishing subtleties of behavior that by analogy require perhaps 5 to 10 years to establish in humans.

Although it may be granted that gains in experimental control would likely result from pushing our variables to extremes, it is often argued that to do so is not feasible in the usual experimental situations. It is argued here, however, that it would indeed be helpful to alter those experimental situations, and that, in fact, it will be ultimately necessary for the serious examination of multi-operant repertoires.

PART II: AN APPROXIMATE CONCEPTUAL AND NOTATIONAL SYSTEM

The following system was the outgrowth of attempts to briefly characterize involved procedures and to provide a conceptual analysis by which extensive samples of behavior could be expressed as special combinations and arrangements of simpler components. It was not designed for exact specification of procedures such as schedules of reinforcement, nor for the elaborate identification of special experimental conditions such as color of lights, etc. Rather, it assumes these will be specified primarily in other modalities.

The system consists simply of a definition of the operant which permits distinction as to several types. The alternative combination of operants results in two larger units of analysis called an option on the one hand and a chain on the other. Combinations of chains and options constitute a larger unit, called a tree; and several trees taken together then define a still larger unit of analysis, called a grove. Generally, the relation between the behaving organism and its environment is limited to three logically exhaustive categories: The first is when specified behavior produces certain consequences; the second is when the nonemission of specified behavior leads to certain consequences; and the third is when environmental events or consequences occur independently of the behavior.

Operants

An operant was previously defined in Part I as a sample of behavior composed of responses of a given class, emitted under given stimulus conditions, and with stated contingencies by which members of that class produce given consequences. It was implied as well that the ultimate meaning and usefulness of such a concept is tied to possible experimental operations and manipulations. Thus, the present definition of an operant as a unit of behavior follows not from a rigorous and formal logical analysis, but simply from the specification of various defining properties which themselves may in turn be specified by experimental operations or convention. These defining properties together with an indication of their notations are presented below.

In the present system, a given set of specifications, one for each of the defining properties, would identify a particular operant. For example, on a fixed-ratio

DEFINING PROPERTIES

1. *Response class*

   a. Positive

   b. Negative

2. *Stimulus conditions prior to reinforcement*

3. *Contingencies for reinforcement*

4. *Nature of reinforcement*

   a. Major reinforcement event

   b. Stimulus conditions and contingencies following reinforcement event.

NOTATION
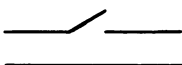
Designated by explicit experimental conditions where necessary.

FR, FI, VI, or other conventional symbols.

S^R, primary positive; S^{R-}, primary negative.

S^r, conditioned positive; S^{r-}, conditioned negative.

, major reinforcement followed by the same conditions as those prior to major reinforcement event. (Subscripts used to denote conditions to which there is a return.)

, major reinforcement event followed by conditions different from those prior to reinforcement.

schedule of one response, bar pressing in the presence of light produces food and then reinstates these conditions. Such an operant would be noted

(LIGHT)

op1 $_S$R (FOOD)

FR1 |
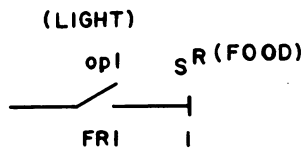
where op 1 would be defined as bar pressing in light; FR 1 is fixed-ratio one; S^R indicates reinforcement; and the vertical bar under the reinforcement symbol with the subscript numeral 1 indicates that following reinforcement, the conditions prevailing prior to reinforcement are reinstated. Another set of specifications which differed in any of the defining properties would identify another operant. Thus, in the above example, a different response class, or the same response class under different stimulus conditions prior

to reinforcement, would define a different operant. Similarly, changes in the contingencies or in the nature of the reinforcement would constitute other operants. Hence, in the present system, an almost infinite number of operants is identifiable. However, a consideration of the response class and the nature of reinforcement suggests general types of operants and a simple classification.

All possible operants are divided into two major categories, positive operants and negative operants. A positive operant is distinguished by a definition of the response class in which the organism is required to emit specified behavior. On the other hand, the negative operant is distinguished by an equally well-specified response class, but it is the nonemission of that specified behavior which leads to given consequences. Thus, an example of a positive operant would be bar pressing under stated stimulus conditions, and stated contingencies producing given consequences. An example of a negative operant would

TYPE	DESCRIPTION
Positive	*Response class specified in positive terms*
(1) op $_S$R	Instance of class produces reinforcement and reinstates conditions prior to reinforcement.
(2) op $_S$R	Instance of class produces reinforcement and is followed by conditions unlike those prior to reinforcement.
(3) op $_S$R	Instance of class produces reinforcement; and at one time reinstates conditions prior to reinforcement, and at another time is followed by conditions unlike those prior to reinforcement.
(4) op $_S$R	Instance of class produces reinforcement; and at one time reinstates conditions immediately prior to reinforcement, and at another time reinstates a different set of conditions also prior to that reinforcement.
(5) op $_S$R	Instance of class produces reinforcement; and at one time is followed by one condition and at another time a second condition, both conditions being different from those prior to reinforcement.
Negative	*Response class specified in negative terms*
(1) op $_S$R	Nonoccurrence of the specified behavior produces reinforcement and reinstates conditions prior to reinforcement.
(2) op $_S$R	Same as Type (2) positive operant except for negative specification of behavior.
(3) op $_S$R	Same as Type (3) positive operant except for negative specification of behavior.
(4) op $_S$R	Same as Type (4) positive operant except for negative specification of behavior.
(5) op $_S$R	Same as Type (5) positive operant except for negative specification of behavior.

be the nonemission of bar presses under stated stimulus conditions and stated contingencies producing given consequences. Although the distinction of a negative operant is something of a logical device and does not draw attention to what the organism is actually doing, it is frequently encountered in experimental work. For example, in avoidance conditions the nonemission of specified behavior may lead to blackout conditions, shock, resetting of contingencies, etc. The use of no-response conditions in other situations is regarded as a limited-hold contingency (Ferster & Skinner, 1957). In general, the lack of apparent specification of the term "no response" is partially compensated for when used in a unit of behavior where the defining properties other than the response class are well specified in positive terms.

In conventional discourse, two terms are often used interchangably: "reinforcement" and "consequences." The term reinforcement is most often used with reference to specified events such as the delivery of food, shock, or specific conditioned reinforcement. The phrase "consequences of behavior" typically has a broader reference, and calls attention not only to specific events such as the delivery of food but also to the nature of conditions following such events. Abundant experimental evidence suggests that a particular behavior is affected by its total consequences, although in certain experimental situations, some aspects of the consequences may be relatively more important than others. In the present system, the operants are classified not only by the positive or negative aspect of their response class, but also by two logical categories suggesting the type of conditions following the major reinforcing event. This classification of operants was presented above.

Although operants could be classified in several ways other than on the basis of the nature of the response class and the consequences, this method has been used here because of its relevance to conventional discourse, and because its notation leads to a relatively simple system of combining several operants.
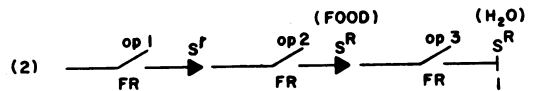
Chains

One conceptual arrangement of separately identifiable bits of behavior is that of a serial pattern in which the consequences of one type of behavior produce the conditions for the next. The term typically used to convey such a sequence of behavior is called a chain (Skinner, 1938). Thus, in the present system, a serial arrangement of two or more explicit operants with no ostensible alternative to the sequence is defined as a chain. It is here considered a larger unit of analysis in that it is reducible to component operants both by definition and experimentally, and since the total sequence of operants may be demonstrated experimentally to vary together in a unitary fashion with the manipulation of given variables (Part III).

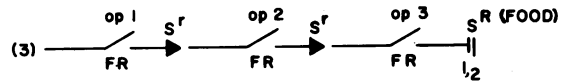Several illustrative chains are presented below with their notations and verbal descriptions. It is assumed that each operant within a given chain would be fully specified as to its defining properties, although the stimulus conditions and exact description of the other properties have been omitted for simplicity.

$$(1) \quad \xrightarrow{\text{op 1}} S^r \xrightarrow{} \xrightarrow{\text{op 2}} S^R \text{ (FOOD)}$$
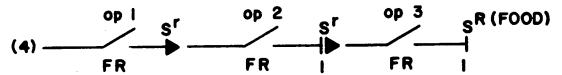$$\text{FR} \qquad \text{FI} \qquad _1$$
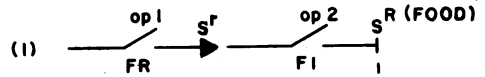
In this two-operant chain, emission of specified behavior, under specified conditions, that satisfies the contingencies (op 1), produces the onset of stimulus conditions for the second operant, where specified behavior that satisfies the FI contingencies produces food reinforcement (op 2), and then reinstates the conditions for the first operant. (The small numeral 1 subscript under the primary reinforcement symbol indicates that following the delivery of food, the conditions for operant 1 are reinstated.)

$$(2) \quad \xrightarrow{\text{op 1}} S^r \xrightarrow{} \xrightarrow{\text{op 2}} S^R \text{ (FOOD)} \xrightarrow{} \xrightarrow{\text{op 3}} S^R \text{ (H}_2\text{O)}$$
$$\text{FR} \qquad \text{FR} \qquad \text{FR} \qquad _1$$

In this three-operant chain, each of two operants (op 2 and op 3) produces a primary reinforcement. Following delivery of the water reinforcement, the conditions for operant 1 are reinstated.

$$(3) \quad \xrightarrow{\text{op 1}} S^r \xrightarrow{} \xrightarrow{\text{op 2}} S^r \xrightarrow{} \xrightarrow{\text{op 3}} S^R \text{ (FOOD)}$$
$$\text{FR} \qquad \text{FR} \qquad \text{FR} \qquad _{1_2}$$

This three-operant chain has a single primary reinforcement which follows a more complex serial order. The general meaning of the double-bar symbol below the primary reinforcement, together with its subscripts, is that following the delivery of reinforcement: Sometimes, the conditions for operant 1 are reinstated, and, at other times, the conditions for operant 2. The particular sequence, whether random, single or double alternation, etc., would be specified with further symbols or simply with a verbal statement. If the subscript were assumed to indicate simple alternation, then the sequence of operants would be 1, 2, 3, reinforcement, 1, 2, 3, reinforcement, 2, 3, reinforcement, 1, 2, 3, reinforcement, etc. The minimum number of operants before primary reinforcement would always be two.

$$(4) \quad \xrightarrow{\text{op 1}} S^r \xrightarrow{} \xrightarrow{\text{op 2}} S^r \xrightarrow{} \xrightarrow{\text{op 3}} S^R \text{ (FOOD)}$$
$$\text{FR} \qquad \text{FR} \qquad _1 \qquad \text{FR} \qquad _1$$

This is a three-operant chain similar to the one above, but providing for the repetition of two early operants in the chain before the third operant (op 3) produces the primary reinforcement. The symbols below the indication of conditioned reinforcement in operant 2 would mean that at one time conditions for operant 1 are reinstated and at another time

operant 2 is followed by the conditions of operant 3. If this is assumed to be simple alternation, the sequence of operants would be: 1, 2, 1, 2, 3, reinforcement, 1, 2, 1, 2, 3, reinforcement, etc. In this case, the minimum number of operants before reinforcement would be five.

$$(5) \quad \xrightarrow[\text{FR}]{\text{op I}} S^r \xrightarrow[\text{FR}]{\text{op 2}} S^r \xrightarrow[\text{FR}]{\text{op 3}} S^r$$
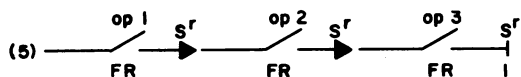
In this three-operant chain involving no primary reinforcement, the reinforcement for each operant would simply be the production of the conditions for the next operant. Although it is only occasionally investigated experimentally, such a chain focuses attention upon the manipulative properties of the response classes selected. Thus, the classes of behavior would presumably be wheel turning, latch manipulation, or other bodily movements reinforcing in their own right. On the other hand, if the conditioned-reinforcement symbols had specific designation such as S^r (tone), the chain would focus attention upon the external sensory consequences of the behavior in the sequence. In this latter case, the response classes would presumably be chosen to minimize inherent reinforcement.

$$(6) \quad \xrightarrow[\text{FR}]{\text{op I}} S^r \xrightarrow[\text{T.C.}]{\text{op 2}} S^{R(\text{FOOD})}$$
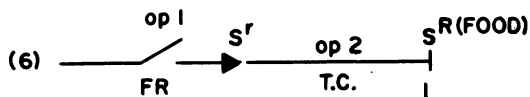
This two-operant chain is composed of one positive operant and one negative operant. Emission of specified behavior in the first operant which satisfies the given contingencies produces the conditions for the second operant. The nonemission, or absence of behavior, of a specified class satisfying a given temporal contingency (T.C.) produces food reinforcement and then reinstates the conditions for operant 1. It should be noted that in a negative operant the contingencies for reinforcement always involve temporal factors; moreover, these are not specifiable independently of the consequences provided for positive instances of the response class. For example, it could be stated that no bar press within 1 minute would produce the food; however, the consequences of a bar press as they affected the temporal requirement would also need specifications, such as resetting of the interval. It would seem that with the consequences of both positive and negative instances of a class specified, the operant would be positive. However, such is not the case, since it is the nonemission of the behavior which produces the food and in turn defines the class. The positive instance of the class only produces changes in the temporal requirement, hence the term, negative operant. If the temporal contingency is defined independently of the behavior, we are no longer dealing with an operant, but with a behaviorally independent event or contingency (B.I.C.). These are discussed under a separate heading.

$$(7) \quad \xrightarrow[\text{T.C.}]{\text{op I}} S^r \xrightarrow[\text{T.C.}]{\text{op 2}} S^r \xrightarrow[\text{T.C.}]{\text{op 3}} S^{R(\text{FOOD})}$$
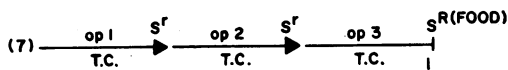
This three-operant chain is composed of negative operants and involves primary food reinforcement. Nonemission of behavior in the first operant which satisfies the temporal contingencies produces the conditions for the second operant, which in turn produces the conditions for the third operant, which produces the food and reinstates the conditions for the first.

$$(8) \quad \xrightarrow[\text{FR}]{\text{op I}} S^{R(\text{FOOD})} \xrightarrow[\text{T.C.}]{\text{op 2}} S^{R-(\text{SHOCK})}$$
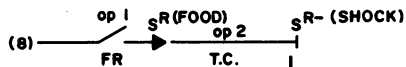
This is a two-operant chain composed of a positive and negative operant with both positive and negative primary reinforcement. In this chain, completion of the FR requirement produces food reinforcement and the conditions for the second operant. The nonemission of specified behavior in the second operant produces an electric shock and the conditions for the first operant. In such a chain, the resulting behavior in each operant would presumably be a function not only of its own nature, but also of the conditions of the other.

$$(9) \quad \xrightarrow[\text{T.C.}]{\text{op I}} S^{R-} \xrightarrow[\text{T.C.}]{\text{op 2}} S^{R-} \xrightarrow[\text{T.C.}]{\text{op 3}} S^{R-}$$
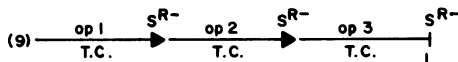
This is a chain composed of three negative operants, each with primary negative reinforcement. Although not usually investigated experimentally, such a chain would suggest three avoidance-type operants, with the nonemission of specified behavior producing negative reinforcement and the conditions for another such operant. Variations in the severity of each aversive event suggest interesting experimental possibilities.

$$(10) \quad \xrightarrow[\text{T.C.}]{\text{op I}} S^r \xrightarrow[\text{T.C.}]{\text{op 2}} S^r \xrightarrow[\text{T.C.}]{\text{op 3}} S^r$$
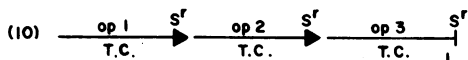
This is a three-operant chain with negative operants and no primary reinforcement. Although again not usually established experimentally, such a chain would suggest the nonemission of various specified behavior producing a variety of sensory events. By the inclusion of primary positive reinforcement and the careful selection of particular response classes, a sequence of behavior presumably could be established whose outstanding properties would be the absence of overt movements.
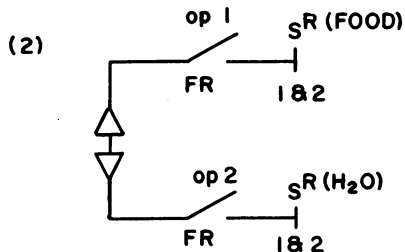
Options

Although all complex samples of multi-operant behavior may be said to involve the chaining process, designating all such behavior as chains would be overworking the term. Hence, in the above section the term chain was restricted to a serial-type arrangement of operants which demanded a prescribed sequence.

In this section, a parallel arrangement of operants is considered and is referred to as an option. A parallel combination of operants suggests at least two major types of conditions, which have been generally regarded as concurrent scheduling on the one hand, and alternative or choice behavior on the other. Experimental investigations focusing upon both of these types of behavior situations have been extensive. From the experimenter's point of view, since the organism may be said to have a choice in both instances, a parallel arrangement of operants is termed an option; and the two types are designated simply as reversible or nonreversible. It should be noted that even when the behaviors are made explicit according to the above definition of an operant, much critical behavior of the organism is left unspecified in an option. For example, in concurrent scheduling of reinforcement conditions, the experimenter usually cannot specify the exact stimulus and behavioral events that eventually lead to one consequence or the other at a given instance in time. Experimental attempts to bring more of such behavior under explicit experimental control suggest that a behavioral chain is involved (Findley, 1958). However, when it is impractical to specify such a chain, or the focus of investigation is upon other aspects of the organism's behavior, it would seem most advantageous to identify that behavior which is specifiable and consider it a unit of analysis in its own right. Thus, in the present system the option is considered a unit of behavior. Experimental evidence bearing upon its manipulative properties is presented in Part III. Examples of several options are described below.

(1)

op 1 S^R (FOOD)
FI   1 & 2

op 2 S^R (H_2O)
FI   1 & 2
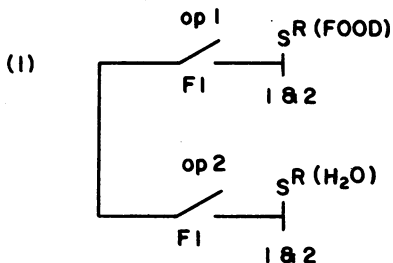
This is a reversible option composed of two operants, each involving a positive primary reinforcement. The vertical line connecting the two operants designates that the conditions for both are concurrently in effect. Thus, the organism could pursue both specified behaviors without the emission of one affecting the contingencies of the other. The satisfaction of either contingency, however, would produce a specified reinforcement and then reinstate the original conditions of the option. The reinstated events are indicated by the subscripts 1 and 2 under each reinforcement.

Option (2) is similar to the one above but is nonreversible. In this case, the two symbols located on the vertical line connecting the operants indicate that the two behaviors are alternative and mutually

(2)

op 1 S^R (FOOD)
FR   1 & 2

op 2 S^R (H_2O)
FR   1 & 2

exclusive. If the FR requirement were one, no problem in description would be encountered because the first emission of a response of either class would produce reinforcement and reinstate the option. However, if other schedules of reinforcement were used, some ambiguity in description would be possible. In general, the above symbolization is taken to mean that the first response of either class eliminates the stimulus conditions and possibility of reinforcement in the other; hence, the term nonreversible.

(3)

op 1 S^R (FOOD)
FR   1 & 2

op 2 S^{R-} (SHOCK)
T.C.   1 & 2
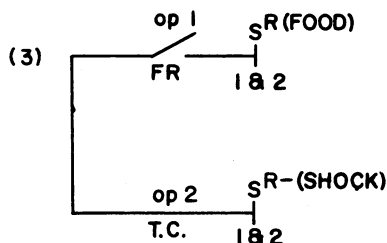
This is a reversible option involving a negative operant with the possibility of both positive and negative primary reinforcement. Emission of behavior defined in the first operant which satisfied the FR requirement would produce food and reinstate the option. The nonemission of the behavior specified by the second operant would produce shock and reinstate the option. It should be noted that the delivery of either reinforcement would reset the contingencies of both operants, but that the contingencies for each would be unaffected by alternation from one class to another.

(4)

op 1 S^{R-} (SHOCK)
T.C.   1 & 2

op 2 S^{R-} (SHOCK)
T.C.   1 & 2
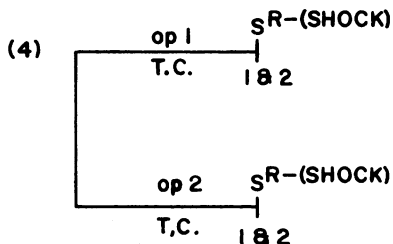
This is a reversible option with two negative operants. This option would suggest the maintenance of two avoidance behaviors with perhaps chronic alternation. Interesting possibilities exist for the con-

sequences of nonemission of either behavior. If the temporal contingencies were different, the aversive event delivered would be the one associated with the shortest contingency. However, if the contingencies were identical, the above symbolization would indicate the delivery of both.

(5)

op 1 S^R (FOOD)
FR
op 2
VR 1 & 2
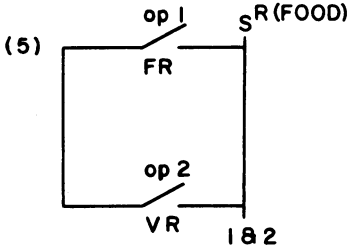
This is a two-operant reversible option with a single positive primary reinforcement. In such an option, the completion of either contingency would produce the same reinforcement condition and then reinstate the option.

(6)

op 1 S^R (H$_2$O)
FR
op 2
FI 1 & 2
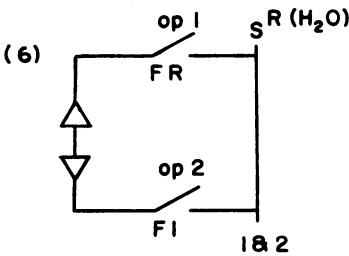
This option is similar to (5), but is nonreversible. In this case, the first emission of a response of either class would remove the conditions for the other operant. Such an option would suggest a schedule-preference experiment in which the defining properties of both operants were for all practical purposes identical except for the reinforcement contingencies.

(7)

op 1 S^R (FOOD)
FR
op 2
FR
op 3
FR 1, 2 & 3
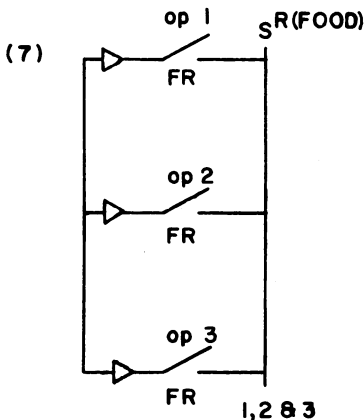
This is a nonreversible option composed of three positive operants and having identical reinforcement

conditions. This option is essentially of the same form as (6) except for the inclusion of an additional operant and for the rearrangement of the non-reversibility symbols. With identical reinforcement schedules and stimulus conditions but different response classes, such an option should suggest a procedure for evaluating response preference, the dimension of the response being perhaps magnitude, force, or position.

(8)

op 1 op 3 S^R (FOOD)
FR FI
op 2 op 4
FI FR 1 & 2
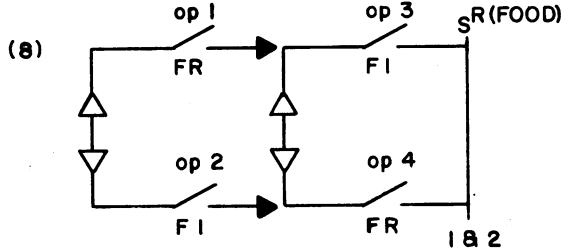
This is a nonreversible four-operant option. In this option, the alternative behaviors of operants 1 and 2 both produce the conditions for the alternative behavior of operants 3 and 4. Satisfaction of the contingencies of either of these latter two behaviors produces the food reinforcement and reinstates the option. Although the option here is of a complex nature and obviously involves a serial order and the chaining process, it is designated as an option because the experimenter only partially determines the specific serial order of operants. The schedules indicated above were included to describe a possible experiment in which the preference for two alternative schedules of reinforcement might be examined as a function of the proximity to the primary reinforcement.

(9)

op 1 S^R (FOOD)
FR
op 2 S^r
FR
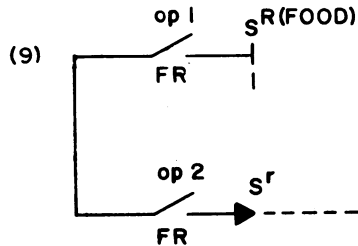
This is a two-operant option in which one operant leads to food reinforcement and reinstatement of the option and the other leads to conditions other than those of the option. Such an option would ordinarily be examined in conjunction with more complex samples of behavior, but it is included here to illustrate that particular behaviors within an option need not always reinstate themselves.

Option (10) with two operants, one of which is negative and produces conditions other than those of the option. In this option, the positive emission of behavior in the first operant leads to food and reinstatement of the option, and the nonemission
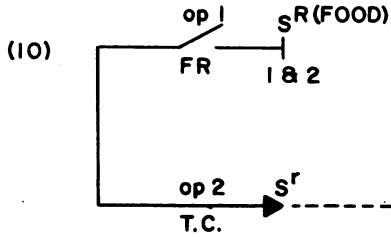
of behavior in the second operant leads to conditions outside of the option. An interesting complication presents itself if the positive emission of . behavior in the second operant not only resets its temporal contingencies, but also resets the contingencies of the food-reinforced operant. Such an interconnection of contingencies could also be reversed such that a positive response of either operant resets the temporal contingencies of the second operant. However, the symbolization presented in (10) is not usually taken to mean that the contingencies for one operant are partly specified in terms of behavior on the other; rather, it means that the contingencies for reinforcement of each operant are independent. It will be noted that in this latter case with the contingencies independent, the nonemission of the specified behavior of operant 2 resembles what is termed in common experimental procedures a limited-hold condition. It differs from the usual limited hold in that the behavior which keeps the option in effect is the explicit, positive responses in operant 2, not the food-reinforced behavior of operant 1. Because the nonemission of behavior in operant 2 leads on to conditions other than those of the option, it might suggest a similarity to conditions of a multiple schedule. However, in the present system the use of the term multiple schedule is restricted to conditions involving behaviorally independent contingencies.
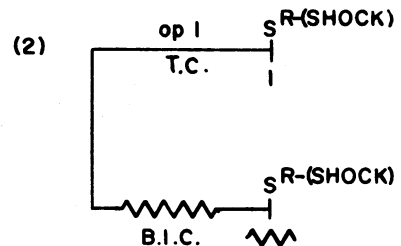
Behavior-independent Contingencies

In the laboratory examination of behavior, procedures are frequently arranged in which various events occur independently of the behavior of the organism under observation. Examples of such procedures in the laboratory are identified by the experimenter's delivery of "free reinforcement," arbitrary alternation of stimulus conditions, reinforcement contingencies, etc. Even when such events occur independently, they nonetheless often result in behavioral effects. Such effects have been referred to as superstitious behavior (Skinner, 1948). The laboratory implementation of independent events is usually by the use of temporal contingencies defined independently of the behavior of the organism under observation, but used concurrently with observation of particular behaviors under other contingencies. Occasionally, such independent events are arranged not by clocks, but by the behavior of other experimental organisms. In the present system, both types of independent events, i.e., from the use of clocks or

another organism's behavior, are termed behavior-independent contingencies and are symbolized by option-type notation because of their concurrent use with other samples of behavior. Several such arrangements are illustrated below.
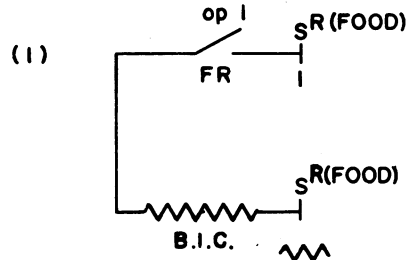

This is an independent contingency producing a primary reinforcement and programmed concurrently with an operant. Completion of the FR contingency in the operant would produce food and reinstate only that contingency. Satisfaction of the independent contingency similarly would produce food and reinstate only its contingency. If the operant reinstated the original conditions of the independent contingency as well as its own condition, the former obviously would not be a behaviorally independent event. On the other hand, more complex cases are possible if the production of food by the independent contingency were to be followed not only by the reinstatement of itself, but also the reinstatement of the original conditions for operant 1. In this case, however, the contingencies of reinforcement as a defining property of operant 1 would not be specified simply by the FR, but would also have to include reference to independent events.

This is an independent contingency similar to (1) above but used concurrently with a negative operant producing electric shock. Such a symbolization would suggest an avoidance experiment using the delivery of "free" shocks.

Option (3) shows three independent contingencies used with three different operants. The conditions for the first operant are in effect until the first independent contingency is satisfied. This then produces the conditions for the second operant and the second independent contingency, which in turn gives rise to the third pair of concurrent conditions. Completion of the third independent contingency
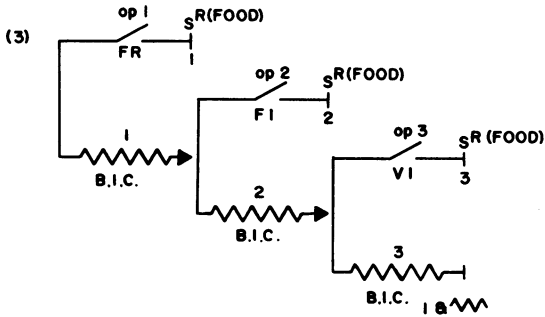
reinstates the original conditions. This complex of operants and independent contingencies describes what is basically a "multiple-schedule" procedure (Ferster & Skinner, 1957). It should be noted that technically the contingencies for reinforcement within each operant are not completely specified in such a procedure since they interact with the behaviorally independent event. In general, even when the independent contingency is combined with an operant, it is not here considered a unit of behavior. The unit in question here is simply the operant. However, an independent contingency would be permissible as part of a behavioral unit, as, for example, in an option when one of the alternative behaviors produced or put into effect an independent contingency.

Trees and Groves

Thus far, three units of behavioral analysis have been described—the operant, chain, and option—together with behaviorally independent contingencies. These samples of behavior may be studied in themselves or used to build and describe still larger samples of behavior. Thus, chains or operants may be combined with options to yield what is termed a tree. A combination of two or more trees describes an even larger sample of behavior, referred to as a grove.

The tree is defined as a combination of an option with a chain or operant such that behavior from at least one specific operant is always required for each completion of the behavioral sequence. When one considers the possible variations in operants, chains, and options, such combinations greatly increase the scope of possible behavior samples which could be described. The following illustrations, however, are largely restricted to simple cases and are not intended to be exhaustive.
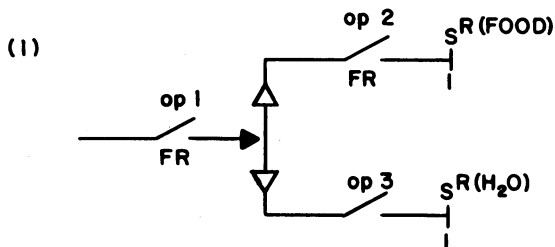

This is a simple tree composed of an operant and an option. Behavior of the first operant leads to the alternative operants 2 and 3. Either of these operants produces a primary reinforcement and reinstates the conditions for operant 1.
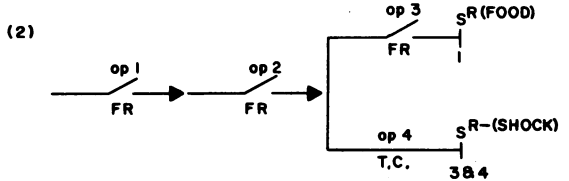

This is a tree composed of a chain and a reversible option. Here, operant 1 produces operant 2, and operant 2 produces the concurrent conditions of operants 3 and 4. Following the delivery of food from operant 3, the tree is reinstated, whereas the nonemission of behavior of operant 4 leads to shock and reinstatement of only the option. Numerous possibilities could follow alteration of the reinstatement patterns.
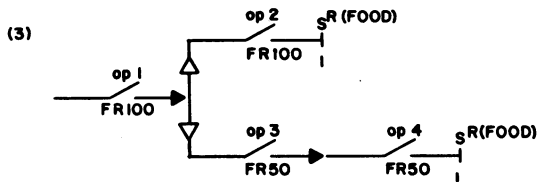

This tree is composed of an operant and a nonreversible option, in which one of the alternative behaviors does not reinstate the tree but produces an additional operant. The specific schedules were included to suggest a possible preference-type experiment. For example, if the option for operant 2 is exercised, two operants precede primary reinforcement. However, three operants would precede reinforcement with the choice of operant 3.
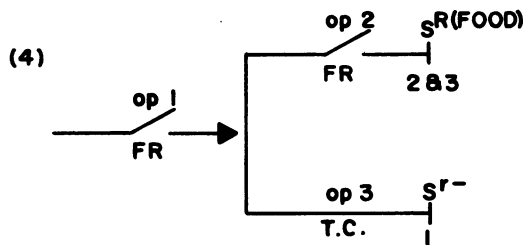

This tree is composed of an operant and an option in which the organism may remain under the conditions of the option provided the temporal contingency of operant 3 is not satisfied. Both the delivery of food in operant 2 and the positive emission of the specified behavior of operant 3 would reset the temporal contingencies. Once the temporal condition times out, however, the conditions for operant 1 would be reinstated.

(5)
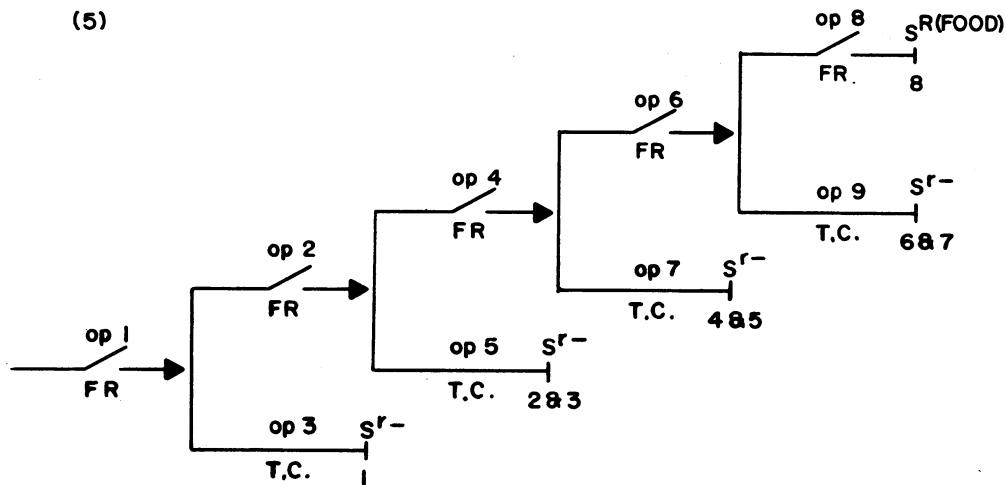
This is a behavior grove composed of several trees similar to (4). In this grove, the organism may remain in the conditions of operant 8 provided the temporal contingencies of operant 9 are not satisfied. Thus, provision is made for regression to earlier members of the grove or for progression in the sequence depending upon the behavior within each option.

(6)

(8)
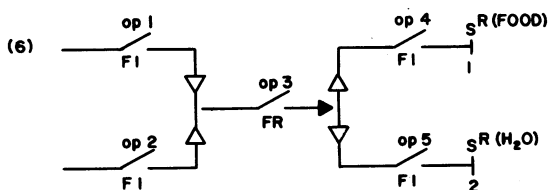
This grove is composed of two trees with a common operant, in which several possible sequences of operants are available to the organism. The reversal of the direction of the nonreversibility symbols in the first option simply indicates that the alternative behaviors of operants 1 and 2 both produce the conditions for operant 3. Following the delivery of food in operant 4, the conditions for operant 1 are reinstated; and following water, the conditions for operant 2 are reinstated. Thus, operant 3 is always common to the several sequences of operants.
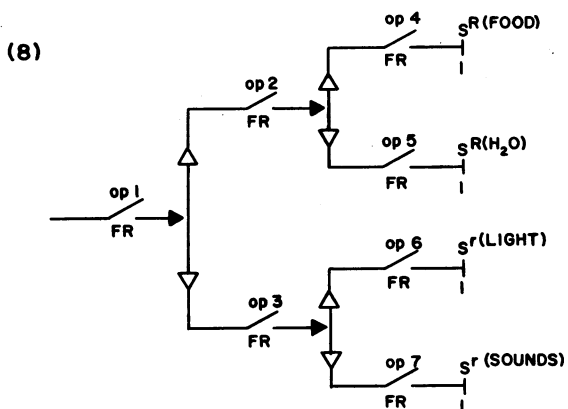
Grove (7) is composed of two trees arranged essentially in tandem and illustrates a matching-to-sample type of procedure. Each operant is numbered, and the (a) or (b) symbols are used to indicate that in each operant the defining stimulus conditions are of either type. Operant 1 (a) produces an option between operants 2 (a) and 3 (b). If operant 2 (a) follows, food is produced and followed by the conditions for operant 4 (b). A choice of 6 (b) in the last option produces food and reinstates the conditions

(7)
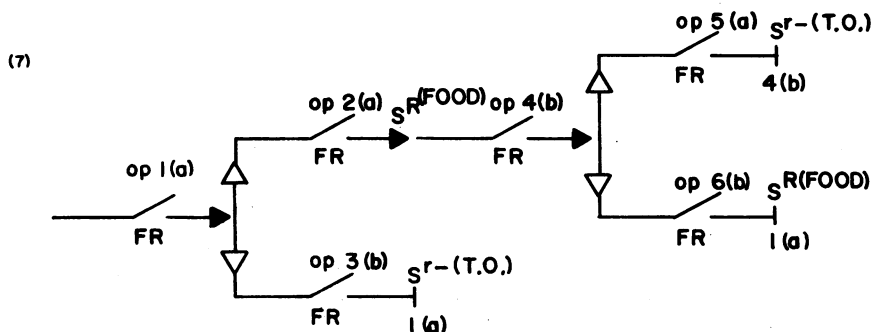
for 1 (a). The failure of the organism to select the operant in each option which matches the stimulus properties of the operant producing the option leads to a timed-out condition and reinstatement of that part of the grove.
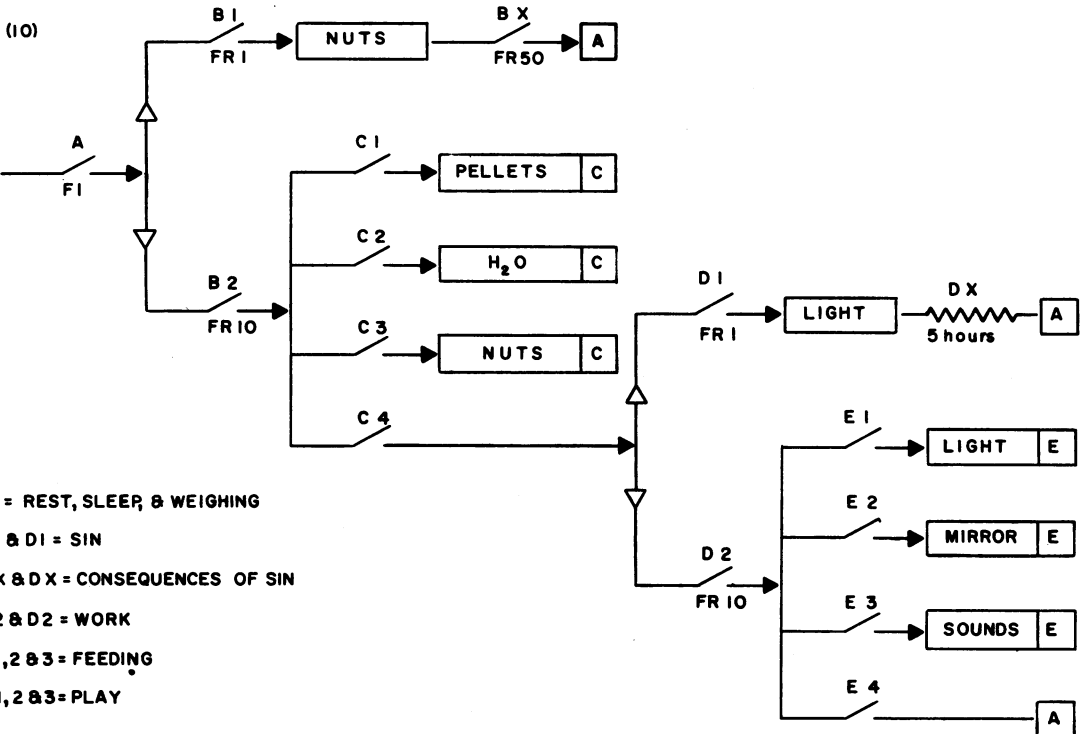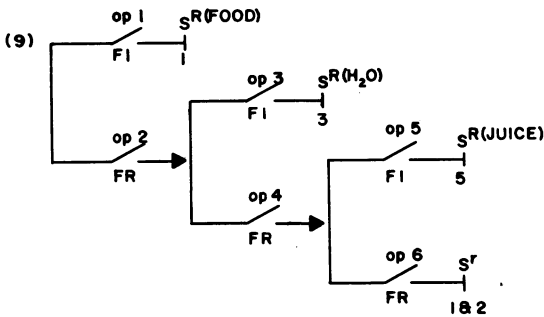
Grove (8) is composed of several trees and provides for the production of four different reinforcement conditions. The delivery of each reinforcement is followed by reinstatement of the conditions for operant 1. Numerous possibilities exist for different sequences by alteration of the reinforcement conditions. For example, if both operants 4 and 5 produced food, operant 4 could be arranged to reinstate operant 2 and operant 5 to reinstate operant 1. Such an arrangement could be used to compartmentalize the behavior associated with reinforcers of a given type and thus circumvent the necessity of

going through the entire sequence for each primary reinforcement.

Behavior grove (9) is composed of trees in which one operant is common both to the preceding option and the subsequent tree. Thus, in this grove, operant 1 produces food and reinstates only itself. Operant 2 is concurrently in effect with operant 1, but its only function is the production of the subsequent option. Although this type of grove suggests some similarities with a multiple-schedule procedure, the translation of conditions from one reinforced operant to the next is under the organism's control via the specific operants 2, 4, and 6. It is also similar in some respects to the grove in example (5), but it allows the progression of operants to flow in only one direction.

In most of the illustrations of the present system presented above, emphasis has been placed upon the more or less detailed description of behavior samples. The example grove (10) is included to illustrate an extension of the system to still larger repertoires of behavior. In this case, the meaning of the symbolization is more general. Capital letters designate not operants, but behaviors which might be composed of many operants and described in detail separately. Special reinforcement and reinstatement conditions are described with words or with letters and enclosed in boxes.

In this example, the behavior A is considered to be restricted to a special chamber where the organism

(9)

op 1 — FI — S^R(FOOD)
op 2 — FR
op 3 — FI — S^R(H$_2$O)
op 4 — FR
op 5 — FI — S^R(JUICE)
op 6 — FR — S^r 1 & 2

(10)

B 1 — FR 1 — NUTS — B X — FR 50 — A

A — FI

B 2 — FR 10

C 1 — PELLETS C
C 2 — H$_2$O C
C 3 — NUTS C
C 4

D 1 — FR 1 — LIGHT — D X — 5 hours — A

D 2 — FR 10

E 1 — LIGHT E
E 2 — MIRROR E
E 3 — SOUNDS E
E 4 — A

A = REST, SLEEP, & WEIGHING

B 1 & D 1 = SIN

B X & D X = CONSEQUENCES OF SIN

B 2 & D 2 = WORK

C 1, 2 & 3 = FEEDING

E 1, 2 & 3 = PLAY

rests, sleeps, and is weighed. Specific behavior is required to escape from this chamber and for the production of the option between behaviors B_1 and B_2. The behavior B_2 is considered a matching-to-sample task. Completion of an FR of 10 correct matches produces the feeding option. Within this option, the organism may emit alternative behaviors producing food pellets, water, or nuts; and following reinforcement, they produce reinstatement of that option. If the behavior of B_1, which is a relatively easy behavioral requirement, had occurred in .the first option, it would have produced a reinforcement of nuts to be followed by the conditions for behavior B_x. The behavior of B_x is considered to be an FR requirement of 50 on a manipulandum requiring considerable work. Completion of the requirement in behavior B_x would be necessary for reinstatement of behavior A and access to all other aspects of the grove. If the organism is in the feeding option and emits the behavior of C 4, the next option is produced, which is a choice between behaviors D_1 and D_2. The behavior of D_2, which is considered a complex counting task when properly executed, produces the next option, composed of several behaviors reinforced with conditioned rewards. The behavior of D_1 would lead to a more immediate reinforcement than the behavior of D_2, but it is followed by a 5-hour blackout condition and the eventual reinstatement of condition A_1. In this example then, the occurrence of behaviors called sinful (B_1 and D_1) could presumably be controlled not only by their own requirements and consequences, but also by the relative requirements of their alternative behaviors. Many specific questions

and variations of procedures would be possible within such a repertoire.

Such complexities of behavior as suggested in example (10) would imply that the option, chain, tree, and grove could be considered not only as descriptive statements of behavior, but that they should also be subject to empirical demonstration of their functional and unitary properties by manipulation in a fashion analogous with that of the operant. By placing the entire sequence of behavior in a tree, for example, under specific stimulus conditions and by providing for contingencies which are satisfied not by the occurrence of operants but by trees, such samples of behavior should be able to be manipulated in the same manner as the behavior of an operant, regardless of whether one instance of the class occurs or many. Thus, one can conceive of chains composed not of operants, but of trees, of options between trees, etc. Recent work by Ferster (1960) has already suggested the feasibility of such programs by placing a matching-to-sample task under several schedules of reinforcement. Hence, by such manipulations it should be feasible to deal not only with much larger samples of behavior having unitary properties, but with samples which are reducible to explicit and identifiable components as well.

Although the present system is at best only approximate, it provides a descriptive and conceptual language instrumental to the building of elaborate behavior repertoires in the laboratory. Their investigation may eventually suggest better units which indeed reflect the structure of complex behaviors in the everyday world outside of the laboratory.

PART III: A DESCRIPTION OF SOME EXPLORATORY EXPERIMENTS WITH MULTI-OPERANT BEHAVIOR

The following experiments taken together are offered as evidence of the feasibility of building and analyzing elaborate multi-operant samples of behavior. The character of these experiments is exploratory in that where results of one experiment suggested interesting formal questions as well as techniques for bringing more of an organism's behavior under experimental control, it was this latter activity which was largely pursued. Thus, some of the experiments to be reported offer less of an exhaustive account than might be desired. They do, however, outline experimentally various forms of multi-operant behavior samples and reveal the changes in conception and methodology which were necessary for the establishment of the more extensive ones.

Experiments with Chains

Numerous experiments have been reported which involve the establishment of simple multi-operant chains (Ferster & Skinner, 1957; Keller & Schoenfeld, 1950). In addition, several of these experiments have shown that the operant most remote from the primary-reinforcement condition is sensitive to the fre-

quency of reinforcement and the contingencies used with the behavior in the latter part of the sequence (Autor, 1960; Hanson, 1959). The first experiment reported here illustrates one such effect in some detail.[5]

Three rat litter-mates were placed in individual chambers and trained so that pulling a metal chain in darkness produced a light after a variable interval of time. In the presence of the overhead light, a bar press after another variable interval resulted in food reinforcement and termination of the light. This two-operant chain was established to determine the effect of the mean schedule of the second operant (bar pressing in the light) upon the performance of the first operant (chain pulling in darkness). The experiment consisted of maintaining a 4-minute, variable-interval schedule constant on the first operant, while systematically varying the schedule on the second operant. Each rat was maintained at a body weight of 75 per

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[5]Taken from the author's unpublished doctoral dissertation under the guidance of Prof. F. S. Keller, Columbia University, 1954.
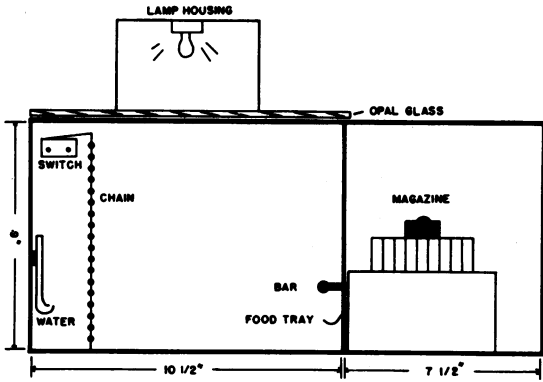
Fig. 1. Experimental chamber used with two-operant chaining procedure.

cent of its free-feeding weight and was run 6 hours daily for 7 days at each of five different mean schedules, ranging from 30 seconds to 8 minutes. Two such d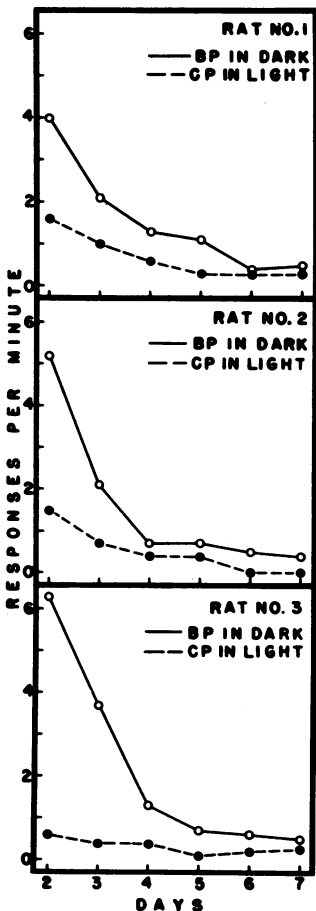eterminations were made at each of the schedules used with the second operant. Figure 1 illustrates the experimental chamber.

The two-operant chain was established by first conditioning bar pressing in the light; introducing a 1-minute, variable-interval schedule; and then placing the rat in darkness and permitting a chain pull in darkness to produce the conditions for the second operant. Once the chain pulling had been established, it was placed under a 4-minute VI schedule. Within approximately 7 days, the chain was well established, with little inappropriate responding. Figure 2 shows the gradual decline in such "out-of-sequence" responding.

The major effect of varying the mean schedule of the second operant is shown in Fig. 3, which is a plot of the mean chain-pulling rate during the last 2 days of each condition as a function of the schedule used with the bar pressing. In general, the first operant was dramatically affected by the reinforcement conditions of the second operant.

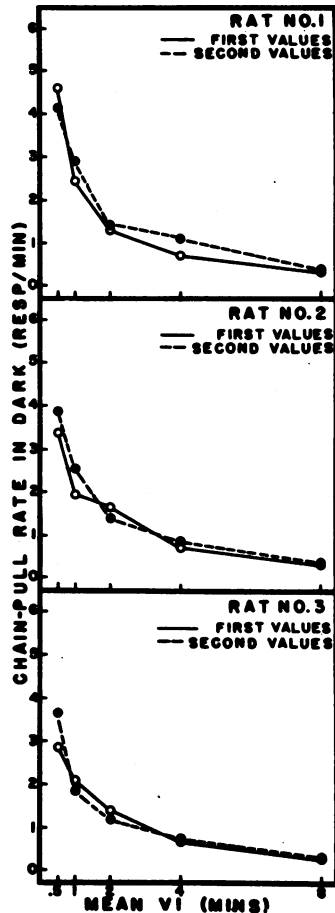Fig. 2. Decline in "out-of-order" responding during acquisition.

Fig. 3. Chain-pulling rate in the dark as a function of the mean VI schedule on the second operant.
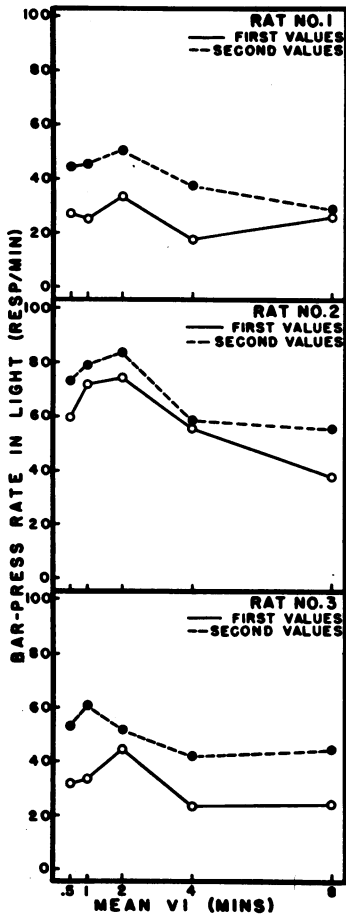
Fig. 4. Bar-pressing rate in the light as a function of the mean VI schedule used with that operant.
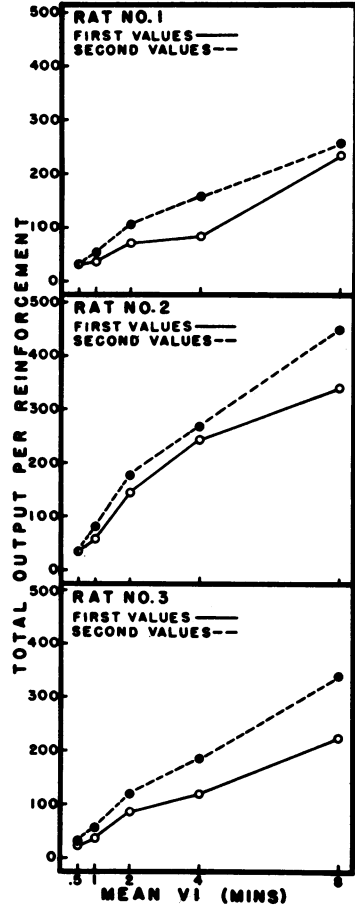

Fig. 5. Total response output per reinforcement as a function of the mean VI used with the second operant.

Figure 4 shows the effect of the different mean schedules upon the bar-pressing response rate. Although the data of Fig. 4 suggests that the response rate passes through a maximum, detailed examination of the data suggested that such a function is largely a product of changes in the pattern of the animal's responding confounded with the gross measure of over-all rate.

An examination of all performance measures in this experiment revealed the following changes in the rats' behavior. At the longer mean VI schedules on the bar, in contrast with shorter schedules, the rats pulled the chain in darkness at a lower rate and traveled to the bar more slowly having once produced the light. In the light, they responded at about the same rate while responding, but took "breaks" or pauses more frequently and for longer periods of time. Having received the food reinforcement and terminated the light, they also returned to the metal chain more slowly. In spite of these changes in the
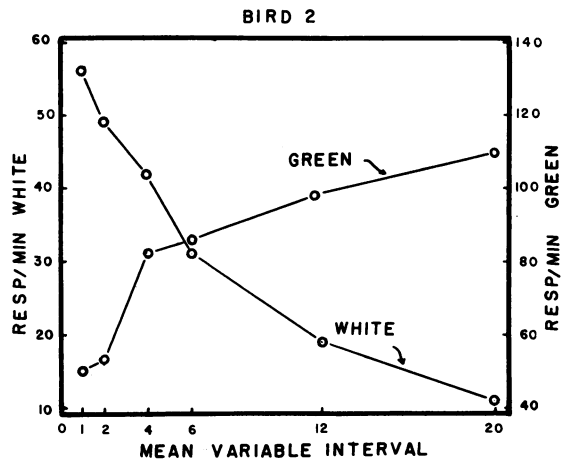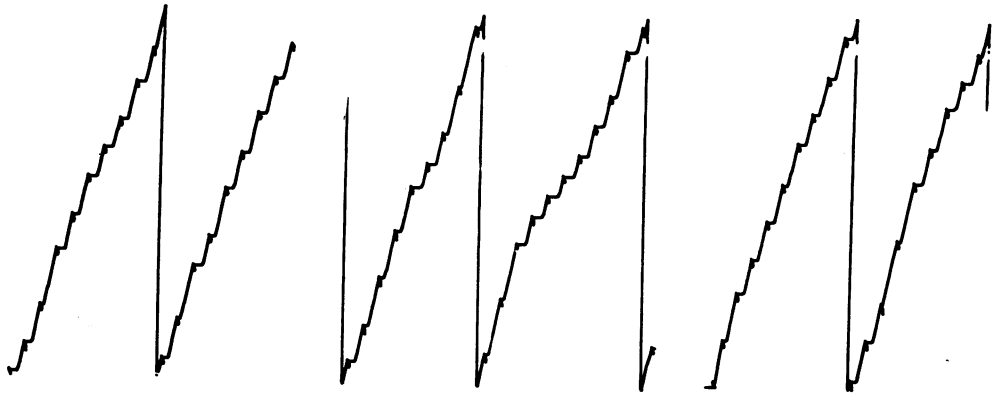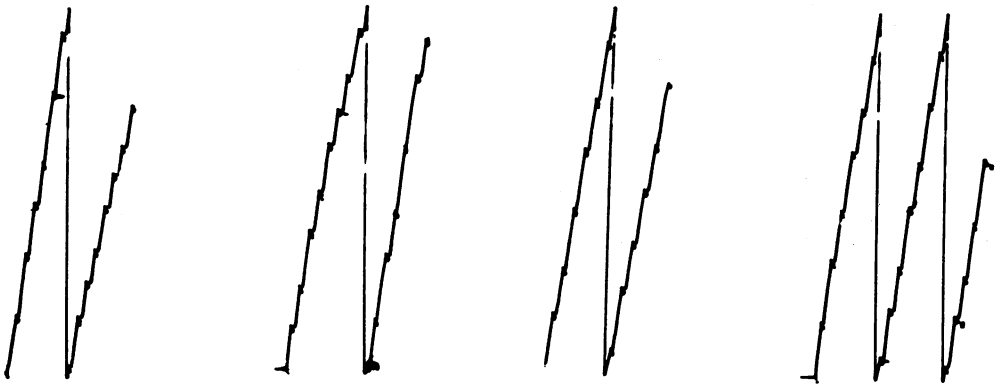

Fig. 6. Response rate during the white and green conditions as a function of the mean VI schedule used in the white condition.

BIRD 2

DAILY FI PERFORMANCE WITH VI 4' IN WHITE

DAILY FI PERFORMANCE WITH VI 20' IN WHITE

IO MINUTES

Fig. 7. Comparison of daily FI performance in conjunction with two different VI schedules used as the first operant in a sequence.

pattern of responding, under the longer mean VI schedules the rats actually emitted a considerably larger total number of responses. This effect is illustrated in Fig. 5, which is a plot of the total responses from both operants during the last 2 days under each condition as a function of the mean VI. Over the range of schedules used, the increase in total output is a factor of 8 to 14.

The importance of this experiment then was largely restricted to two findings. First, the properties of the last operant in a sequence could be expected to have a systematic effect upon the prior operants in a sequence; and second, the use of chaining procedures and intermittent reinforcement contingencies could be expected to result in greater outputs of experimental behavior. Rather than pursuing the implications of the latter finding, which were not fully appreciated, the question was asked: "To what extent could the conditions of a first operant in a chain affect the performance of a second?" Thus, since the

first experiment had demonstrated that the properties of a second operant could affect the first, the reverse question was now asked.

To answer this question, a two-operant chain was established in a pigeon with one manipulandum. Pecking a white key on a VI schedule changed the illumination of the key to green, where pecking on an FI 1-minute schedule produced a 4-second exposure to grain and then reinstated the white condition. The experiment consisted of holding the 1-minute, FI condition in the green color constant, while varying in successive stages the mean VI schedule in the white from 1 minute to 20 minutes. The order of mean schedules was 1, 2, 4, 6, 20, 4, 12, and 20 minutes. The experimental sessions were 3 hours, and the bird's weight was carefully maintained at 80 per cent of its free-feeding weight.

The results of this experiment are in Fig. 6 and 7. Figure 6 is a plot of the mean response rate from both the white and green conditions as a function of the mean VI schedule in the white light. The data are from the last 3 days under each condition, and

the rates plotted at 4 and 20 minutes are the mean of two determinations. This figure shows that although the response rate in white declined with longer mean intervals in that color, the response rate in the condition which produced the grain increased. The changes in response rate in the white primarily reflect an over-all slowdown in the VI performance without extensive alteration of its characteristics. However, the changes in response rate under the FI condition reflect changes in the pause following reinforcement and in the local rates while responding. These effects are apparent in Fig. 7, in which samples of the FI performance are compared in conjunction with two different VI schedules in the white. Since longer mean VI schedules in the white necessitated a longer average time prior to the green condition, it is likely that changes in the FI performance were largely due to those temporal factors. Although examination of the records revealed no obvious correlation between the length of a given interval in the white and the subsequent performance in the green, a later experiment involving a somewhat more com-

BIRD O

(A)   5" NO RESPONDING IN GREEN

(B)   16' PLUS 5" NO RESPONDING IN GREEN
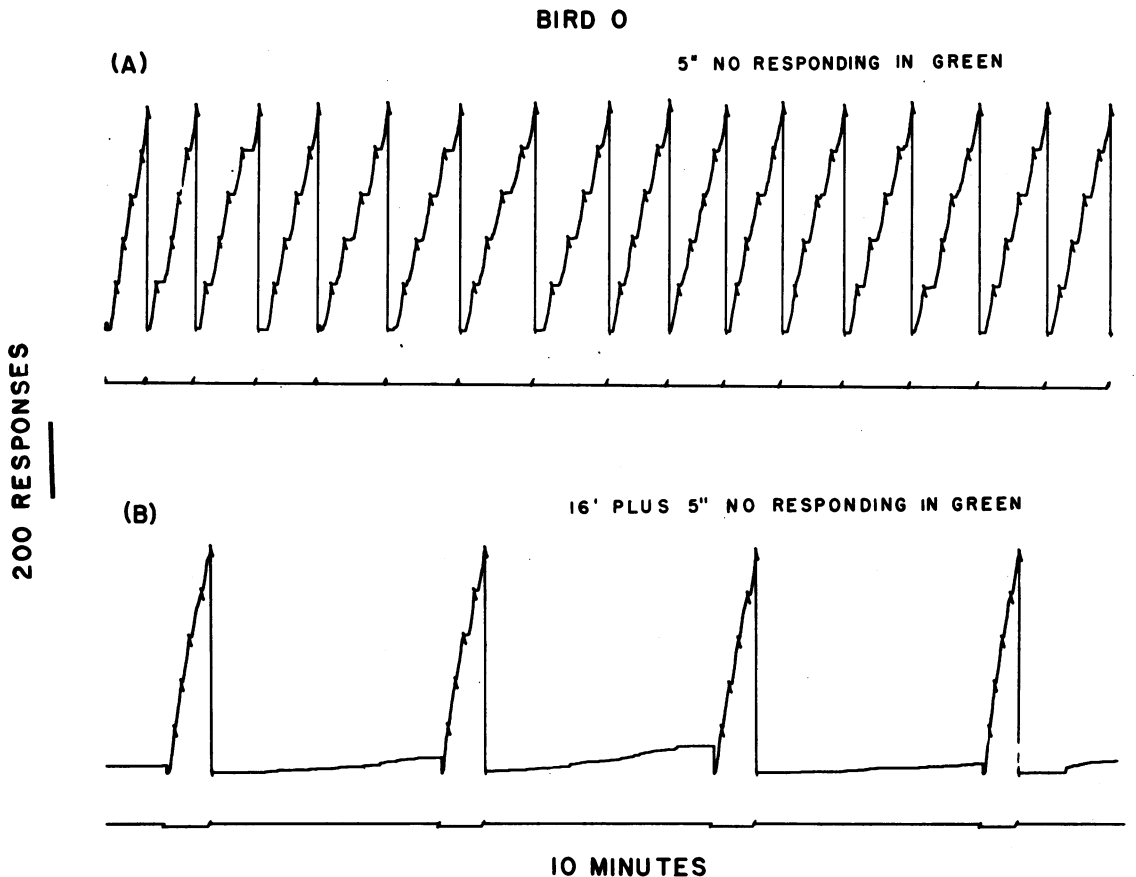

200 RESPONSES

10 MINUTES

Fig. 8. Sample records for a two-operant sequence, showing effect of an increase in the temporal contingency of a first operant upon the performance of a second.

plex procedure showed that effects similar to the above could be obtained simply with a negative operant as the first member of a two-operant chain.

In this experiment, a pigeon was given long-term training on a chain involving a single key and two stimulus colors. Not pecking the key for a period of 5 seconds when the color was green changed the color to red. On an FR 125, pecking in the red produced a 3-second exposure to grain and reinstated that FR condition for four successive grain reinforcements. Following the delivery of the fifth reinforcement, the green light and conditions for the first operant were reinstated. In the presence of the green light, each key peck delayed the production of the red condition by 5 seconds. This chain may be noted as follows.
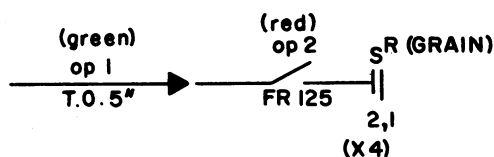
The bird was trained on this procedure in excess of 30 days, until no systematic change in ratio performance was observed. Each daily session was limited to 80 reinforcements and the weight maintained at 75 per cent of the free-feeding condition. Figure 8A is a sample cumulative record from the last day under this procedure. In this record, the pen resets to the base line following the fifth reinforcement, and the lower pen is in the up position during the green condition.

On the following day, the contingencies in the green light were altered such that now 16 minutes plus the 5 seconds of no responding were required for the production of the red condition. Figure 8B is a portion of the record from the first day under these new conditions. A comparison of the records in Fig. 8 suggests two effects. First, the pauses prior to a ratio run are considerably shorter when a longer temporal contingency is required in the first operant; and second, under both conditions, pause length tends to increase with successive ratios. These effects are further substantiated by the pause data in Fig. 9. In this figure, the mean time prior to the first response in each ratio has been plotted for the five successive ratios. The data is from the last 3 days under each temporal contingency. The most obvious effect of the longer time requirement in the green light was a shortening of the pauses in the subsequent operant. It can be noted in Fig. 8 that it also resulted in more responding during the green condition. These effects were further confirmed by two additional replications of the experiment.

In general, the results of this experiment were in agreement with the variable-interval experiment described above, showing that the conditions of a first operant could alter the performance of a subsequent one. In this latter experiment, however, the progres-

sive changes in pauses within the block of five ratios called for an additional account. It seemed most likely that the performance in the red condition was not only affected by the temporal requirement of the green, but also by its production of the green following the last of the five successive ratios. A number of further experiments were then pursued in an attempt to explore this latter type of effect.
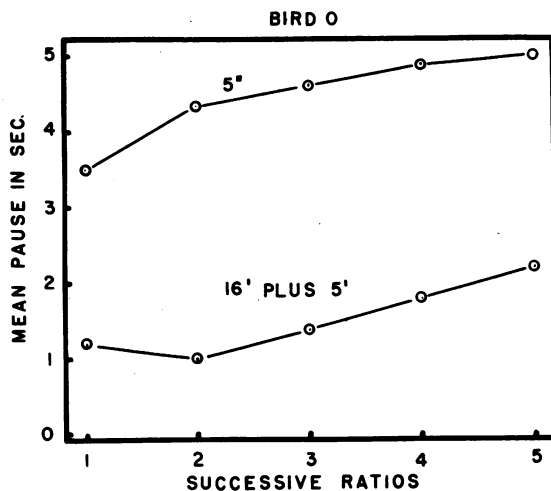

Fig. 9. Mean time to first response in each of five successive ratios under two different temporal contingencies in the first operant.

The first of these experiments consisted of a procedure in which five progressively increasing fixed ratios were programmed under a single green light, and the same five ratios, but in a decreasing order, were programmed under a red light. Each ratio produced reinforcement and the next requirement. Thus, the fifth ratio in each sequence produced not only reinforcement, but changed the color and reversed the sequence of ratios. Three different organisms, a rat, pigeon, and monkey, were used in this experiment, each with individual chambers and programming conditions. The reinforcements were condensed milk for the rat, grain for the pigeon, and pellets for the monkey. Although the series of five ratios differed for each organism, each was a simple progression with a multiplicative factor of 2.

The aim of this experiment, then, was to determine if the organism would pause consistently prior to the different ratios. Since in this procedure the consequence of a given ratio was not only the production of food but also the conditions for either a larger or smaller ratio, it was hoped that a possible mastery of the sequences would clarify the relative importance of the different consequences.

After approximately a month's training with 60 daily reinforcements, each of the organisms showed a promising mastery of the sequences. In general, the pauses increased in length with successive increasing

ratios in the red, and decreased with decreasing ratios in the green. The variability from one ratio to the next, however, was large. Continued training over approximately 3 months indicated no improvement in mastery and showed that the performance of each animal was quite subject to disruption. In an attempt to improve the performance, the number of progressive ratios in each sequence was reduced to three and larger increments were provided in each step. Under these new conditions, each organism quickly demonstated an orderly progression of pauses which was stable from day to day. Figure 10 contains sample records after 5 days that show the exact conditions. These records also show that the pauses prior to large ratios are longer than pauses prior to shorter ratios. It should be noted, however, that in this procedure a given pause is likely both a function of the ratio size just completed as well as a function of the ratio programmed next. That the pause length is not determined simply by the size of the previous ratios is suggested by an examination of the pauses prior to the largest ratio. It can be seen that the length of such pauses is not greatly different whether preceded by the largest ratio or by the middle-size ratio. Additional evidence that the ratio pause is not simply a

function of the size of the previous ratio was obtained by continued training of the monkey and bird with a slightly altered procedure. In this new procedure, the ratios in the red were 33, 132, and 528. In the green, however, the ratios were 132, 132, and 132. The last ratio in each color produced the next color and sequence as before. Figure 11 contains samples of the performance after it had stabilized. These records show that the pauses in the green following a ratio of 132 are relatively uniform, whereas in the red the pauses following 132 are considerably longer. This effect was shown even more dramatically when the bird was accidentally run almost to satiation. The record obtained is shown in Fig. 12.

It was concluded from these experiments with progressive ratios that after considerable training, chains, in effect, were established in which each ratio performance came under the eventual control of the stimuli arising from the organism's own behavior. Presumably, completing a given ratio and obtaining a reinforcement produced discriminative stimuli which specifically controlled the nature of the following behavior. Hence, in the chaining experiment described earlier, in which one finding was a progressive increase in pause length with successive ratios of
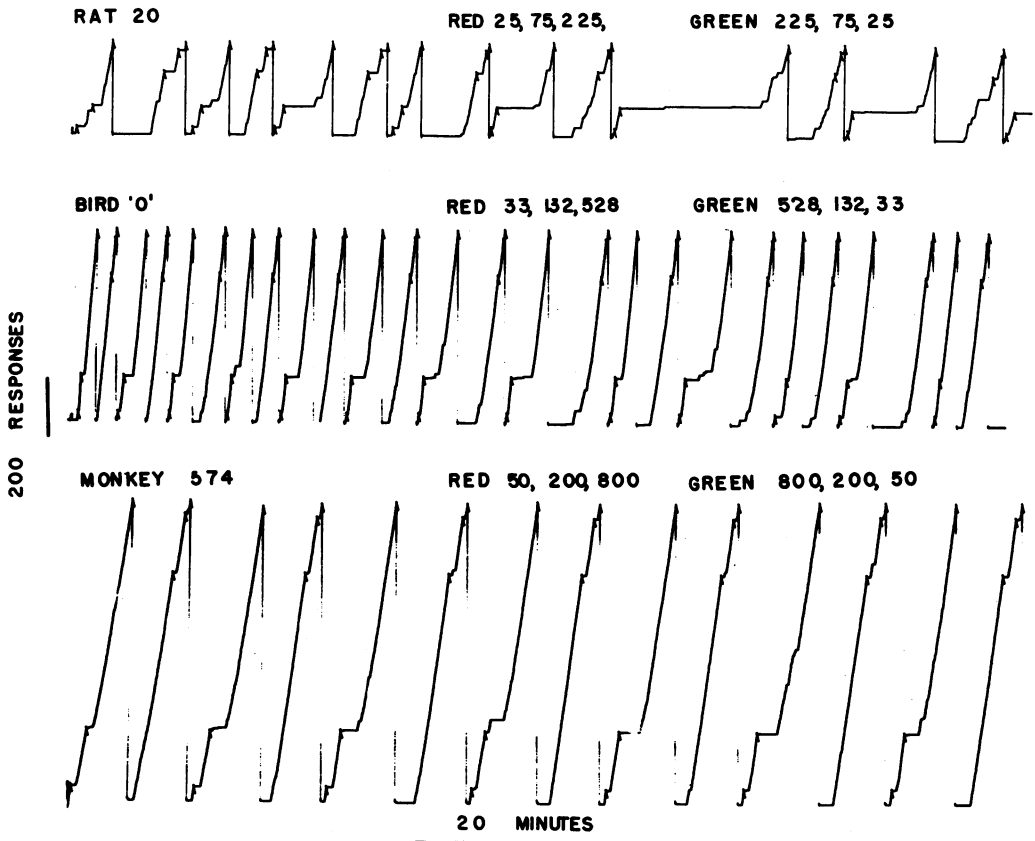

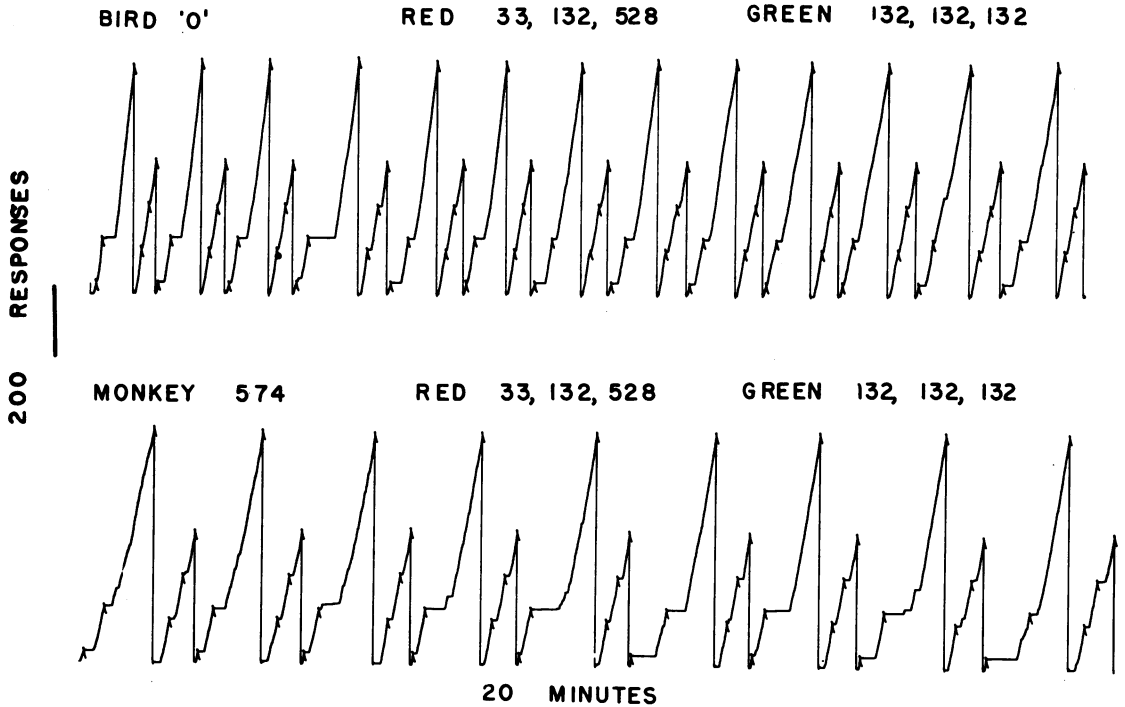Fig. 10. Performance under alternate increasing and decreasing sequence of ratio values.

Fig. 11. Performance under an alternate increasing and fixed sequence of ratio values.

equal size, such an effect presumably was due to the consequence of the last ratio, producing not only grain reinforcement but also the conditions for a temporal delay.

From the experiments described thus far, it was generally concluded that in a sequence of chained operants, the properties of each might be expected to have interaction effects upon other operants in the sequence. The effect of an early operant in a sequence upon later operants, however, was judged to be less dramatic than the reverse. It was also more generally concluded that the analysis of behavior sequences was made only more difficult by exploring procedures in which most of the critical stimulus conditions were left to the organism's own behavior. The direction of work was therefore shifted to the establishment of longer and more explicit chains.

The first effort with this new bias was the establishment of a five-operant chain. Four pigeons were individually trained to peck a single key which could be illuminated with five different colors. Pecking in each color after a fixed-interval contingency had been satisfied produced the next color. Pecking in the last color produced 4 seconds of grain and was followed by the first color in the sequence. The behavior was originally established with a short FI contingency of 15 seconds in each color. Within 3 days, the chain appeared well established. Sample records from three of the birds are in Fig. 13A, 13B, and 13C. All birds

showed an orderly progression in responding during the successive colors, reaching a maximum during the last color. With continued training, however, the behavior in the early colors became progressively weaker. A typical daily performance would consist of several completions of the sequence during the early part of the session to be followed by a gradual lengthening of the pause during the first or second color. An example of this performance for Bird 5 is in Fig. 13D. The limitations to be found in establishing such fixed-interval chains with birds have been extensively described by Gollub (1958).

Since it was clear that the above procedure offered considerable difficulties for the establishment of long chains, a variety of alterations were explored to enhance the performance. Most of these variations, such as increasing the feeder time or changing to VI schedules, proved largely unsuccessful except for one. In this variation, two of the birds were trained in the above manner, but the length of the sequence was variable instead of being five operants. Thus, following a given reinforcement, the sequence of colors was reinstated, but the delivery of grain and resetting of the sequence were programmed to follow randomly but equally often at the end of any of the five colors. With this new procedure, the value of the fixed interval was at first 15 seconds as before. The most immediate effect was a reduction in the pauses in the first color. Since with continued training it was clear that

the behavior was being well maintained, the value of the FI was increased to 30 seconds, and then later to 1 minute. Under both of these values of the FI, the long pauses in the first color, characteristic of the previous procedure, did not appear. Samples of the performance during the latter days under the 30-second and 1-minute FI are in Fig. 14. When the FI was increased to 2 minutes, however, considerable pausing in the early operants began to reappear. An example of this performance is also in Fig. 14.

In spite of the fact that with the above procedure, behavior was being maintained on the five-operant chain with values of the FI considerably larger than before, the general character of the performance was quite variable. This variability was judged not to be an inherent result of the variable-length sequence as such, but most likely due to its combination with FI contingencies. It was then decided to examine in some detail a three-operant chain with fixed-ratio contingencies in the hope that the performance would be less variable.

The same four birds used in the above procedures were now trained in a chamber which contained three keys. The procedure in general was as follows. During a delivery of grain, all three keys were illuminated white. Following reinforcement, the key on the left changed to blue and the other two keys remained white. Completion of a fixed ratio on the blue key changed its color to white and changed the middle key from white to green. Completion of a fixed ratio on the green key changed its color to white, and changed the key on the right from white to red. Completion of a fixed ratio on this final key again produced a white light and a 4-second exposure to grain. Following the grain delivery, the sequence was reinstated. This procedure involving three independent keys, three S^D lights, and three S^Δ lights was chosen since the importance of S-delta behavior in the establishment of long chains was generally unknown. With this procedure, then, the S-delta responding was easily measured.

After adaptation to the new chamber, all four birds were exposed to the three-operant chain, the fixed ratio on each operant being 10 pecks. Each bird ran for a 4-hour session or until 50 reinforcements had been obtained, whichever occurred first. Body
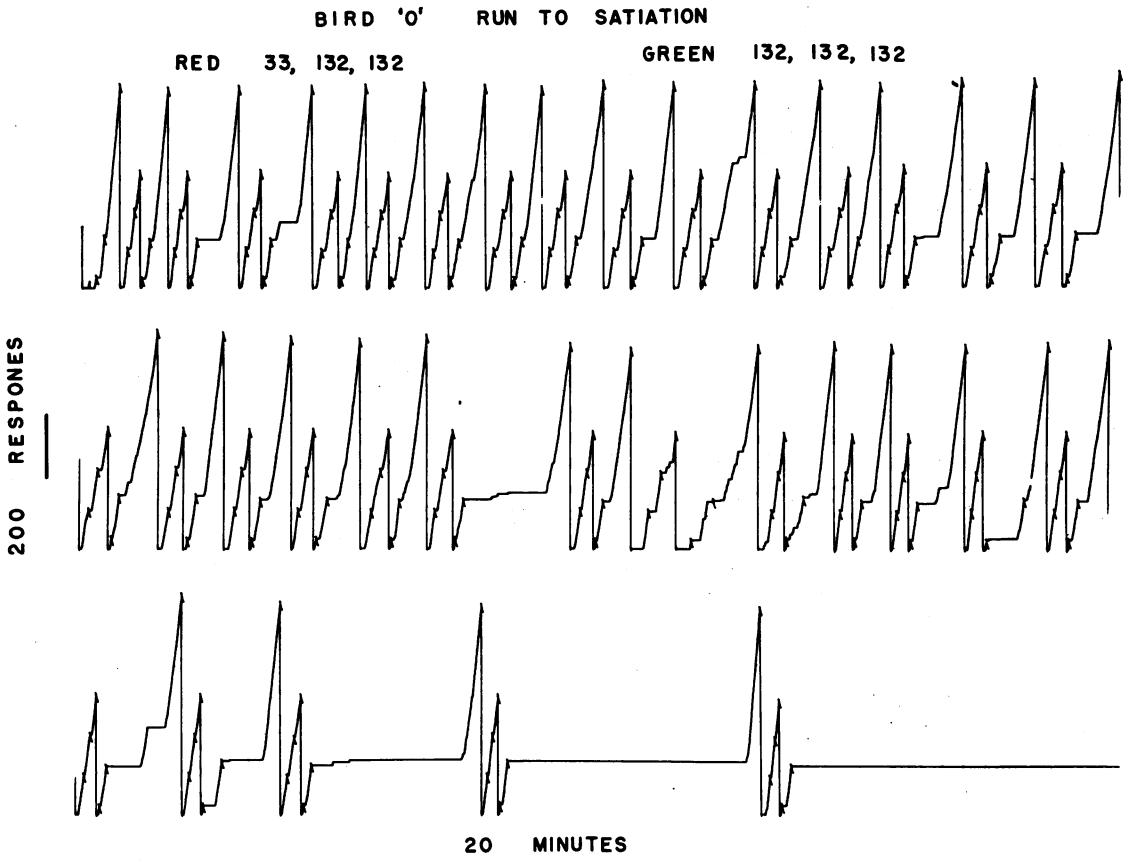

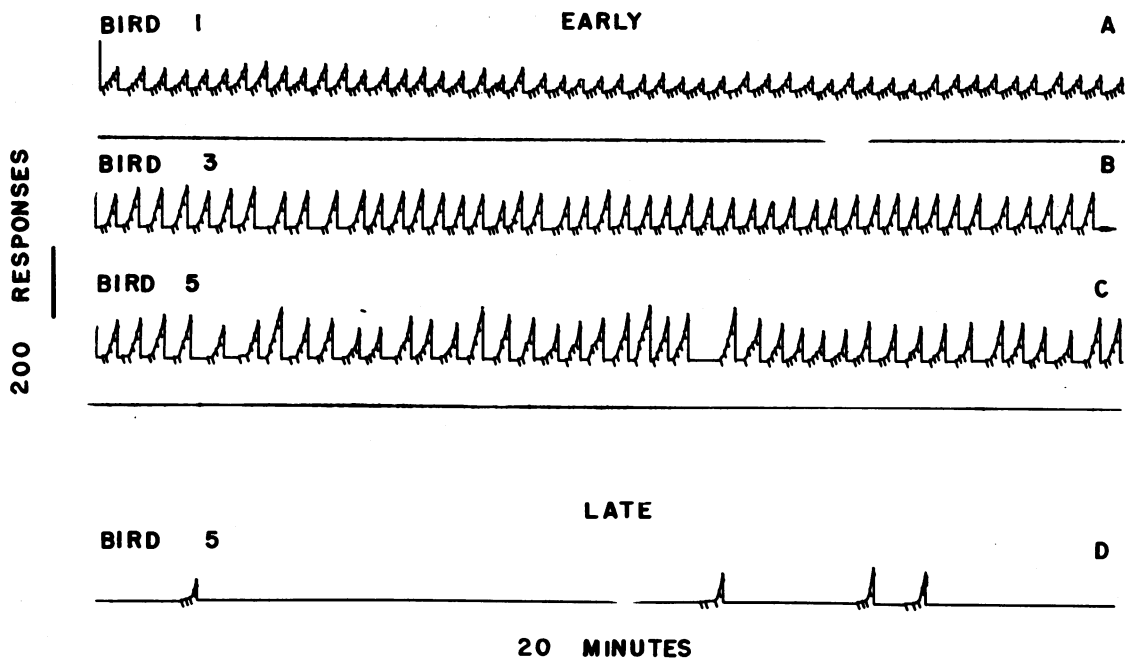Fig. 12. Effects of satiation on an alternate increasing and fixed sequence of ratios.

Fig. 13. Establishment of a five-operant chain with FI 15-second contingencies in each operant.

weights were carefully maintained for each bird at 80 per cent of free-feeding weight.

Within approximately 5 days, all birds demonstrated a good ratio performance on each key and the S-delta or out-of-order responding became negligible. Following a period of continued training to insure stabilization, a different experiment was pursued with each bird. Generally, these experiments consisted of holding the FR 10 constant on two of the keys while varying the ratio on the third in steps. They will be described separately.

For Bird 1, the fixed ratio of 10 was held constant on the last two operants while the ratio on the first (*i.e.*, the one most remote from the grain) was doubled in progressive steps from 10 to 160. The bird was run for at least 10 days and until its behavior had stabilized at each ratio. Sample records from the latter days under each ratio are in Fig. 15. It can be seen from these records that as the ratio on the first operant was increased, the pause prior to that ratio increased in length. These pauses became maximal under FR 160. The performance on the other two operants, however, is little affected, showing perhaps some slight improvement with larger ratios on the first operant.

The procedure with the second bird, Bird 5, was to hold the FR 10 on the first and last operants constant while increasing the ratio on the second operant. The ratio was increased from 10 to 160, and sample

records from the latter days under each condition are in Fig. 16. An examination of the data showed that the performance of the second operant was well maintained even at the higher ratios, although the pause in that operant generally increased. The performance of the first operant, however, shows a decided increase in the pause length and strain with increases in the size of the ratio on the second operant. The last operant shows little, if any, change.

The procedure followed with the third bird, Bird 256, was similar to the above except that the FR on the first two operants was held constant while the ratio on the last operant was varied. Sample records of this bird's performance are in Fig. 17. As the ratio was increased on the last operant, the performance of the two preceding operants shows progressively more pauses and strain. It will be noted that the effects are more pronounced upon the first operant than on the second. The performance of the last operant shows almost no pause or strain, even under the largest ratio, 160.

With the fourth bird, Bird CRS, the value of the FR on each of the three operants was increased together. At first, the values were FR 10, FR 10, and FR 10. They were then increased together to FR 20, 20, 20; FR 40, 40, 40; FR 60, 60, 60; and finally, FR 80, 80, 80. Sample records of the performance through ratio values of 60 are presented in Fig. 18. These records show that as the ratio values of all

three operants were increased, the development of pauses and strain first appeared in the first operant, later, in the second, and, finally, to some extent in the third operant. When the ratio values were increased to FR 80, 80, 80, the pauses during the first operant became so long that the experiment was terminated.

The data from these four experiments suggested the general conclusion that in a serial sequence of operants with FR contingencies, increasing the requirements of a given operant weakens the performance of preceding operants but slightly enhances the performance of subsequent operants. Since each operant is partly under the control of subsequent operants, it is also clear that a gradient of performance extends from the most remote operant to the terminal one which maintains the behavioral sequence. Presumably then, the length of a serial sequence which can be maintained in practice is determined in part by the behavioral requirements and reinforcement conditions of the terminal operant. It is interesting to note that the chaining performance did not collapse in the experiment with Bird CRS when the FR requirements were maximal. Rather, it simply occurred too infrequently to be

adequately examined under the general procedures and methodology used. Thus, questions of the possible length of serial chains, the effects of extreme requirements, and the effects of deprivation became, in part, methodological problems. An example of this difficulty was encountered when one of the birds was accidentally run to satiation while under the three-operant chain described above. Examination of the bird's performance in Fig. 19 reveals a progressive lengthening of the pause during the first operant. There is also some indication that the responding in the second operant is weakened. However, a reliable description of the nature of the performance during extreme satiation was limited by the infrequency of the behavior. After several deliberate attempts to describe the effects of satiation and other limiting conditions upon serial chains, it was clear that they awaited the development of improved methodology. Rather than directly pursuing the changes in basic methodology which were indicated, the subsequent research involved an attempt to gain a greater output of behavior in a serial chain by placing the total sequence under an intermittent contingency. Several exploratory experiments were pursued in an attempt to gain this output.
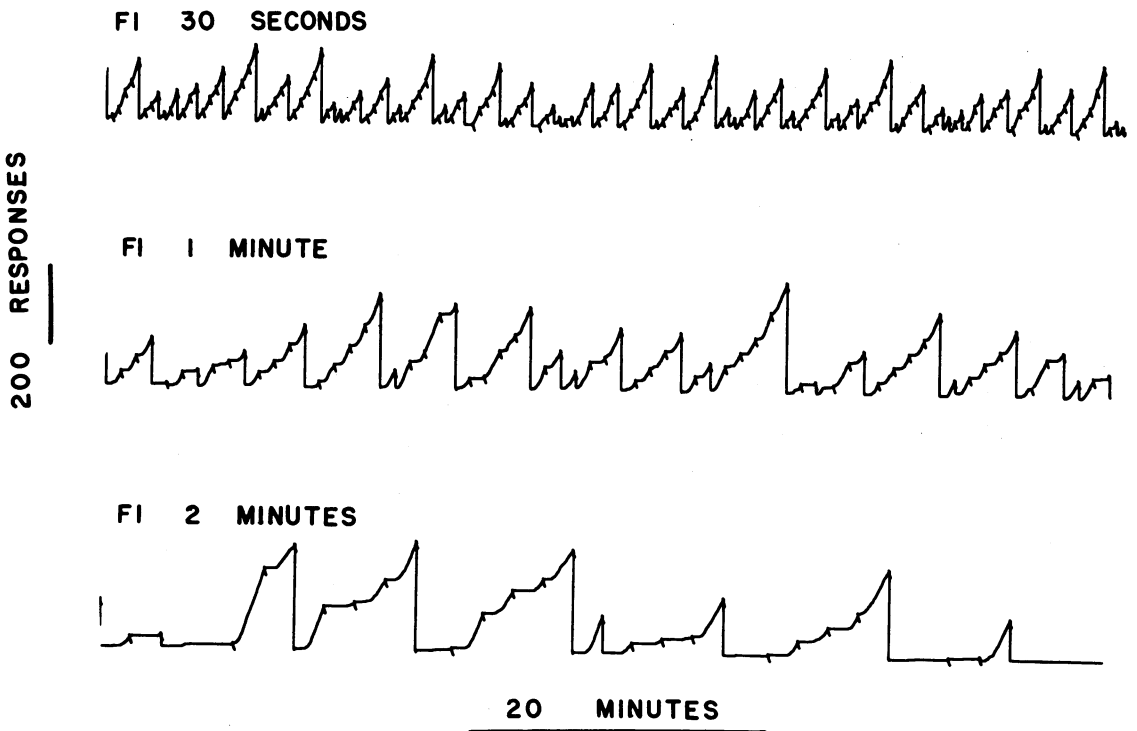

Fig. 14. Performance on a variable-length chain under contingencies of 30-second, 1-minute, and 2-minute intervals in each operant.

FR 10, 10, 10   BIRD I

FR 20, 10, 10

FR 40, 10, 10

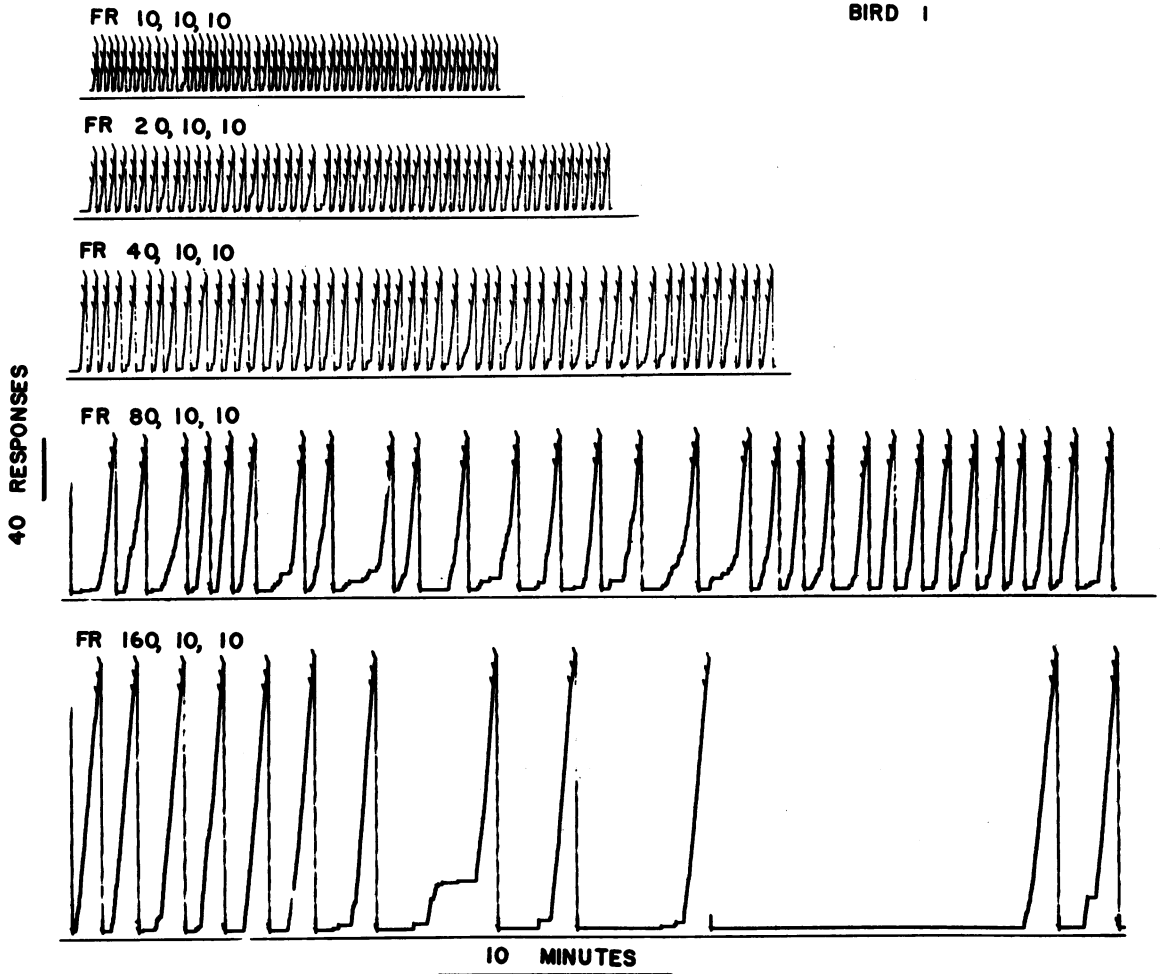FR 80, 10, 10

FR 160, 10, 10

10   MINUTES

Fig. 15. Performance on a three-operant chain as a function of the FR requirement on the first operant.

In one of these experiments, Bird CRS, which had been straining badly under the requirement of FR 80 in each operant, was exposed to an alteration of the procedure in which an FR of only 10 was required in each color, but the sequence of three operants had to be completed eight times before delivery of grain. Since the satisfaction of the third operant had been followed by the appearance of the final white light and the presentation of grain for 4 seconds, the completion of a nonreinforced sequence in the new procedure simply produced the final white light for 4 seconds and then was followed by the appearance of the first color in the sequence. When the sequence of colors had been completed eight times, grain was presented accompanying the white light.

When Bird CRS was placed under the new procedure, the immediate effect was an increase in the total output of responding. A portion of the record from the first day under this condition is in Fig. 20A.

In this record, the reinforcement pen marks the change from one color to another only during the eighth completion of the sequence. With continued training, the pauses following the grain reinforcement occurred regularly, and a stable performance developed which was maintained for 20 days. Typically, the bird would earn 40 to 50 reinforcements in each session. An example of this performance is in Fig. 20B. Upon returning to the previous procedure, FR 80, 80, 80 with reinforcement at the completion of each sequence, the long pausing in the first operant returned. By the fifth day on this procedure, the bird was obtaining only four or five reinforcements each day. Figure 20C shows an example of this performance during the early part of a session.

It was now clear that for this bird the total behavior requirement of 240 pecks per reinforcement was better sustained by the use of a short ratio on

each operant and intermittent reinforcement of the sequence than by three large ratios of 80. Since other procedures were used with the other birds, the generality of this finding was unknown. Results under continuous experimental sessions (to be reported in a later section) suggest that the intermittent reinforcement of a total sequence is a useful device for analysis and for obtaining a substantial performance. However, the maximum output of behavior has more generally been found to be limited by the total work requirement, the past history, and the nature of the reinforcement rather than by any special variations in procedure.

Another illustration of intermittent reinforcement of a total chain is found in the case of Bird 1. This bird was re-stabilized on the chain of three operants,

the ratio requirement being FR 10, 10, 10, with the completion of the last ratio producing the grain and the first color. The procedure was then altered such that two completions of the three-operant sequence were required for production of the grain. The bird quickly adjusted to the new procedure. Figure 21A shows a record for the third day. The requirements were then again raised such that only the fourth completion of the sequence was reinforced with grain. An example of the early performance is in Fig. 21B. After approximately 15 days' further training, the behavior had stabilized but was characterized by strain and long pauses following reinforcement which increased during a given session. A portion of a record from the last day under this condition is in Fig. 21C. Recalling the previously described experi-
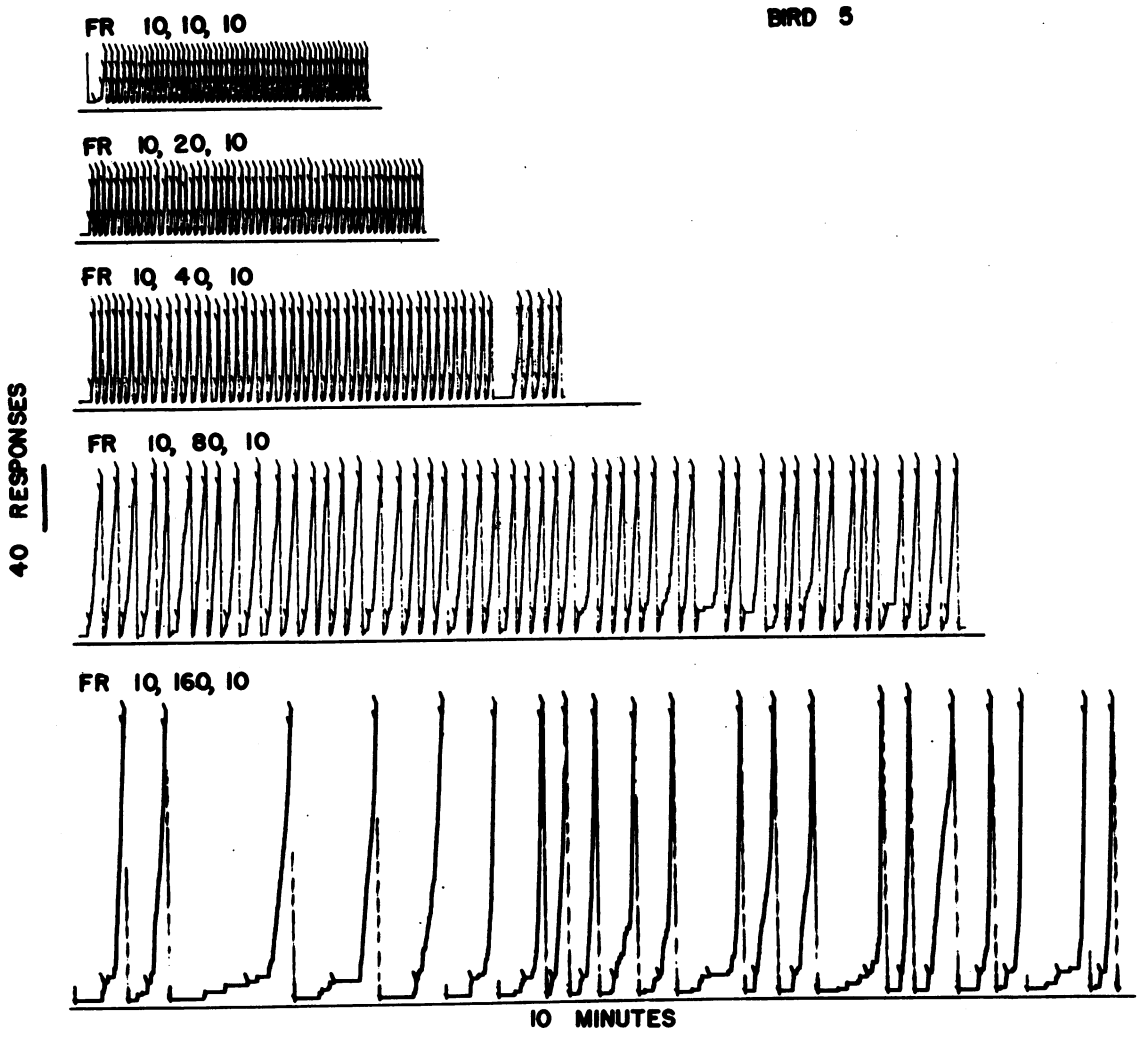

Fig. 16. Performance on a three-operant chain as a function of the FR requirement on the second operant.
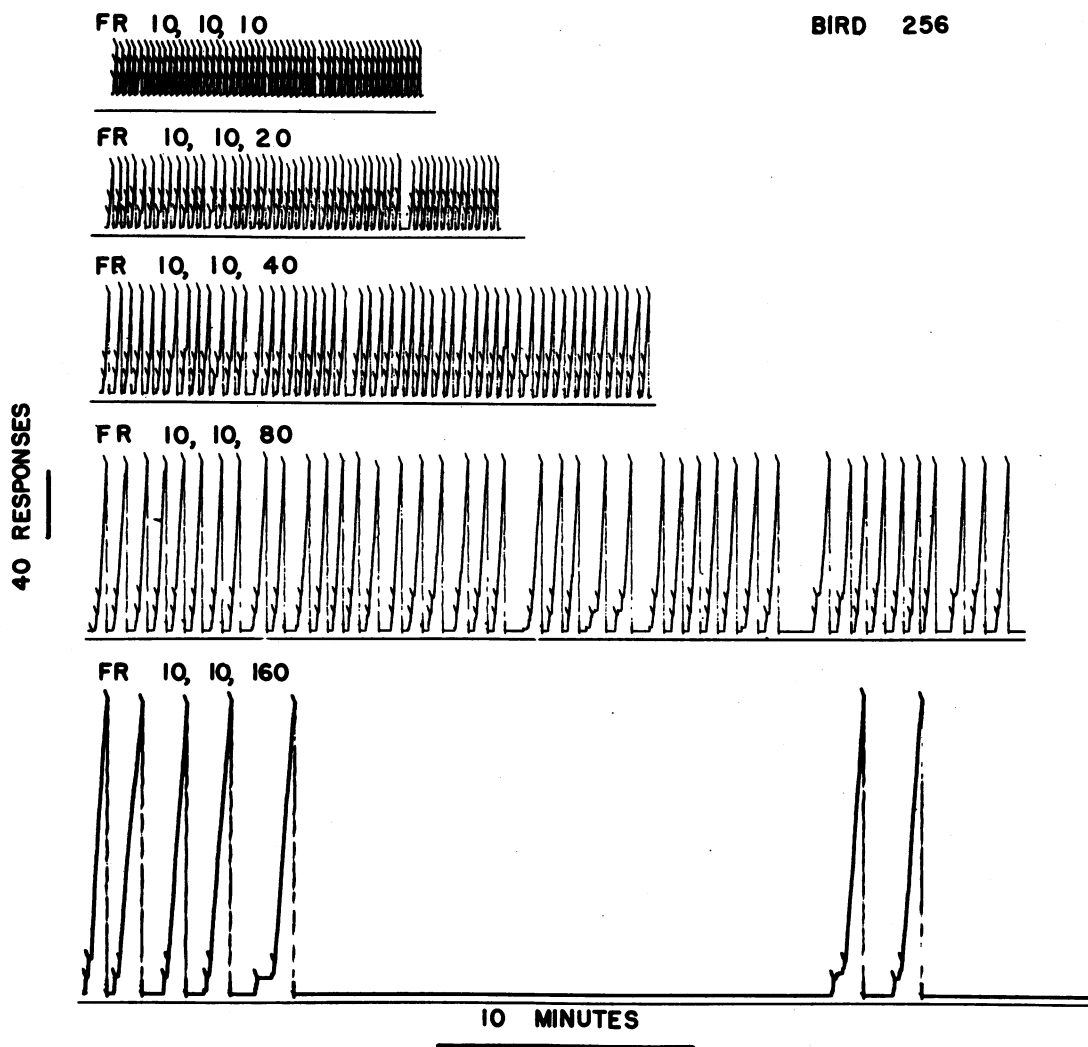
Fig. 17. Performance on a three-operant chain as a function of the FR requirement on the final operant.

ment in which enhancement of performance on a five-operant FI chain had followed the introduction of reinforcement after various operants, a similar alteration was used here. In the present procedure, however, the total sequence of the three operants (rather than a single operant) was placed under a variable schedule. In this arrangement, the grain was produced on a variable basis after the first, third, fifth, or seventh completion of the three operants. The mean number of sequences required was thus four. The bird quickly adapted to the new contingencies, showing a marked decline in strain and almost no pausing during the first operant. After 15 days' further training, the bird continued to show good performance. Two complete daily records from the last days under this variable-ratio contingency are

in Fig. 21D and 21E. For this bird, then, a variable reinforcement of the sequence of three operants was well maintained, whereas work requirements equivalent but arranged under a fixed ratio of sequences resulted in considerable strain and long pausing.

Early Experiments with Options and Trees

The experiments described above dealing with serial arrangements of operants had answered several specific questions but had raised many others. Aside from the specific questions regarding chains and the chaining process, the work suggested two general implications. First, that ideal laboratory techniques were not being used for the examination and establishment of long serial patterns of operants; and secondly, that in spite of the success with intermittent

reinforcement of sequences, much of an organism's behavior did not readily lend itself to either a laboratory or theoretical analysis strictly in terms of serial arrangements. This work was then shifted to multi-operant procedures involving options.

One such procedure examined in some detail was essentially a tree of the general form,
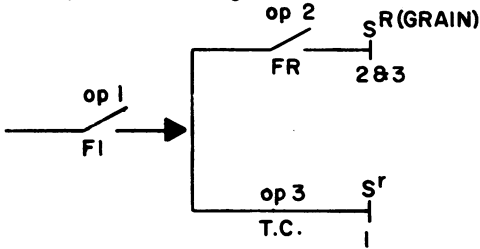
in which the response class of every operant was defined with a single manipulandum as a reference base. The following was the implementation of this procedure that was used. The birds were trained to peck at a key that would change to red when it was illuminated blue only when a fixed-interval contingency was satisfied. When the key was illuminated red, two concurrent contingencies were in effect. One of these was a temporal contingency. It operated such that if a peck did not occur for 6 seconds (including the feeder time itself), the FI and blue condition was reinstated. The other contingency in the presence of the red provided for the delivery of a 4-second grain reinforcement with each completion of 100 responses. Following the delivery of grain, both contingencies in the red were reinstated. In the presence
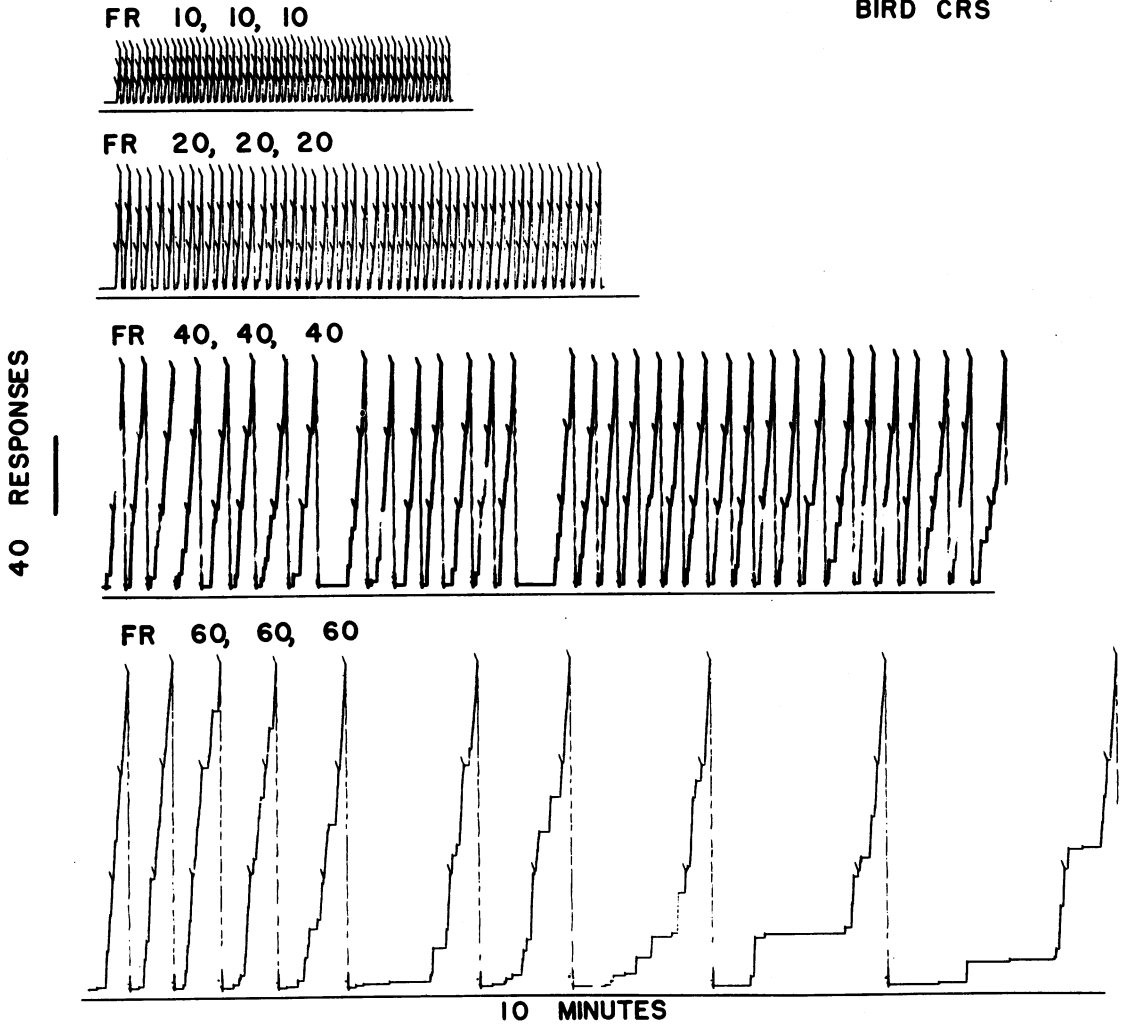

Fig. 18. Performance on a three-operant chain as a function of increases in the FR requirement on all three operants.
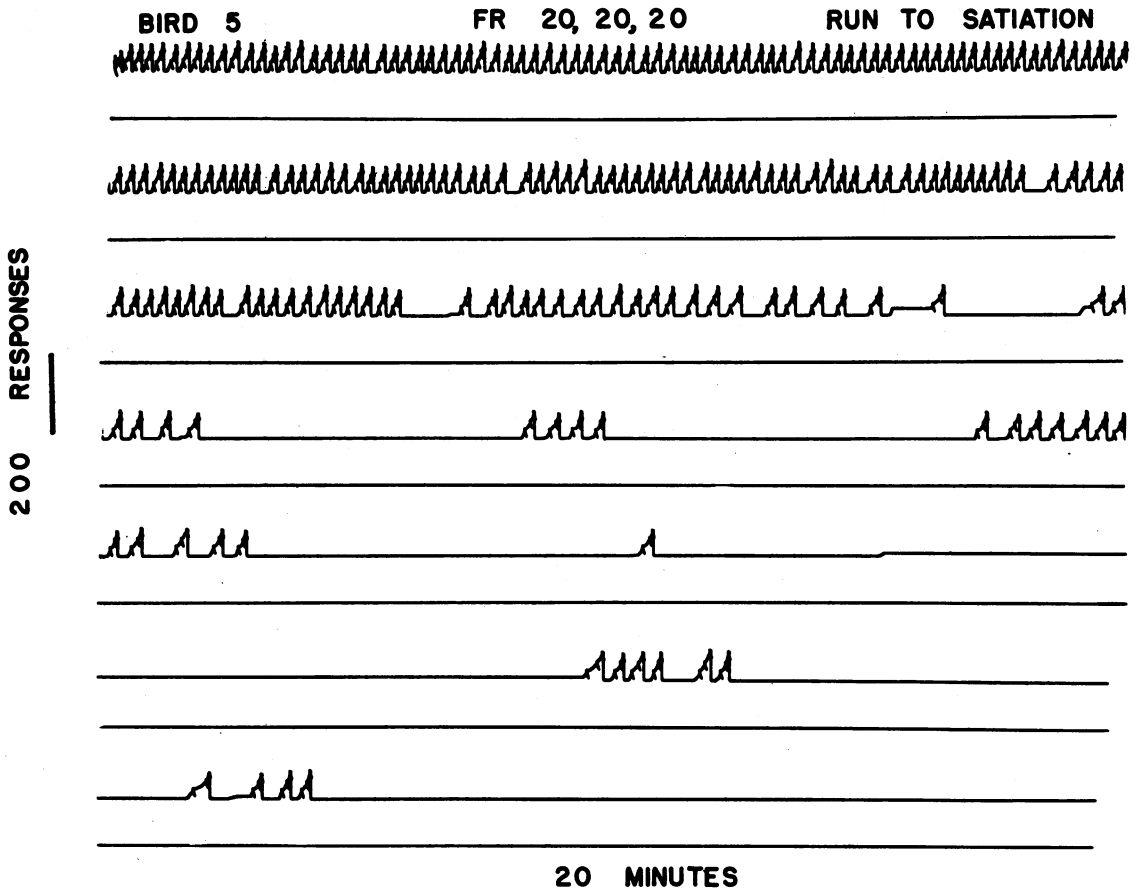
Fig. 19. Effects of satiation on the performance under a three-operant chain.

of the red, then, an option was in effect between a positive operant producing grain and prolonging the red condition, and a negative operant whose function was the reinstatement of an earlier condition.

Four pigeons were trained under this procedure with the temporal contingency set at 6 seconds, the FR at 100, and the FI at 2 minutes. After 23 daily sessions consisting of 60 reinforcements each, the performance had become stable from day to day. Typically, the behavior in the blue condition consisted of a pause followed by an acceleration in rate terminating in the change of color from blue to red. Once in the red, the performance was characterized by the completion of one or more ratio runs with a minimal pause following reinforcement and, finally, by a pause following reinforcement which reinstated the blue condition; *i.e.*, 6-second pauses almost never occurred in the red except following reinforcement. After the behavior had been stabilized the red condition was altered such that pauses, or inter-response times, of 6 seconds were recorded but did not have their pre-

vious consequence. For all birds, the pauses following reinforcement lengthened. Figure 22 contains sample records of the performance for two birds under these two conditions. In these records, the pen resets to the base line upon a change in color. During the removal of the temporal contingency from the red condition, the reset indicated not a change in color but only the occurrence of a 6-second pause. These records show that without the temporal contingency and its associated consequence, the pauses following reinforcement in the red almost always exceeded 6 seconds. With a return to the original conditions, the speedup of performance in the red was recovered for all birds. The effect of such manipulations is illustrated in more detail for one bird in Fig. 23, in which the number of 6-second pauses per grain reinforcement is plotted by days. It is evident that the birds show an increase in number of pauses during the removal of the temporal contingency, but that they return to their original level following the reintroduction of the temporal contingency.

Since it was now clear that the presence or absence of the concurrent temporal contingency in the red had a striking effect on the performance in that color, further experiments were undertaken in order to examine the role of the major variables in the procedure. Thus, with one bird, Bird 4, the size of the fixed ratio in the red was varied from 25 to 125 responses in successive stages, allowing the behavior to stabilize at each ratio. During these manipulations, the FI remained at 2 minutes, and the critical pause length in the red was 6 seconds. Under the smallest ratio, 25, the bird never paused sufficiently long in the red to incur the blue, or fixed-interval, condition. When the FR 50 was imposed, the stable performance revealed only an occasional entrance into the blue condition. With successive increases in the ratio size, frequency of behavior in the blue condition increased until under the FR 125 at least one completion of the FI in the blue preceded every reinforcement in the red. Sample records of the performances under FR 50 and FR 125 are in the top half of Fig. 24. It will be noted that under FR 125, the ratio performance is relatively poor, and, occasionally, two successive completions of the FI precede a performance in the red sufficient to produce reinforcement. A sum-

mary plot showing the performance under the different ratios is presented for Bird 4 in Fig. 25. In this plot, the frequency of entrance into the blue condition per grain reinforcement obtained in the red (BF/reinf.) is expressed as a function of the ratio size in the red condition. The data are from the last 3 days under each condition. The size of the ratio in the red, then, was clearly one parameter of the present procedure.

With Bird 7 the length of the permissible pause in the red condition was examined. After the original demonstration of the effects of the presence or absence of the temporal contingency, the conditions for this bird were changed to an FR of 75 responses in the red, an FI of 2 minutes in the blue, and a critical pause length of 16 seconds in the red. Under these conditions, the bird almost never paused sufficiently long in the red to incur the blue. The length of the critical pause then was decreased in successive stages to 1.5 seconds, allowing the performance to stabilize at each value. Sample records from the 8-second and 1.5-second conditions are in the lower half of Fig. 24. These records show that with a very short critical pause such as 1.5 seconds, the bird typically returned to the blue condition following a reinforcement in
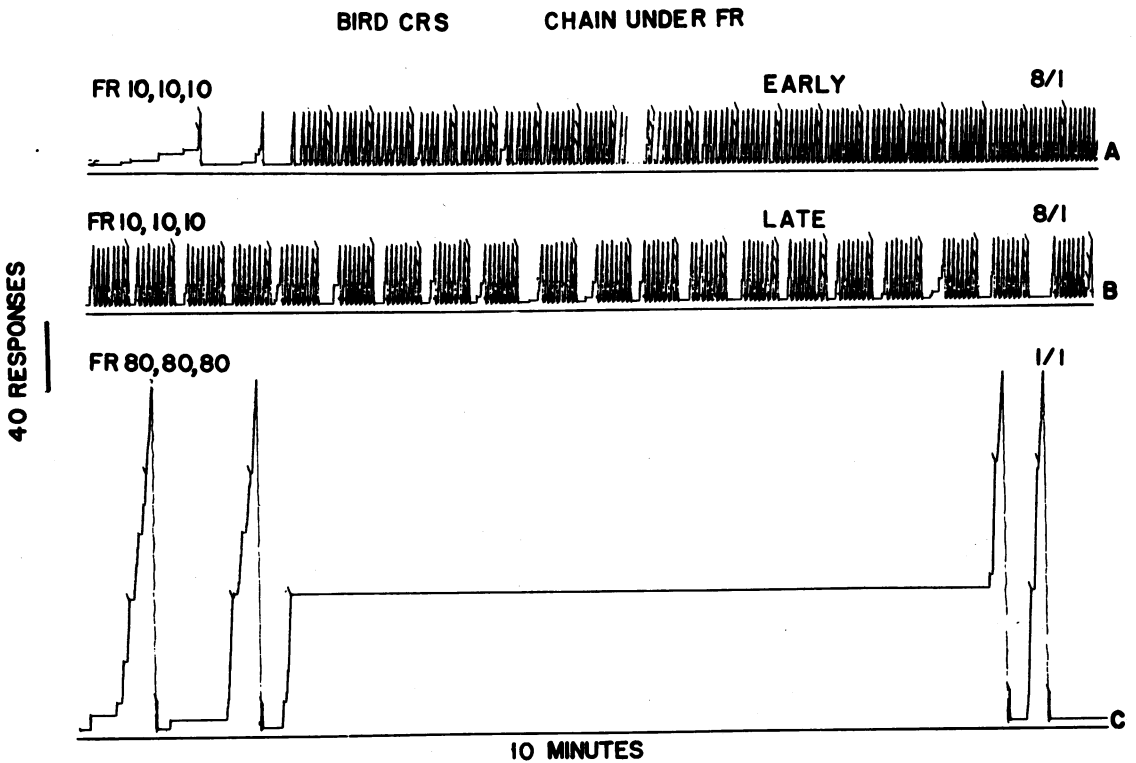

Fig. 20. Comparison of performance on a chain placed under two different fixed ratios but with equal work requirements.
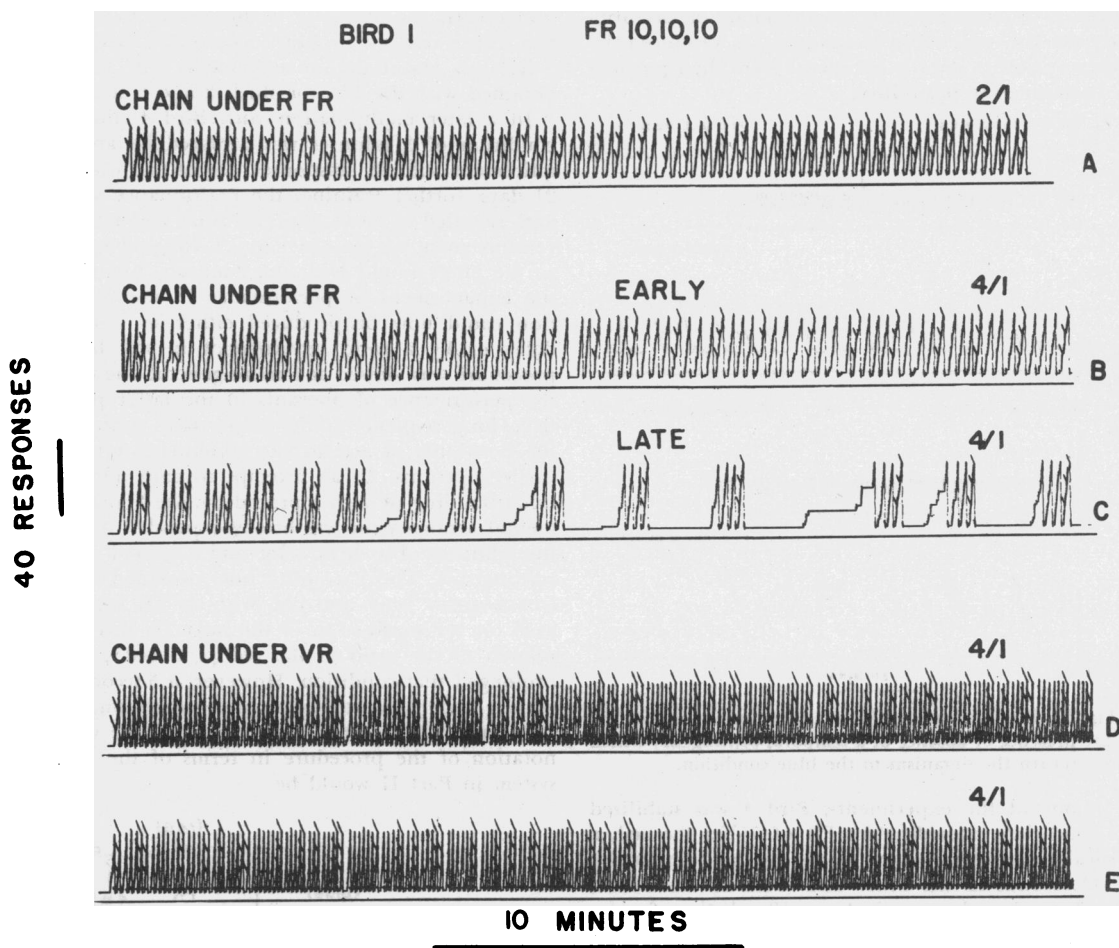
Fig. 21. Performance on a three-operant chain placed under fixed-ratio and variable-ratio contingencies.

the red. Unlike the effects of increasing the size of the ratio, however, the short critical pauses were generally not found to weaken the ratio performance in the red; rather, they produced a possible enhancement. The effect upon the frequency of entrance into the blue is shown in Fig. 25 for all values of the critical pause. Generally, with a longer permissible pause, the frequency of behavior under the blue condition was less.

The experiment conducted with the two remaining birds, Birds 2 and 6, was designed to examine the effects of varying the length of the FI in the blue. For Bird 2, the performance was determined at an FI of 0.5, 1, 2, 4, and 6 minutes. For Bird 6, the fixed intervals were 2, 6, 12, and 24 minutes. Figure 26 contains sample records of the typical performance under the extreme values. In general, the effects of longer fixed intervals in the blue were an improvement in the ratio performance and a decline

in the frequency of return to the blue condition. Figure 25 shows plots of the blue frequency per reinforcement under each value of the FI for each bird. In these plots, the data from the previously described manipulations in which the temporal contingency was removed are also included and are plotted for comparison as a zero FI. Increases in the length of the FI beyond a particular value for each bird did not result in a further decline in the frequency of entrance into the blue. Presumably, the minimum ratio of blue frequencies per reinforcement was determined by the other parameters of the procedure.

After consideration of the effects produced by variation in the length of the FI, it seemed likely that similar results could be produced either by the substitution of a behaviorally independent condition, or S-delta, in the blue, or by requiring a ratio of responses in blue. In other words, since the FI con-

tingency required both the passage of time and the emission of behavior, the enhancement of performance in the red could seemingly be produced by either or both. Other experiments were then pursued to examine this possibility.
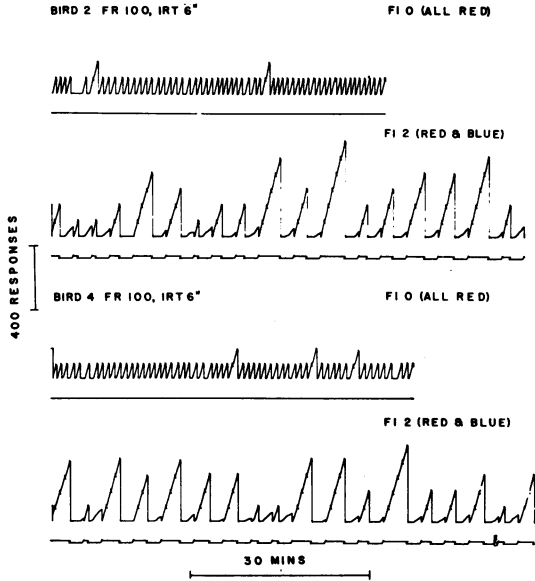

Fig. 22. Performance in the red condition as a function of the presence or absence of a temporal contingency which could return the organism to the blue condition.

In one of the experiments, Bird 4 was stabilized on conditions providing an FR of 75 in the red, a critical pause of 3 seconds in the red, and an S-delta of 30 seconds in the blue. The value of the S-delta was then altered successively to 12 minutes, 6 minutes, and 3 minutes. The data revealed that, indeed, effects analogous to those with the FI could be obtained simply with an S-delta. Figure 27 is a plot of the mean blue frequency per reinforcement under
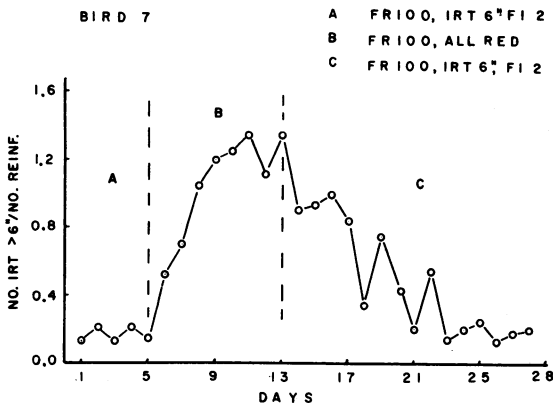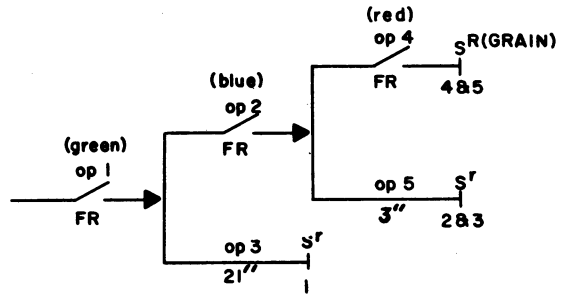

Fig. 23. Ratio of number of pauses greater than 6 seconds to number of grain reinforcements during the presence or absence of the temporal contingency.

each S-delta value. The data are from the last 3 days under each condition. It is interesting to note that the linear decline in blue occurrences with longer S-deltas is essentially in agreement with the effects obtained with the FI's for Birds 2 and 6 in Fig. 25.

In a later manipulation with Bird 4, the S-delta condition of 3 minutes was replaced by an FR requirement of 33 responses. After approximately 21 days' further training, the performance stabilized and revealed a mean ratio of blue frequencies per reinforcement on the order of 0.7, roughly equivalent to the effect found with the 3-minute S-delta. Since the enhancement of performance in the red condition could now be produced either by a temporal delay or by a ratio requirement in the blue, the procedure was viewed as a more general one in which the performance of operants in the latter part of a behavioral sequence could be partially controlled by the possibility of a return to stimulus conditions for earlier operants. In an attempt to gain more of an understanding of such a procedure, the above experimental arrangement was briefly expanded to include the addition of a third color and a second temporal contingency. The procedure now provided for three colors, green, blue, and red, with an FR required in each for the production of the next. As before, completion of the ratio in the red produced grain and prolonged that condition. However, a 3-second pause in the red reinstated the blue condition, and a 21-second pause in the blue reinstated the green. A notation of the procedure in terms of the previous system in Part II would be:

Two birds were trained on this procedure, with each being FR 75 responses. Unfortunately, the manipulations with one bird were too complex to establish any finding except that the performance could be established and maintained under all three colors. With the other bird, however, after the behavior had stabilized under the FR's 75, 75, 75, the FR in the blue condition was reduced to 5 responses and the training continued. A sample daily record from the latter days under this condition is in Fig. 28. In the records of Fig. 28 the pen resets to the base line with each change in color. The data revealed that under the conditions of equal ratios of 75 responses, the bird spent most of the time in the red condition, with an occasional return to the blue; returns to the green

BIRD 4 FI 2, IRT 6"

FR 50

FR 125

IRT 8"

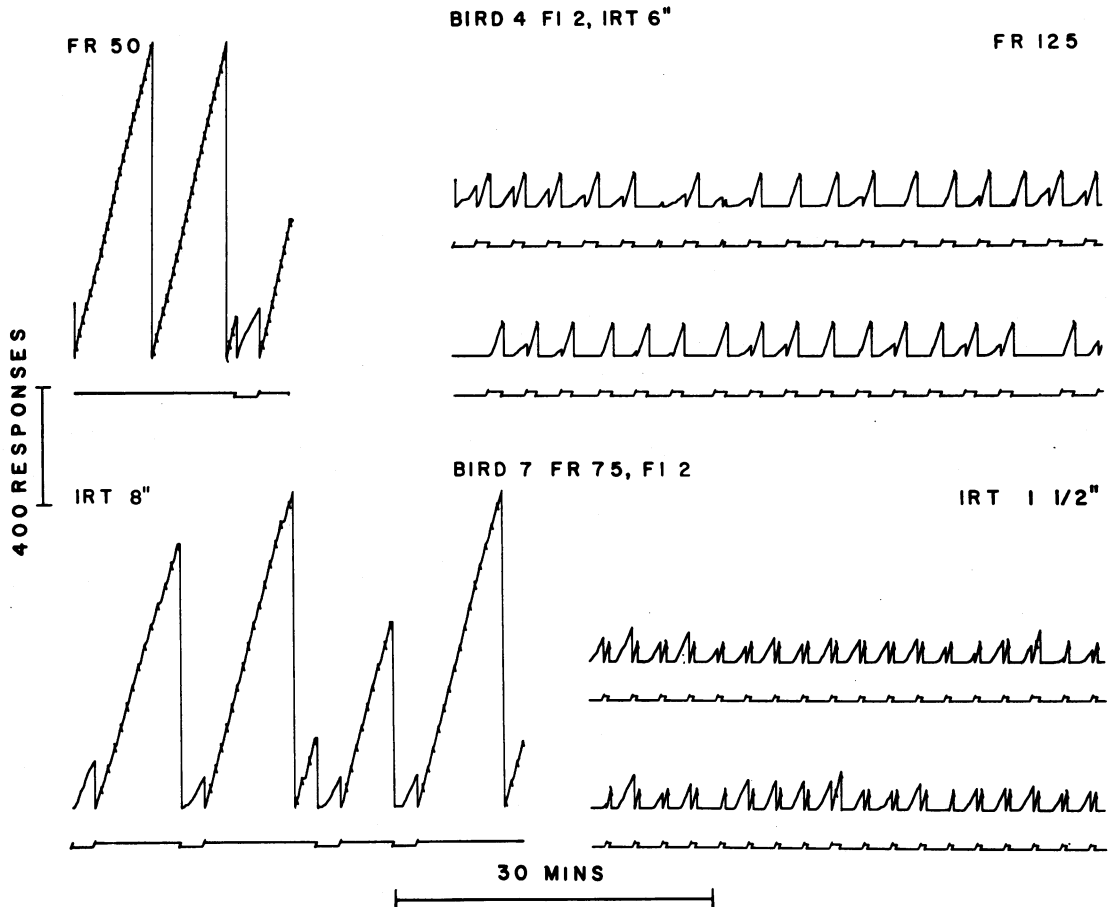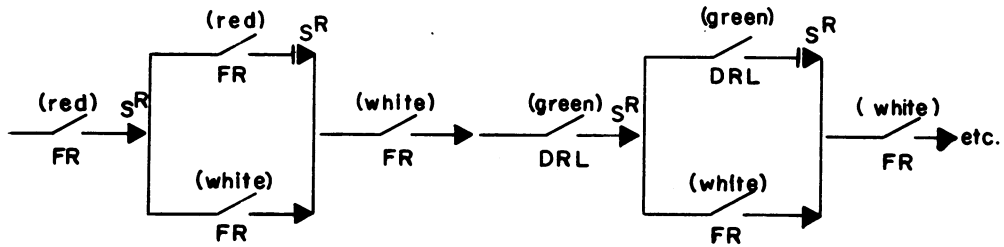BIRD 7 FR 75, FI 2

IRT 1 1/2"

400 RESPONSES

30 MINS

Fig. 24. Sample records illustrating effects of variation in FR size and in length of critical pause upon performance in red condition.

color were very infrequent. After the FR required in the blue had been reduced to 5, however, the frequency of entrance into the blue increased, while the low frequency of entrance into the green remained substantially unchanged. A further manipulation, in which the FR in the green was also reduced to 5 responses, resulted in an increased frequency of both the blue and green conditions. Figure 28 also contains a sample record from this latter condition. It was tentatively concluded from this experiment that the return to the more remote conditions in the sequence could be partly controlled by the particular properties of those conditions. Thus, if the bird were in the red condition, its failure to remain there was partly determined by the contingencies in the red and partly by the properties of the blue condition. Similarly, once in the blue condition, a move to either the red or green depended not only upon the contingencies in the blue, but also upon those of the green and red.

In one sense, the results of this latter experiment were disturbing. It had been conducted in an attempt to clarify the general nature of the simpler procedure; but rather than leading to a simplification, it suggested numerous possibilities for further manipulations and expansions. An assessment of the meager conceptual and methodological tools for further work with this general procedure, however, led to its termination. Another series of experiments, also involving explicit options, but of a different kind, are described briefly below.

In this series of experiments a general procedure was used which was previously described as a switching procedure (Findley, 1958). Its general feature consists of a sequence of options in which one part of each option provides for the attainment of primary reinforcement, and the other part allows the organism to move on to the next option. By providing different conditions in each option, variations in the general procedure have been of value in assessing

BIRD 2 FR 100, IRT 6"   FI 1/2

Fig. 26. Sample records showing effects of variation in size of the FI upon the performance in the red condition.

Fig. 27. Frequency of entrance into the blue condition as a function of the length of the s-delta used.

the given color for the maximum permissible number of reinforcements, the color was removed, leaving only the alternative of working for the next grain schedule. Once the bird was in the presence of the red, for example, two possible events could terminate that light and the possibility of obtaining grain. These two events were: first, the delivery of the last

obtainable reinforcement under that given color; and second, the first response on the white key when illuminated. Thus, the addition of maximum and minimum requirements for the number of reinforcements obtainable in a given color had complicated the basic procedure considerably. In terms of the present notation system, the sequence of conditions is shown at the top of page 146.

With this procedure, the fixed ratio required on the white key was generally regarded as the FR to switch. Since behavior on this key preceded both the red and green stimulus conditions, it was hoped that the pattern of responding on this key would

BIRD 6   RED   IRT   3", BLUE   IRT   21"

G 75, B 75, R 75   G 75, B 5, R 75

G 5, B 5, R 75

20   MINUTES
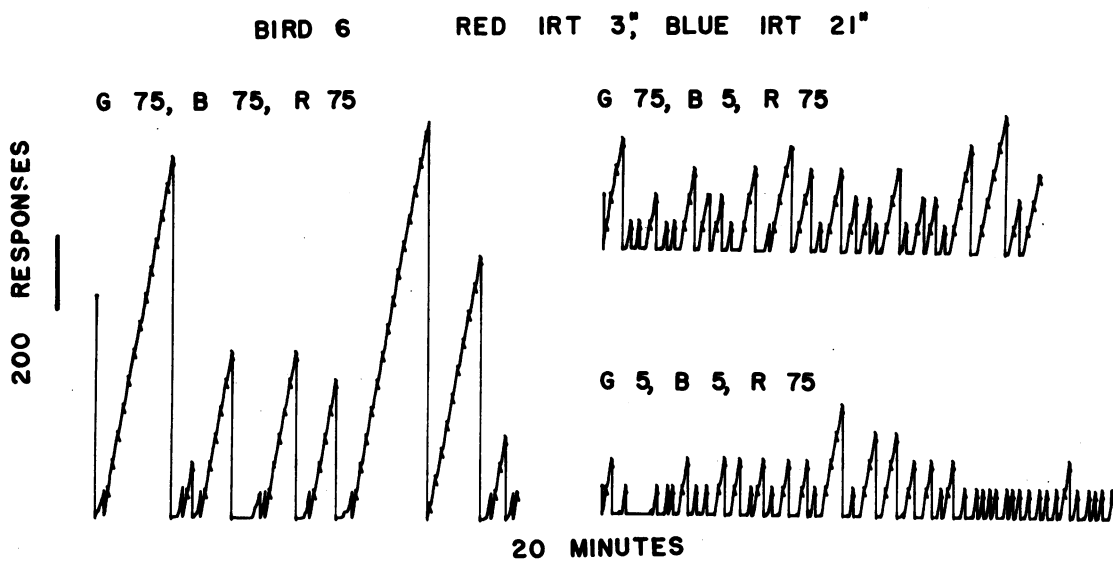
Fig. 28. Sample records showing effects of decreasing the requirements in portions of the sequence to which the bird could be returned by the temporal contingencies.

reflect differential preferences and reinforcing prop-
erties of the two colored conditions.

Four pigeons were trained on this procedure, with
daily experimental sessions limited to 60 reinforce-
ments and body weight maintained at 80 per cent
of the free-feeding weight. The early phase of this
work involved several manipulations with the birds
in order to assess the general stability of the perform-
ance and to gain some notion of the relative prefer-
ence between the FR in the red and the DRL in
the green. For one bird, the requirements were a
10-second DRL in the green, an FR 20 to switch in the
white, and a maximum of five grain reinforcements
during any one color presentation. The FR required
in the red was varied several times in an attempt to
establish an equal preference for green and red. An
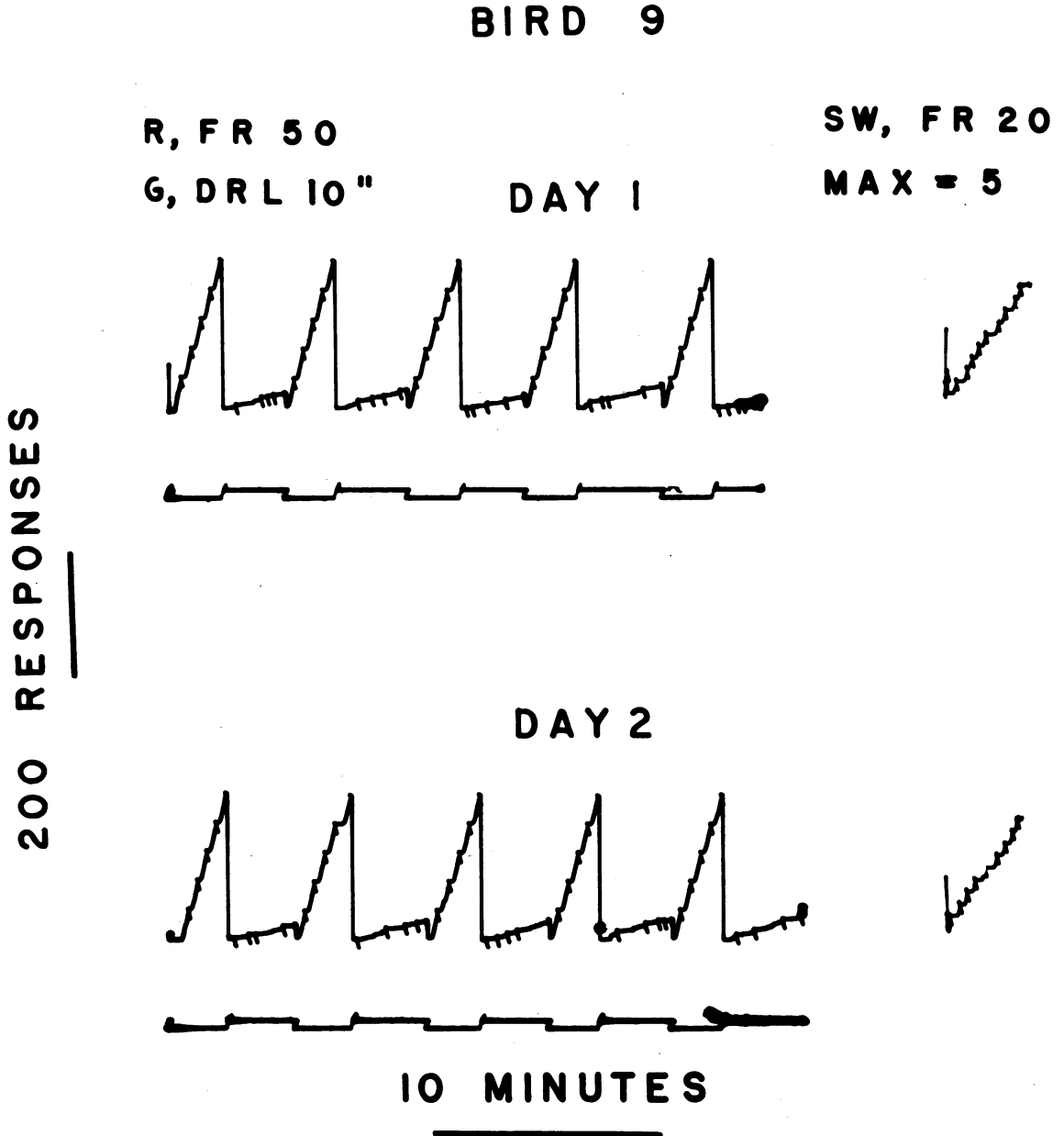
Fig. 29. Two successive daily records showing equal preference between FR and DRL conditions.

BIRD II
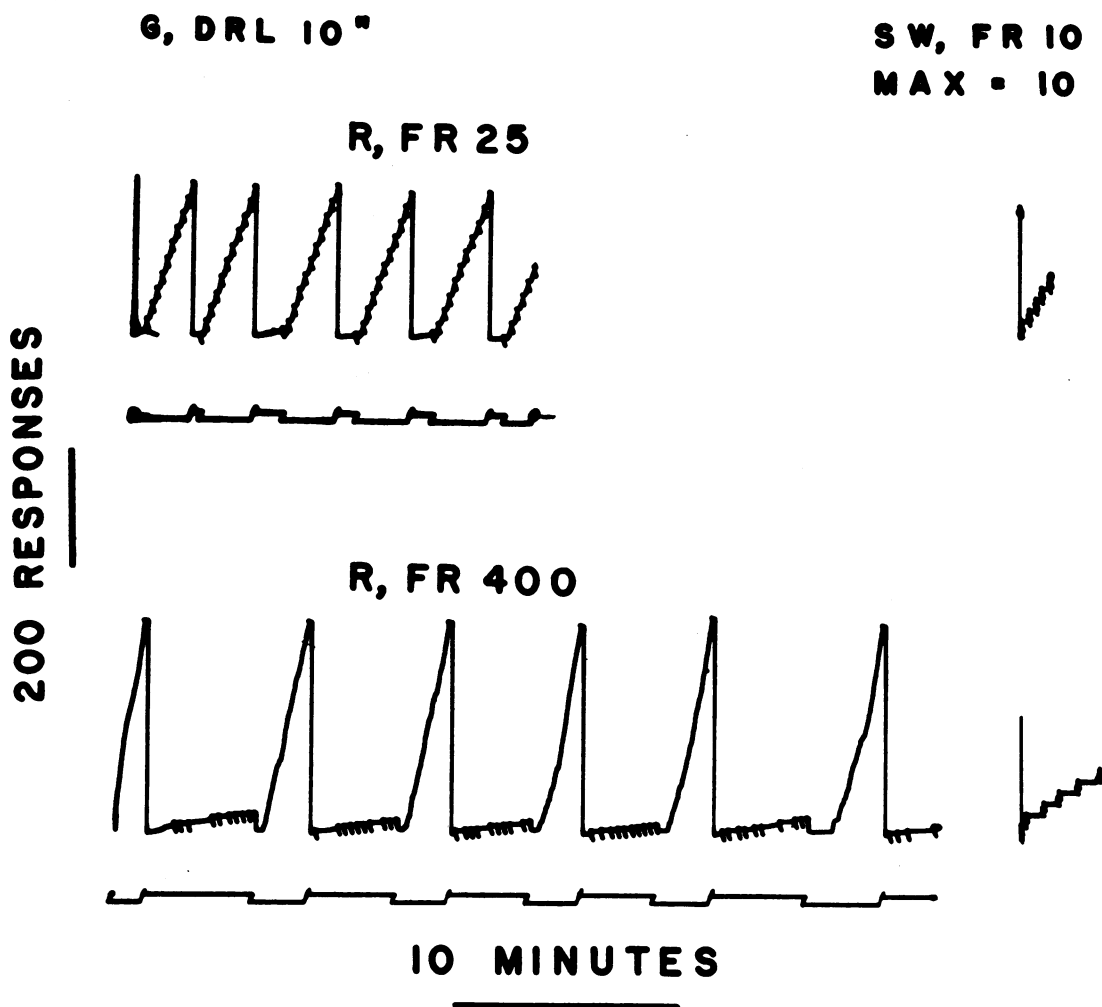
Fig. 30. Comparison of performance under two extremes in the FR requirement in the red.

FR of 50 was found to result in such an equivalence, and further training under these conditions was continued for more than 30 days. Sample daily records from 2 successive days after the performance had stabilized are in Fig. 29. The responding on the key which produced grain reinforcement was recorded separately and is shown in the records on the left. With this method of recording, the pen reset to the base line during a change in colors and the paper drive halted. The event pen is displaced downward during the presence of the red condition. The small records to the right show the switching performance on the second key. Its paper drive was engaged only during the absence of a color on the key producing grain. The records in Fig. 29 show that the bird always remained in both the red and green conditions until it had obtained the maximum number of reinforcements. Examination of the switching performance shows an equal pause prior to completion of each ratio, and thus suggests that production of either the red or the green was equally reinforcing. It should also be noted that since the absolute time spent in each color is approximately equal, the frequency of reinforcements per unit time is approximately equal, and, as suggested by Brady and Thach (1960), may well underlie the equal preference.

Since it was now clear that stable performances could be obtained, several experiments were undertaken in order to determine more precisely the effects of each variable upon the development of preferences

and to determine if such preferences could in turn affect the switching performance. In one such experiment, Bird 11 was stabilized on the following conditions: FR 25 in the red; DRL 10 seconds in the green; a maximum of 10; and an FR of 10 to switch. The size of the ratio was then raised in successive stages, allowing the performance to stabilize at each value: 25, 50, 100, 200, 300, and 400. In general, striking effects were found upon both the preferences and the switching performance. An illustration of these effects appears in Fig. 30, in which sample records from the extreme conditions are compared. This figure shows that under the FR 25, the bird obtained the maximum number of permissible reinforcements during the FR condition and the minimum number during the DRL condition. On the other hand, this preference was completely reversed at FR 400. Here, the bird took the minimum number of reinforcements during the FR condition and the maximum possible during the DRL condition. A close examination of the switching records under these conditions shows a pattern of one long and one very short pause

prior to completion of the switching requirement. The length of this pause is correlated with the nature of the preference. Thus, for FR 25, when the FR condition was highly prepotent, the longer pauses prior to completion of the switching requirement occurred following the termination of the red but before production of the less-preferred DRL condition. The very short pause occurs prior to the switching behavior which produces the red, or FR 25, condition. The pattern of these pauses prior to the completion of the switching ratio was reversed under the conditions of the FR 400 in the red. There, the long pause was prior to the production of the FR, and the short, prior to the DRL condition. Generally, then, variations in the size of the ratio in the red were found to be effective in controlling the preference; and these preferences at the extremes were nicely reflected in the switching performance.

With two other birds, an attempt was made to determine the effects of the maximum number of reinforcements obtainable during any one color pres-

Fig. 31. Comparison of performance under two extremes in the number of reinforcements permissible under any one color presentation.

BIRD 10

Fig. 32. Sample records illustrate effects of increasing the FR-to-switch colors.

entation. In one bird, the other parameters of the procedure were held constant while the maximum was varied from 2 to 32 reinforcements. These manipulations resulted in no obvious alterations in either the preferences or the switching performance. With the other bird, two extreme values, maximums of 2 and 20, were alternated several times with essentially the same result. Figure 31 contains sample records comparing the stable performance of this bird under maximums of 2 and 20 reinforcements. It will be noted that with a maximum of 20, the bird always takes the maximum number of reinforcements possible in the green but the minimum during the red condition. Similarly, with a maximum of 2 imposed, the bird again takes the maximum number of reinforcements in the green and the minimum

during the red. This preference is also reflected in the switching performance, in which the long pauses always follow the removal of the green color and precede the production of the red. The role of the maximum then appeared to be limited generally to minor effects upon the over-all stability of the performance.

A further experiment was then performed with Bird 10 in order to examine the effects of the FR required to switch. The bird was first stabilized with an FR 200 in the red, a DRL of 10 seconds in the green, a maximum of 10, and an FR of 10 to switch. The size of the FR to switch was then raised in successive stages from 10 to 360. A sample record of the performance with an FR 10 to switch is in the top half of Fig. 32. With a relatively small FR re-

BIRD 9

R, FR 100
G, DRL 10"
B, FI 10'

SW, FR 30
MAX = 4

BIRD II

R, FR 200
G, DRL 10"
B, FI 10'

SW, FR 30
MAX = 8

IO MINUTES
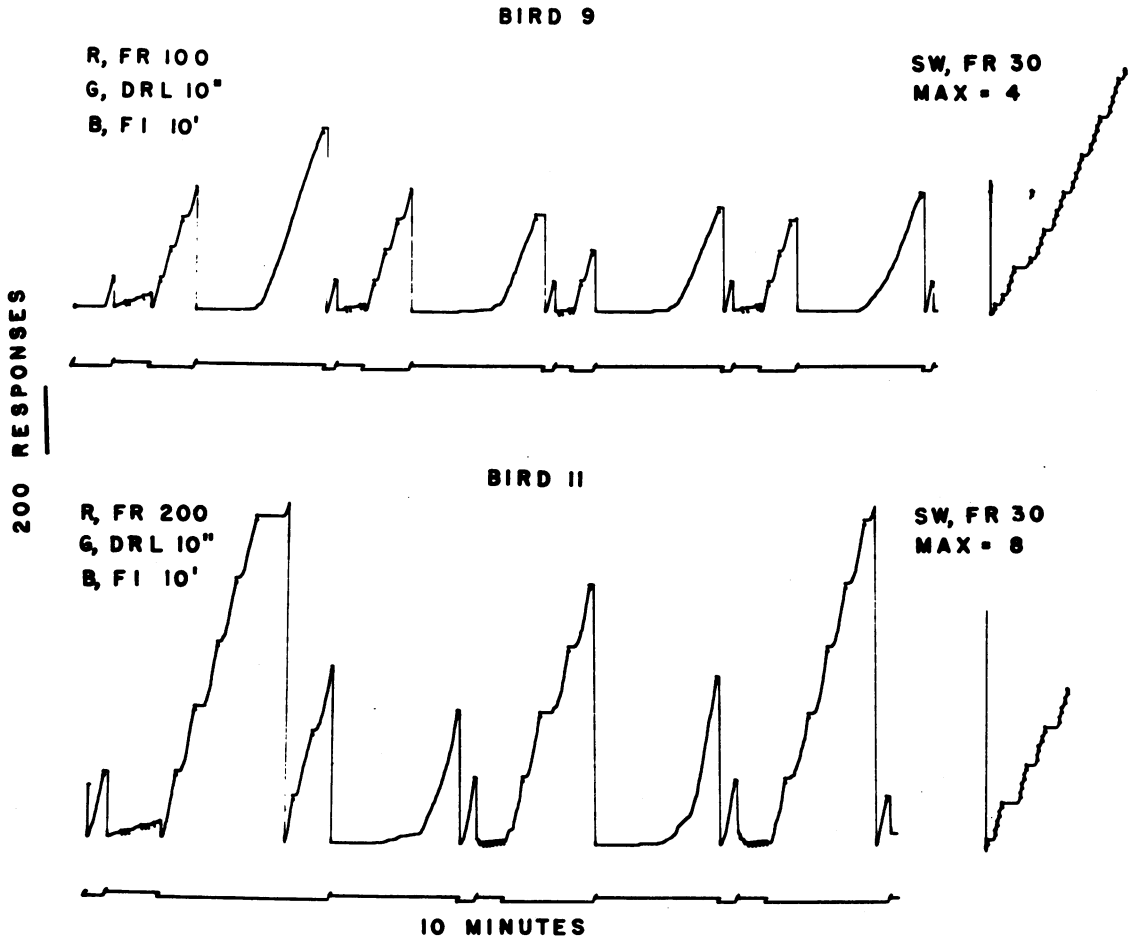
Fig. 33. Performance under three stimulus conditions arranged in a red, green, red, blue, red green, etc., sequence, showing differential performance in the red prior to the other conditions.

quired to switch, the bird revealed a decided preference for the green, always taking the maximum number of possible reinforcements during this color. With increases in the FR to switch to values of 20 and 40, this pattern of behavior was altered only slightly. When the requirement to switch was raised to 80, however, a new pattern of performance emerged. Now, the bird continued to take the maximum in the green condition, but would occasionally take more than the minimum of one reinforcement in the red. An example of this performance is in the lower half of Fig. 32. This record shows in better detail the pattern of long and short pauses prior to completion of the switching requirement. Again, the longer pauses are prior to switching into the least-preferred condition. From an examination of the records, it is clear that the size of such pauses is a function of both the ratio size and the specific nature of its consequence. With further increases in

the FR to switch, the bird began to take the maximum number of reinforcements during both colors, and the differential pauses prior to switching gradually disappeared. With an FR of 360 to switch, the pauses prior to switching became excessive and the experiment was terminated.

The major variables in this procedure having been explored, the situation was now complicated by the addition of a third color and grain-reinforcement schedule. Thus, a fixed-interval schedule associated with a blue light was added to the program which had provided an FR in the red and a DRL in the green. The order in which the schedules appeared was arranged such that red, the FR condition, always preceded both the green and the blue conditions. The sequence of conditions, then, during which the bird could obtain grain reinforcement was red, green, red, blue, red, green, etc. Two birds were trained on this procedure, making use of their prior experi-

ence with the simpler procedure. During the early phase of this training, several alterations of the parameters were made for each bird in order to bring about a stable performance and one that would hopefully reflect three levels of preference. For Bird 9, the values of the situation finally selected were an FI of 10 minutes, an FR of 100, a DRL of 10 seconds, a maximum of 4, and an FR to switch of 30 responses. After approximately 10 days' training under these values, the performance began to show good stability. An examination of the performance revealed that not only had three preferences been established, but there was considerable evidence that the bird had essentially mastered the sequence of conditions as well. An example of this performance after a total of 20 days' training is in the top of Fig. 33. A close examination of this record shows that the bird always took the minimum of one reinforcement during the FI or blue condition, and always took the maximum during the DRL or green condition. The number of reinforcements obtained in the red, however, is differential with respect to the condition following next in the sequence. Thus, if the bird were in the red and switching would produce the green, the bird always switched at the first opportunity. If, however, the bird was in the red and this condition was programmed to be followed by the blue, the bird continued taking reinforcements in the red, frequently up to the maximum. The associated switching performance shows a pattern of one long pause and three short ones. In all cases, the long pause occurs following termination of the red condition and prior to producing the least-preferred FI condition. Similar results were obtained with

the second bird, and a sample of its performance after approximately 18 days' training is also in Fig. 33. For this bird, these effects outlined above are even more striking in view of the larger ratio in the red and the larger maximum. It will be noted that the performance in the red is not only differential with respect to the conditions programmed next, but that this control, presumably based in some manner on the sequence of colors, is maintained during the red frequently in excess of 10 minutes.

In further experiments with this procedure, more involved sequences of the colors were examined. In one case, for example, a double-alternation type of sequence was presented. The sequence was red, green, red, green, red, blue, red, blue, etc. After considerable training, the birds began to show a fair mastery of this more involved sequence. Two successive daily records from one bird are in Fig. 34. In these records again, it may be seen that the bird always took the maximum number of reinforcements during the DRL condition and the minimum during the FI. The number of reinforcements taken in the red condition, however, is not always consistent with these preferences. Continued training with this procedure revealed that the differential pattern of switching from the red condition was highly sensitive to any type of disturbance, such as alterations in the way the bird was handled before it was placed in the chamber or extraneous noises. Recognition of this sensitivity, together with the fact that only two completions of the total sequence could be programmed each day without exceeding the weight levels maintained, generally suggested that the procedure
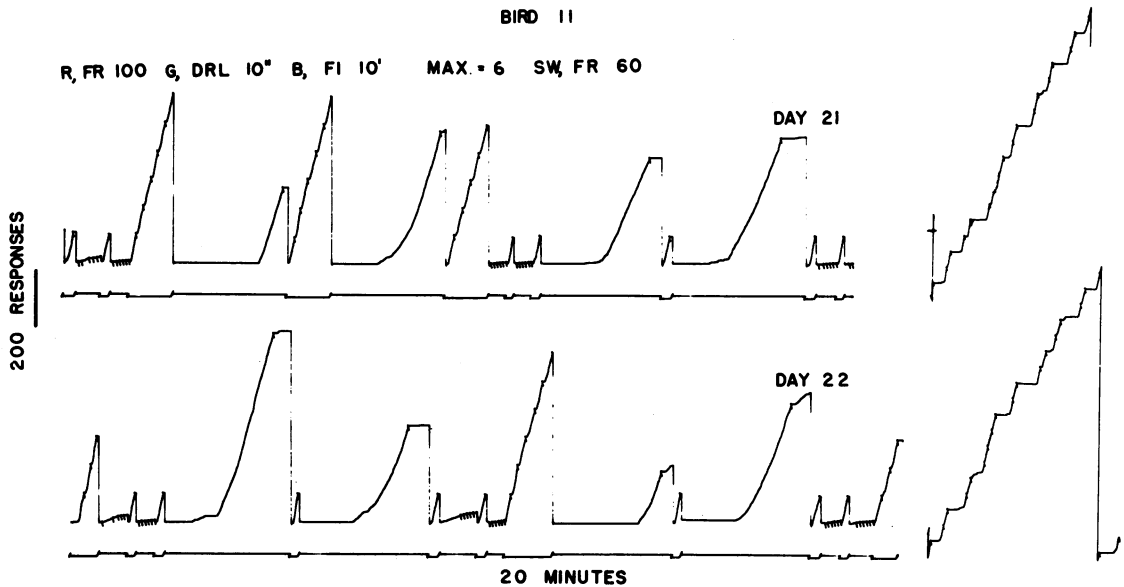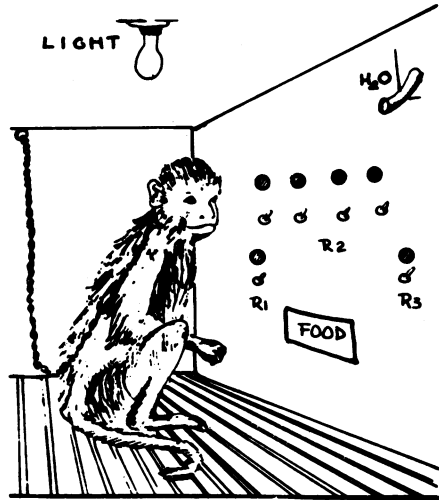

Fig. 34. Performance under three stimulus conditions arranged in a red, green, red, green, red, blue, red, blue, etc., sequence showing only a fair differential performance in the red condition.

had been complicated beyond the limits of appropriate experimental control. The fate then of this series of experiments, like the majority of those already described, was one in which following the examination of basic variables a slight complication of the procedure made it necessary to terminate the research due to the lack ot a technology appropriate to the establishment of the more complex behavior samples. The emphasis of research was then shifted to the development of that technology.

Experiments with Complex Samples Under Continuous Experimental Sessions

Since it was clear that the success in the above experiments was primarily due to the degree of experimental control that had been currently available, it was equally clear that real success in building complex repertoires would require considerable advances in general experimental control. In an attempt to improve that control, a number of experiments were begun in which the experimental subjects, rather than trained a few hours each day and presumably disturbed by the transfer from the living area to the training area, were placed in individual chambers where they lived and worked continuously. It was decided that as well as living continuously in the chambers, they would be placed under the experimenter's program 24 hours each day, and they would be required to obtain all food, water, and other necessary conditions via the experimental program insofar as possible. The new approach, then, was to be an environment more "realistic" in human terms, and one that would afford greater experimental opportunities and control for the experimenter. What is to follow is a brief description of several of these experiments. Their commonality was the use of continuous experimental sessions, and their aim was the exploration of techniques more appropriate to the analysis of multi-operant behavior.

In the first of these experiments, a male Mangabey monkey worked in a 24-hour experimental space for approximately 6 months, obtaining food pellets,


APPARATUS

Fig. 35. Sketch of the apparatus arrangement used in establishing a complex tree.

water, 1-minute illuminations of an overhead light, and 1-minute receptions of a 24-hour radio station via a complex tree. A notation of the general features of the program is presented in column one.

The implementation of this procedure was by the use of push buttons, momentary switches, and colored stimulus lights. Figure 35 is a sketch of the apparatus arrangement. The first operant in the sequence was defined by the monkey completing a given FR on the push button R 1 in the presence of a white light located just above this button. Upon completion of the ratio, the white light was removed and the row of four stimulus lights and momentary switch shown in the sketch were made operative. Each of the lights above these switches was a different color; and by the depression of any of the switches, all of the lights were extinguished, and the light above the final push button, R 3, was illuminated with a color matching the one above the momentary switch which had been depressed. The completion of another FR on the R 3 button now produced a reinforcement whose nature was determined by the color that had been selected. The sequence thus involved the production of a four-part nonreversible option in which each alternative was eventually reinforced with different consequences.

The monkey was originally trained on this procedure by hand, with an FR of 1 throughout and mild food and water deprivation. Once the animal had reasonably mastered the sequence, the ratios on the R 1 and R 3 buttons were both raised to FR 5, and the monkey was placed on 24-hour operation and essentially left to his own devices. In the early stages of this work, numerous changes were made in the method of recording and in features of
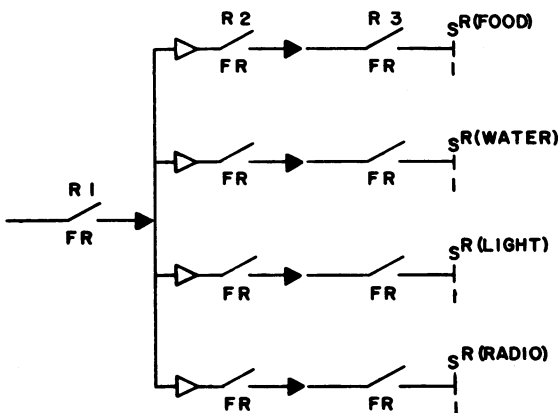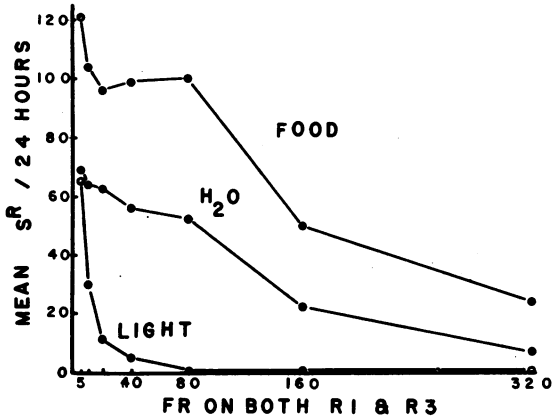
Fig. 36. Mean number of food, water, and light reinforcements obtained each 24-hour period as a function of the FR requirement on R 1 button and R 3 button.

Fig. 37. Total response output as a function of the ratio requirements.

the apparatus. From an intuitive appraisal of the results, however, it was clear that the monkey had well mastered the sequence and stable day-to-day performance was possible. During further training, the alternative behavior producing exposure to the radio was eliminated because of its relatively low frequency. The values of the other reinforcements were adjusted to give either a 0.67-gram pellet, 4 cubic centimeters of water, or a 1-minute exposure of the 20-watt overhead lamp. With the situation thus stabilized, an experiment was begun in which the size of the ratios required on the R 1 and R 3 buttons were increased together in successive stages. The major results of this experiment are presented in Fig. 36, which is a plot of the mean number of reinforcements per 24 hours as a function of the size of the ratio required on both R 1 and R 3. These data, which are from the last 3 days under each ratio value, show that as the ratios were increased from 5 to 80, the number of food, water, and light reinforcements the monkey took declined, approaching something of an asymptote near an FR of 80. It will be noted that at FR 80 the light reinforcements are practically eliminated. Further increases in the ratio beyond 80 resulted in a sharp decline in the food and water intake. At the extreme ratio of 320, the total food and water intake had declined to approximately 20 per cent of that under the smallest ratio, FR 5. In spite of the decline in the number of daily reinforcements with large ratios, the absolute output of behavior was still high. This effect is illustrated in Fig. 37, which is a plot of the total response output during the last 3 days under each ratio as a function of that ratio. It should be noted that at any ratio, the total requirement for one completion of the sequence was twice the size of the ratio plus one response in selecting the nature of the reinforcement. Thus, at the extreme with a ratio of 320 required on R 1 and on R 3, the total requirement was 641 for each completion of the sequence.
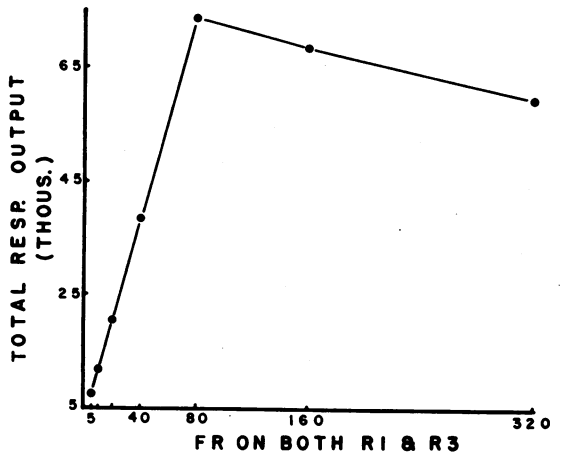
Thus, Fig. 37 shows total output of behavior increased almost linearly up to FR 80, and then declined.

An examination of the over-all distribution of responding within a typical 24-hour period revealed that the monkey engaged in periods of "work," where several reinforcements were obtained, alternating with "no-work" periods, consisting of long pauses in the first part of the sequence. Generally, the length of these long pauses increased with increases in the size of the ratio on R 1 and R 3.

Sample records of typical performance on the R 3 button are in Fig. 38. In these records, the paper
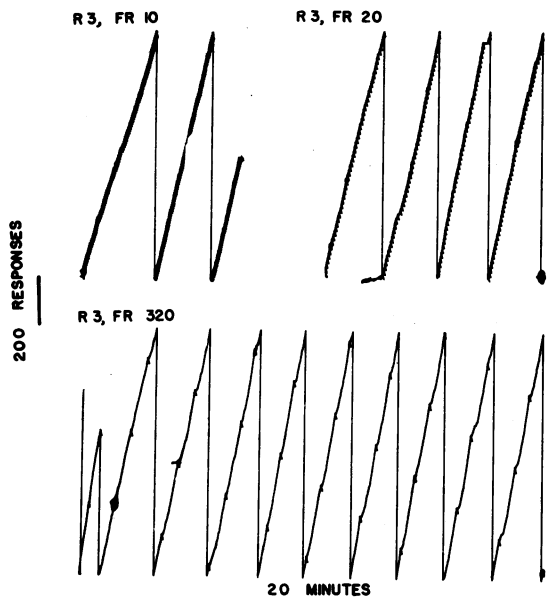

Fig. 38. Examples of the FR performance on the R 3 push button under three different requirements.

feed was connected only during the presence of a colored light above the R 3 button, and thus records the ratio performance prior to all types of reinforcements. The records for FR 10 and FR 20 include performances preceding all three types of reinforcements, whereas the reinforcements were almost exclusively those of food and water in the FR 320 record. These records suggest that the ratio performance on the R 3 button was essentially uniform regardless of the different nature of the reinforcements.

Although the above procedure was perhaps unnecessarily complex in some aspects, the manipulations that had been performed in this experiment suggested several tentative conclusions about the establishment of complex repertoires. First, the results had essentially demonstrated the possibility of maintaining good performance on an involved sequence without placing restrictions as to body weight or number of reinforcements obtained. Second, it was clear that in such an arrangement with given amounts and types of reinforcement, the total output of behavior obtained was likely to be in part a function of the total behavioral requirements. No miraculous effects resulted simply from confining the organism to a permanent and continuous experimental space. It was implied, however, that given adequate reinforcement conditions, much more intricate samples of behavior could be established because of the additional experimental time and flexibility which the continuous sessions permitted. A variety of experiments in which even more involved procedures were examined strengthened that conclusion, but as well, dramatized the necessity of having some conceptual scheme by which to plan and establish these more

involved behavior repertoires in an orderly fashion. With the development of the system outlined in Part II, it was clear that the first job was establishing simple explicit trees and examining the extent to which they would indeed act as units of analysis or as building blocks for more involved repertoires. Two different experiments then were undertaken to examine that possibility.

In one of these the monkey used in the previous experiment was placed in a new chamber which had arrangements for the delivery of water and food pellets via a nonreversible option. Figure 39 is a sketch of the working panel and procedural notation. The first operant in this tree was identified by the monkey completing a given FR on the first push button in the presence of a blue light located just above that button. Satisfaction of the FR removed the blue light and illuminated the red and green lights above the two remaining buttons. The first response on either button extinguished the opposite light and made its associated button inoperative. Completion of a given FR on the button which had been depressed then delivered 4 cubic centimeters of water or a 0.67-gram food pellet. The button under the green light was associated with water reinforcement, and the button under the red light, with food. With the delivery of reinforcement, all stimulus lights were removed for a 5-second period, after which the blue light was re-illuminated.

The monkey was adapted to the new chamber with an FR of 20 throughout the tree. The ratio was then increased to a value of 80 on each operant and training continued. Within approximately 10 days, the number of reinforcements of each kind had become stable from day to day. Records of the performance from 2 consecutive days during this phase of the experiment are in Fig. 40. The records on the left in this figure were obtained by cumulating each completion of the tree against time, and they show the total daily performance except for approximately 15 hours of inactivity. Each record shows a gradual acceleration in the emission of trees followed by alternations between periods of responding and inactivity. Sample records showing examples of detailed performance within each tree are located to the right in Fig. 40. In these records, the pen resets to the base line following the completion of each tree; and within a given tree, or pen excursion, the responses from the first operant are recorded first and are then followed by responses from one of the alternative operants in the option. If during the latter part of the tree, the operant producing food in fact occurred, this is indicated by the depression of the event pen located below the cumulative excursion. The absence of the event-pen depression indicates that the last operant was the one producing water reinforcement. Generally, these detailed records within the tree show a good ratio performance with pauses in the sequence found both prior to the first operant and prior to the terminal operant.
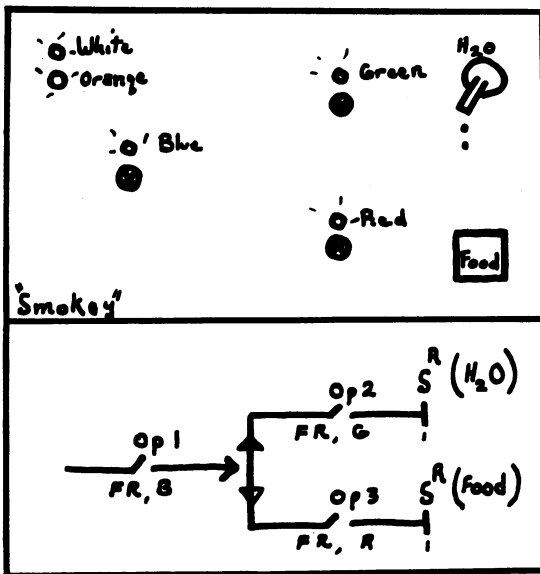

Fig. 39. Sketch of the working panel and procedural notation used in establishing a simple nonreversible tree.
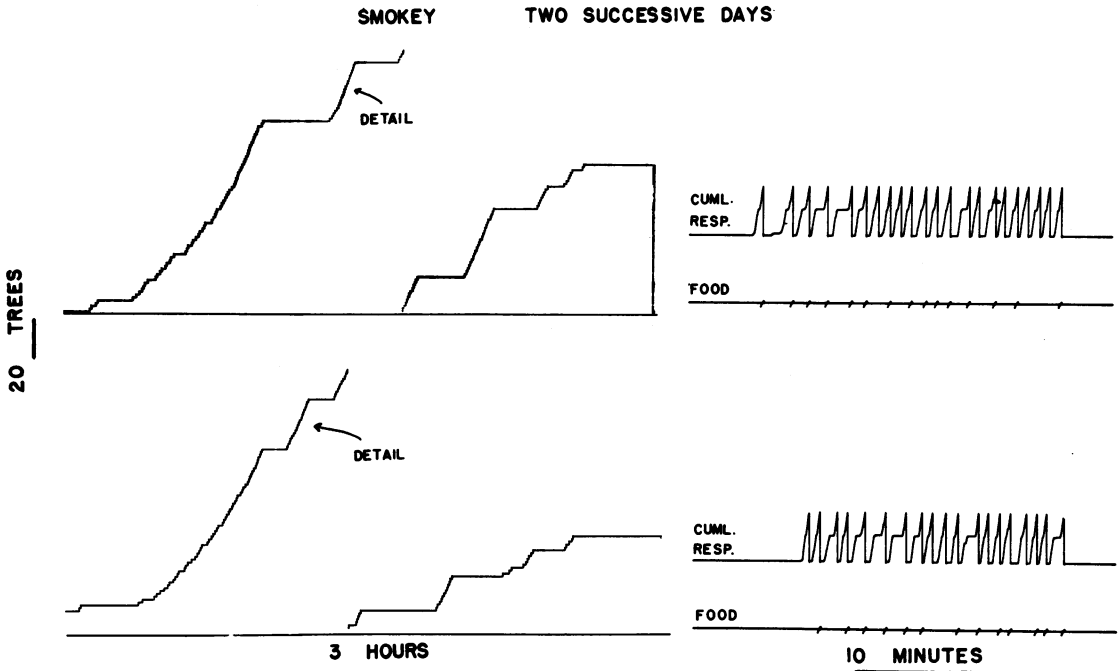
Fig. 40. Sample records from 2 successive days after the performance on the tree had stabilized.

Defining the above procedure as one in which the behavior comprising the tree was essentially placed under continuous reinforcement, the question was now posed as to whether the sequence could be placed under other schedules of reinforcement. Thus, the justification of the tree as a unit of analysis and its practical usefulness as a building block for more elaborate samples of behavior would in part depend upon the extent to which the tree, as a unit, would be subject to experimental manipulations similar to those commonly used with simpler samples of behavior. To explore this possibility, the size of the ratio in each operant in the tree was reduced to FR 20 and the tree was placed under a DRL schedule of 2 minutes. This intermittent reinforcement of the tree was arranged in the following manner. Each completion of the tree produced a 5-second blackout of the stimulus lights above the push buttons. Following the blackout, a 2-minute time interval was placed in effect; and if the monkey began working on the sequence before this interval had timed out, the completion of the tree would produce only the blackout and repeat the above. If, however, the monkey began the tree after the interval had timed out, the completion of the tree would produce not only the blackout but also either a food or water reinforcement, and an over-all increase in the illumination of the chamber for 5 seconds. The DRL condition, then, was interposed between the completion of each tree and the beginning of the next, and thus

was unaffected by the time required to complete a tree once begun. This arrangement therefore demanded that the emission of trees be spaced out in a manner analogous with the DRL reinforcement of simple response classes such as bar pressing, etc.

When the tree was first placed under the DRL contingency, the performance showed typical extinction effects and occasional long pauses within the tree because of the inappropriate delays prior to beginning each tree. With continued training, however, the delays began to show a maximum frequency of approximately 2 minutes, and the pauses within a given completion of the tree diminished. Sample records of the performance after 12 days are in Fig. 41. In these records, the diagonal movement of the recording pen is used to indicate those completions of the tree which were spaced appropriately and resulted in primary reinforcement. The event pens in the detailed recording therefore do not necessarily indicate the delivery of reinforcement, but only which branch in the latter part of the tree was pursued.

Following the success with DRL contingencies, the schedule was altered to an FR requirement such that two completions of the tree were now required for the production of reinforcement. The transition was rapid; and within only a few days' training, the emission of trees began to appear in groups of two rather than being spaced out individually. In order to make the performance more visible on the record-
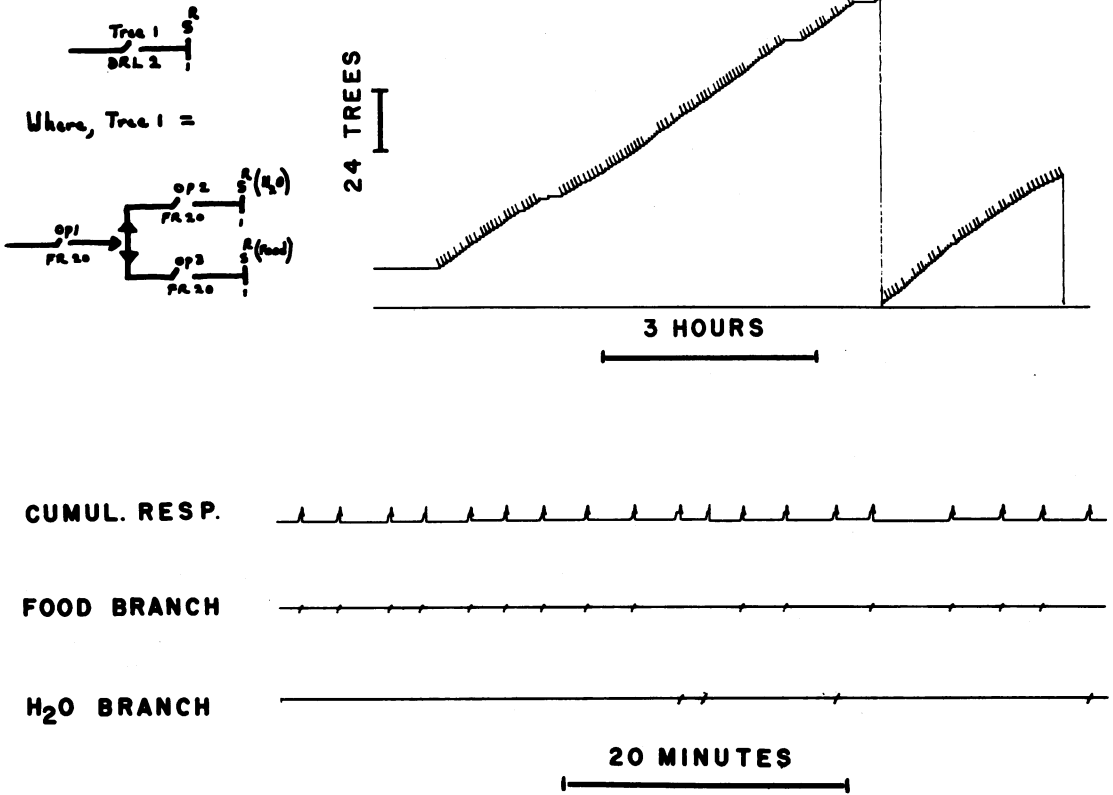
SMOKEY

Fig. 41. Sample record illustrating the performance after placing the tree under a DRL contingency of 2 minutes.

ings, the FR schedule of trees was increased to 4 and the individual FR on each operant within the tree was increased to 40 responses. Figure 42 presents the resulting performance under these conditions after 10 days' further training. The detailed record in this figure is from the terminal portion of the summary record. It shows that in spite of some vacillation within the trees as to which branch was momentarily prepotent, the emission of trees occurred in consistent groups of four.

Since it was now clear that the total behavior of the tree could be placed under either a DRL or an FR contingency and still retain consistent performance within the tree, the procedure was complicated further by demanding both of these behaviors under stimulus control. This latter procedure was implemented by the use of two additional stimulus lights, located in the upper left-hand corner of the working panel, as shown previously in Fig. 39. In the presence of the white light, trees were reinforced with primary reinforcement on a 2-minute DRL schedule; and in the presence of the orange light, the trees were placed under an FR of 4. Each light and asso-

ciated schedule remained in effect until three primary reinforcements had been obtained, and then were reversed.

During the early establishment of this performance, the FR requirement for each operant within the tree was reduced to FR 20, and detailed recordings were taken on a recorder with twice the step size as that in the previous records. Figure 43 is a sample record after 24 days on this procedure. The detailed recording is from the middle section of the summary record following approximately a 1-hour pause of inactivity. Although the sample of the detail recording presented here might suggest a general preference for responding on the food branch of the tree, or for obtaining food during the FR condition and water during the DRL, such generalizations were found to be tenuous because of the large variability within a total session. Despite the variability within trees, however, both the detailed and the summary records show the over-all emission of trees is appropriate to the alternative FR and DRL conditions.

In the above experiment, if the tree is considered to be the unit of analysis in a fashion analogous with
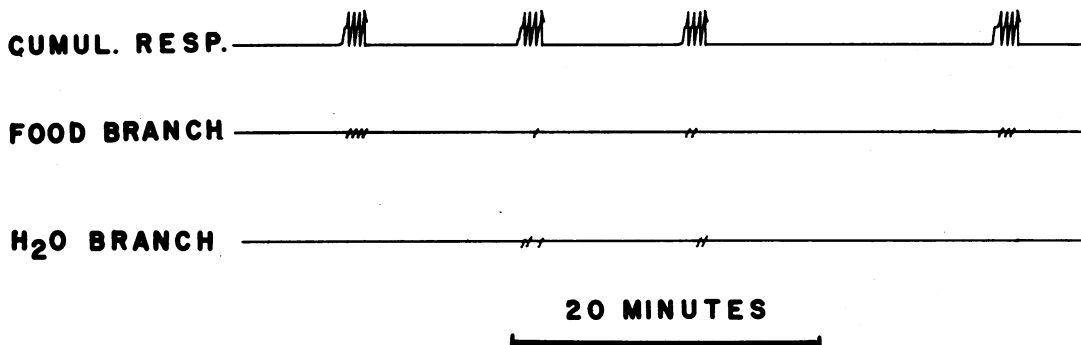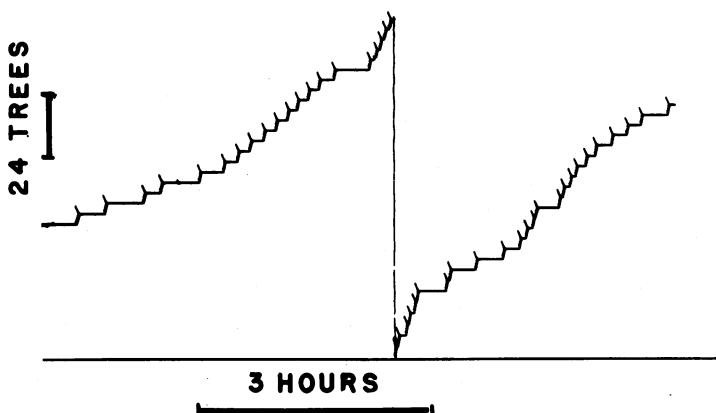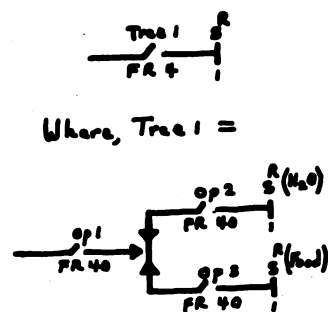
Fig. 42. Sample record illustrating the performance after placing the tree under an FR 4 contingency.

operants or responses, the two schedules, stimulus conditions, and consequences provided for the emission of trees define essentially a still larger chaining type of sequence. Thus, the emission of trees in the presence of the white light, on a DRL schedule, produces reinforcement and reinstates that condition twice. Following the third such reinforcement, a different stimulus condition is produced, in the presence of which trees under an FR contingency produce reinforcement and reinstatement of that condition. Following the third reinforcement under the latter condition the total sequence is reinstated. The general form of the total sequence, then, is essentially a serial chain similar to those described in Part II, with the exception that the response class for each operant of this chain is itself an involved sequence of behavior.

Examination of the summary record in Fig. 43 shows that the emission of trees under the orange light, or FR condition, constitutes the weaker component of the total sequence, due to the pattern of differential pausing. Thus, the relative pauses before the emission of trees are greater under the FR schedule than under the DRL condition. In an attempt to briefly explore to what extent this pattern of pausing could be manipulated, the sizes of the primary reinforcements used above were now increased such that a water reinforcement was 10 cubic centimeters and a food reinforcement was two pellets. An example of the resulting performance after 10 days' training is in the top records of Fig. 44. The performance is generally the same as before except for a somewhat more consistent and exaggerated pause before the emission of trees during the FR condition. In a subsequent manipulation designed to reverse the relative strength of these components of the total sequence, the delivery of primary reinforcement was simply removed from the white light or DRL condition; and
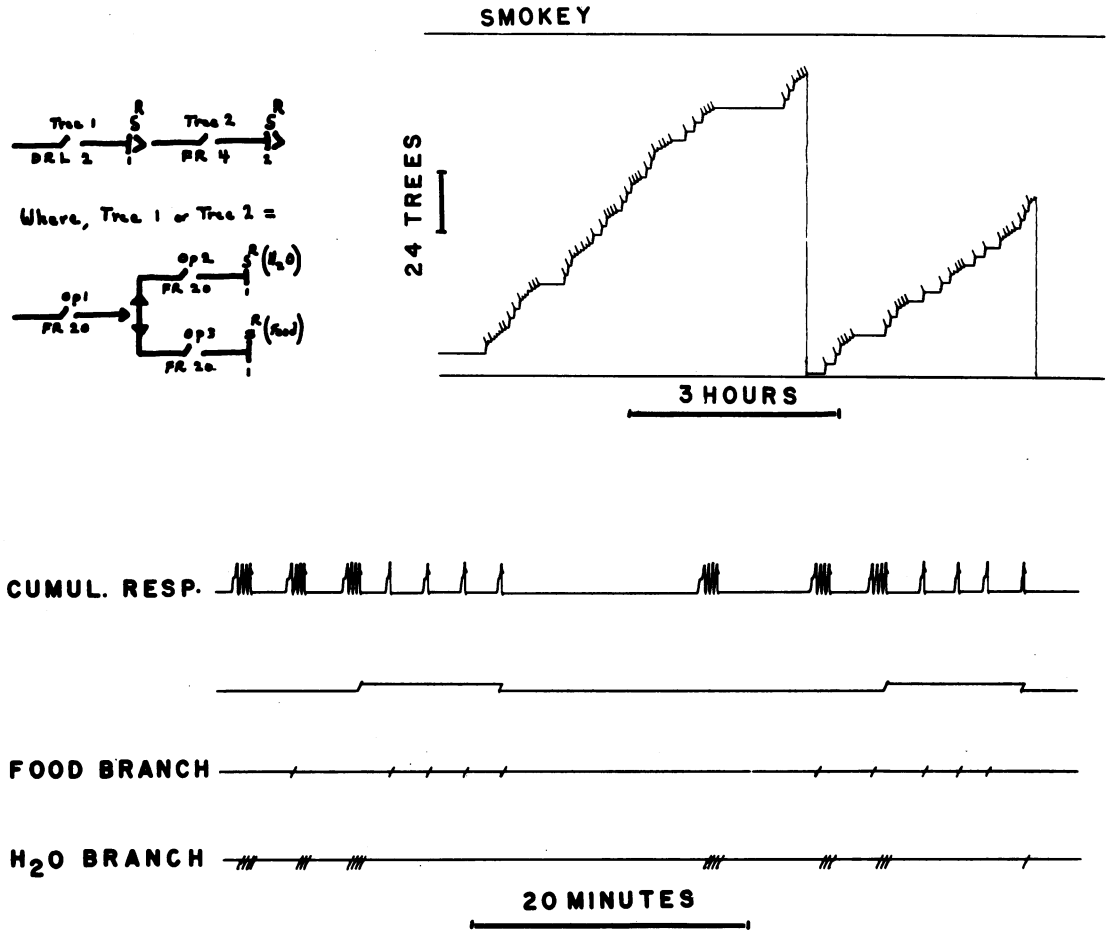
Fig. 43. Resulting performance with tree placed under alternately DRL 2 minutes and FR 4.

the only consequence of correctly spaced trees during this condition was the production of the blackout of the stimulus lights and the increase in over-all illumination for 5 seconds. This manipulation not only reversed the pattern of pausing, but it also demonstrated that the pattern of behavior within the tree and its spacing could be maintained without the necessity of immediate primary reinforcement. A sample record of the performance after 5 days' training is in the lower half of Fig. 44. In the summary record, the long pausing now occurs before the emission of trees during the DRL condition. The detailed record shows that the emission of trees during this condition is essentially of the same nature as when trees resulted in primary reinforcement, except for perhaps a slightly longer pause occurring prior to the selection of a given branch within the tree.

In summary, then, the variety of manipulations performed with this monkey suggested that the sequence of behavior defined as a tree was subject to

many of the types of manipulations performed with simpler samples of behavior. Essentially, the tree had been placed under continuous reinforcement; two intermittent schedules and the resulting performances were used to establish a still larger chaining type of sequence in which the individual trees were partly maintained without the use of primary reinforcement. Taken together, these manipulations not only suggested that the tree could be given functional or unitary properties, but also demonstrated the feasibility of establishing explicit samples of behavior whose complexity demanded some distinctions as to specific levels of analysis.

The aim of the second series of experiments to be reported in this section was also the examination of a tree as a practical unit of analysis. It was conducted with a pigeon (Bird 11) which had been used in several previously described experiments. This bird was placed in a conventional chamber from which it was removed briefly once each day for weighing and checking the equipment. The general feature of the

PRIMARY S^R- VIA DRL & FR

CUML. RESP.

H₂O BRANCH

FOOD BRANCH

NO PRIMARY S^R IN DRL

CUML. RESP.

H₂O BRANCH

FOOD BRANCH

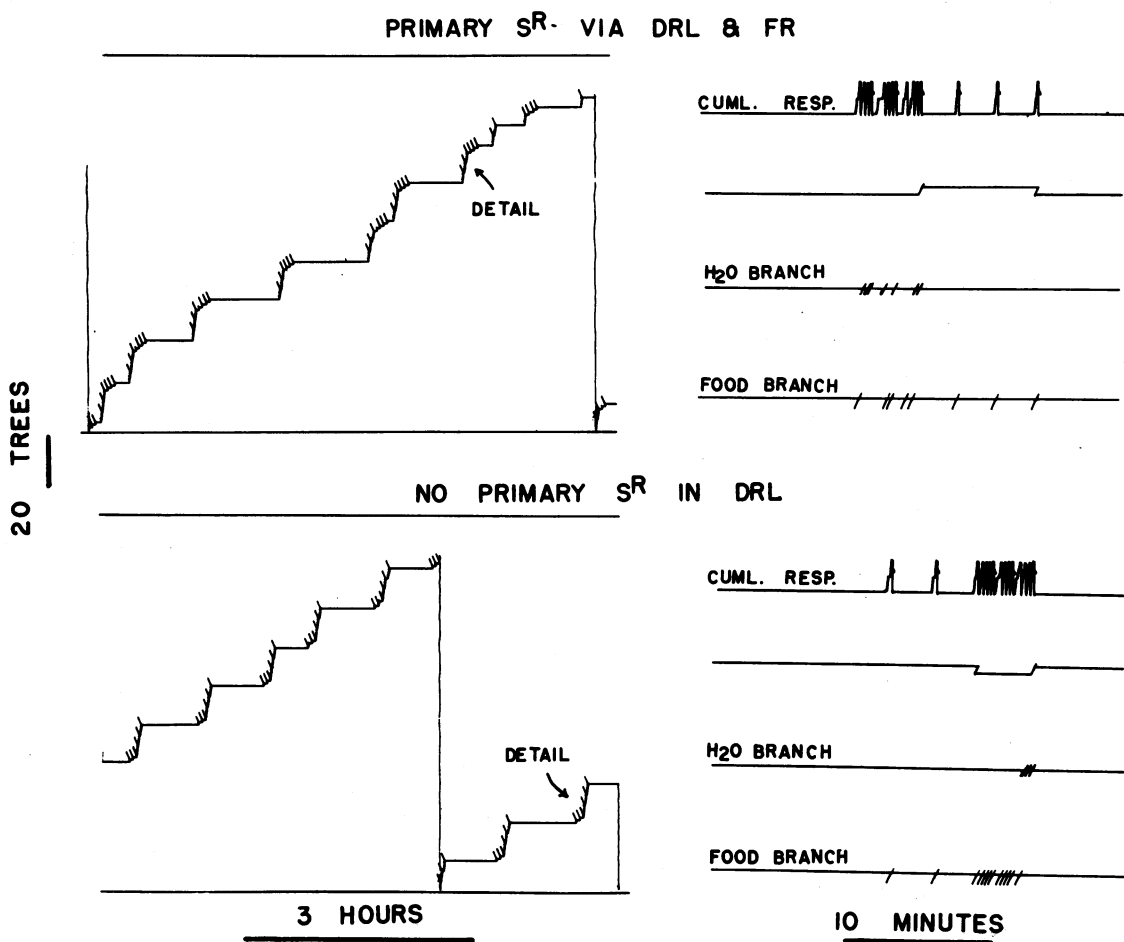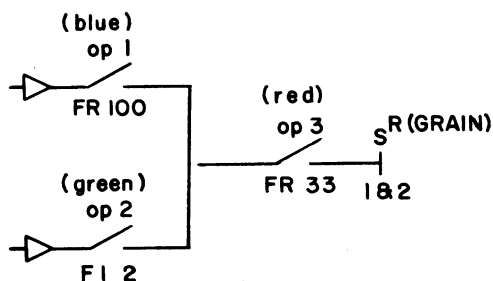**3 HOURS**   **IO MINUTES**

Fig. 44. Effects of removal of possibility of primary reinforcement during the stimulus condition in which trees were under a DRL contingency.

experiment demanded that the bird earn all food by completing a tree as shown below.

This tree, which permitted an option between two alternative schedules as the early part of the sequence, was implemented by the use of three horizontal keys and colored lights. Following the 5-second grain reinforcement and blackout of the stimulus lights, the two outside keys were illuminated; one being blue and the other, green. Associated with these colors was an FR schedule on the blue key and an FI schedule on the green key. The first response of the bird to one of the two keys placed its associated schedule in effect and removed the illumination from the other. Completion of the contingency on the key which had been selected now removed its color and illuminated the third key (located in the center) with a red color. Completion of the FR required on this final key removed the remaining stimulus light and produced the grain. It should be noted that the FI programmed on the green key began timing only if a response were made to that key, and such a response would be effective only if no previous response had been made to the blue key. The conditions, blue and green, then were alternative and mutually exclusive.

Since this bird had been used in a number of previous experiments and pecking behavior was known

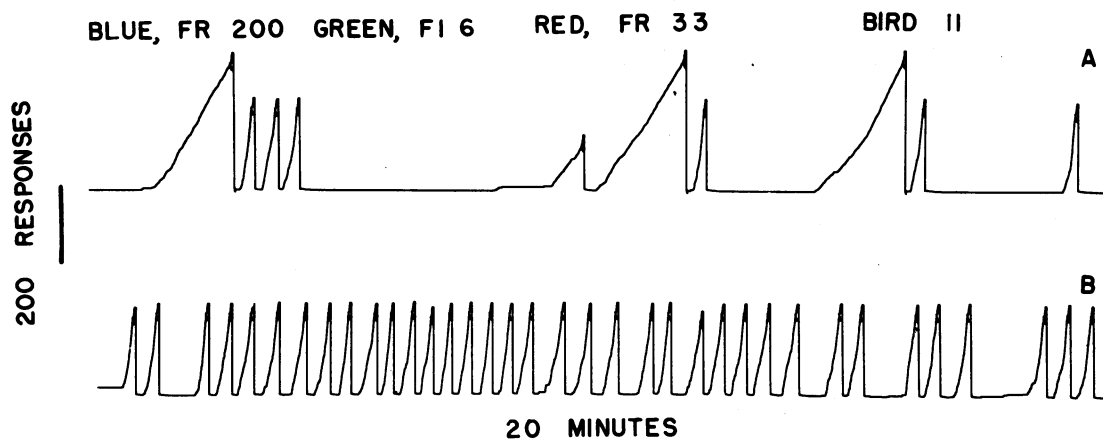BLUE, FR 200   GREEN, FI 6   RED, FR 33   BIRD II

Fig. 45. Samples of two typical performances within daily sessions.

to be well established, it was transferred to the new chamber without preliminary reduction in weight from an essentially free-feeding condition. The original values of the procedure imposed were FR 80 in the blue, FI 15 minutes in the green, and FR 33 in the red. Within 5 days, the bird had adjusted reasonably well to the new procedure and was obtaining on the order of 100 reinforcements each 24-hour period and essentially maintaining the free-feeding weight. Following this period of adaptation to the procedure, a number of manipulations with the size of the FR in the blue and the FI in the green were pursued over a period of approximately 2 months in order to determine to what extent the preference for these conditions could be manipulated. Generally, it was found that with a relatively large FI of 6 minutes, a ratio of at least 200 was required in

the blue in order to prevent that behavior from becoming completely prepotent over the FI. Samples of the performance after 11 days' training under an FR of 200 are in Fig. 45. In this figure, two samples of the performance have been extracted from the total daily record. Sample A was from a period of relatively low behavioral output and shows an occasional selection of the interval portion of the tree. The performance in Sample B was from a period of relatively high behavioral activity, and shows a predominance of the ratio, or blue, component of the tree. Generally, the total daily performance was characterized by a vacillation between such performances and by long pauses of inactivity. Although these results suggested gradual alterations in the preference for one or the other of the alternative components with changes in the body weight during a given

BIRD II   TREE UNDER DRL 2 MINS
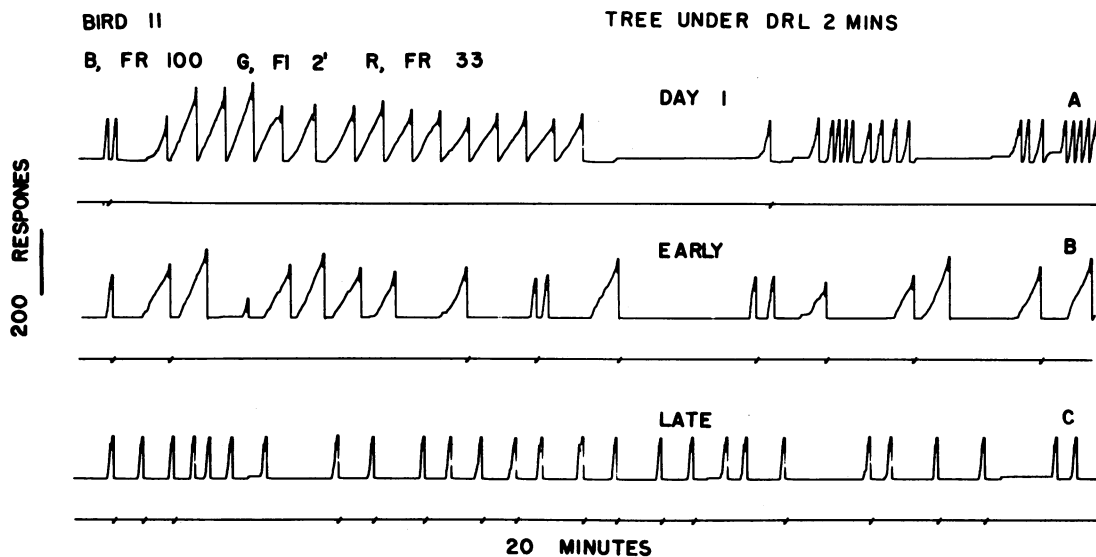
B, FR 100   G, FI 2'   R, FR 33

Fig. 46. Development of a final performance with a tree placed under a DRL contingency.

24-hour period, the far greater proportion of the total reinforcements were obtained via the ratio component. Another interesting feature of the performance to be noted here was that the total number of reinforcements obtained each day were in excess of 100, and that the average weight maintained was from 90 to 95 per cent of the free-feeding condition. At this point in the experiment, then, a decision was demanded as to what aspect of the behavior sample would be pursued. Since it was judged that a simpler procedure would be more appropriate for the examination of cyclic changes occurring within the daily performance, a decision was made to focus attention upon the predominant daily pattern and to continue with the general aim of treating the tree as a larger unit of analysis.

On the day following the records shown in Fig. 45, the FI in the green condition was reduced to 2 minutes, the ratio in the blue was reduced to FR 100, and the total sequence was placed under a DRL contingency of 2 minutes.

The DRL contingency demanded that the selection of either the blue or green component of the tree be delayed at least 2 minutes from the last completion of the tree in order for a completion to result in delivery of grain. Beginning the tree before

the DRL interval had timed out resulted in the final completion of the tree producing only the 5-second blackout of the stimulus lights. In spite of the three alterations thus used in the procedure, the bird's performance was not overly disrupted. Figure 46A shows a sample of the resulting performance immediately after this alteration to the three new contingencies. Only two reinforcements were obtained during the first 2 hours. Within 3 days' continued training, however, the bird showed a much improved performance in both the blue and green conditions, and was spacing the trees sufficiently to obtain a much higher frequency of grain reinforcement. A sample of this performance is in Fig. 46B. After 13 additional days' training, a stable performance resulted in which the selection of the blue or FR branch of the tree was highly predominant. An example of this performance is in Fig. 46C. This record shows that although not all of the trees were spaced sufficiently to produce reinforcement, the nonreinforcement of a given tree is not now immediately followed by another tree, as was typical earlier in training. Examination of the daily records during this final performance again showed that the bird took over 100 reinforcements per 24-hour period and maintained a weight approximately 90-95 per cent of free feeding.
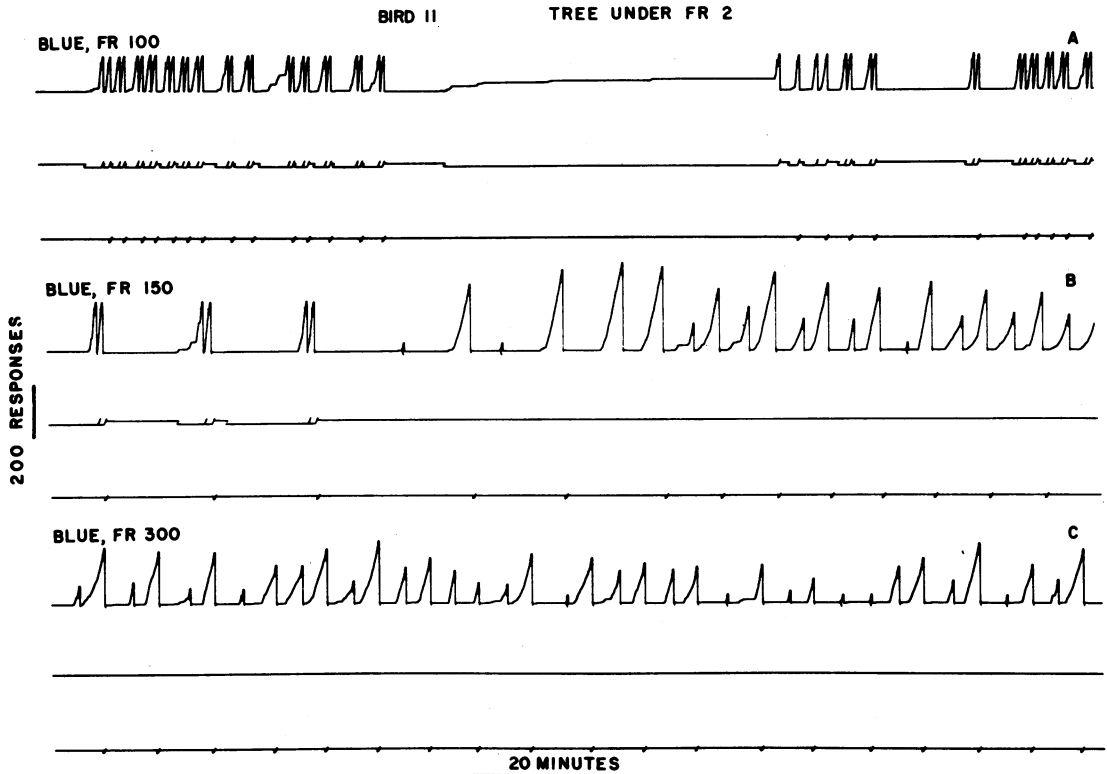

Fig. 47. Sample records illustrating the effects of manipulating a contingency within the tree while it was under an FR 2.

The results of the above manipulations then had not only demonstrated that the total sequence or tree could be placed under a DRL contingency, but they again suggested that the weight maintenance was in part a function of the total behavioral requirements.

To examine this possibility further and to establish a more equal preference between the blue and the green conditions, the size of the FR in the blue was increased to FR 300 and training continued for 15 days. During this period, the preference became approximately equal; the number of daily reinforcements declined; and the weight also declined, leveling off at approximately 80-85 per cent of free feeding. Although this phase of the experiment was terminated because of an equipment failure, it was clear that the bird could be expected to maintain a lower average weight with larger FR requirements within the tree.

The final manipulations to be reported with this bird were conducted with the total sequence placed under an FR 2 schedule. With this arrangement, the

bird was required to complete the tree twice in order to obtain the grain reinforcement. Completion of each given tree produced a 5-second blackout of the stimulus lights, so that every other such blackout was accompanied by the grain delivery. The bird was adapted to this FR 2 contingency, with the values within the tree being FR 100 in the blue, FI 2 minutes in the green, and FR 33 in the red. After 19 days' training, the bird showed a stable performance from day to day, characterized by the emission of trees in pairs and a predominant selection of the blue condition during the early part of the tree. An example of this performance is in Fig. 47A. In these records, the event pen just below the cumulative record is displaced downward to indicate the selection of the blue condition, and the second event pen shows which completion of the tree produced the grain. In the ratio of two trees, the first emission of the tree shows a considerably longer pause before completion and greater strain than the tree which produced reinforcement. In an attempt to increase
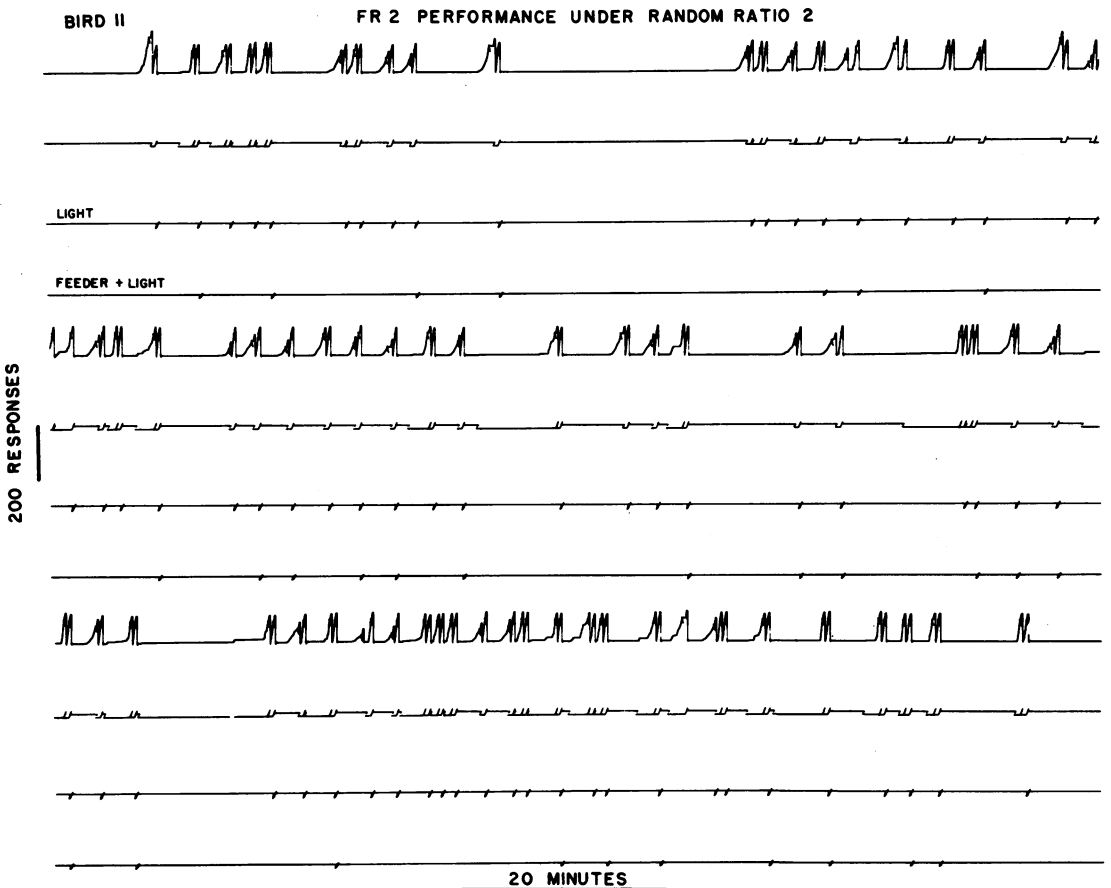

Fig. 48. Showing a 5-hour sample of the performance when the tree already under an FR 2 contingency was placed under an additional contingency of a random ratio of 2.

the frequency with which the bird selected the FI portion of the tree, the FR in the blue was increased in successive stages first to FR 150 and then to 300. Sample records indicating the typical performance after extensive training under each of these ratios are in Fig. 47B and 47C. The increase in the ratio to 150 resulted in a reversal of the preference under the ratio of 100. The bird now selected the FI condition approximately twice for each selection of the FR during each 24-hour period. Examination of the record in Fig. 47B shows a period of responding in which first the FR was predominant and then one in which the FI was predominant. Thus, in spite of the over-all preference for the FI, the bird again showed some cyclical changes in preference during the 24 hours under this condition. When the FR in the blue was subsequently increased to 300, these cyclical patterns disappeared because of the almost exclusive predominance of the FI during the early part of the tree. Examination of the performance during this condition, as shown in Fig. 47C, revealed that the level of FI responding during the first completion of the tree was considerably less than that during the completion of the tree resulting in the delivery of grain. Examination of the weight records during the stable performance under FR's of 100, 150, and 300 in the blue revealed the lowest weight during FR 300; but in no case did the weight fall below 90 per cent of free feeding.

Since the above manipulations had essentially shown how to control the bird's preferences for a given branch of the tree and had demonstrated that the total sequence could easily be placed under a small FR contingency, the procedure was complicated one step further by placing the total performance achieved with the FR 2 reinforcement of trees under an additional contingency. This additional contingency was a random ratio of 2, and was arranged as follows. Each and every completion of the tree produced the 5-second blackout of the stimulus light and then reinstated the conditions for a repeat of the tree. The completion of two trees not only produced the blackout, but was also accompanied by presentation of the feeder light. Finally, on a random basis of 50 per cent, such a presentation of the feeder light would also be accompanied by presentation of the feeder. In a sense then, the FR performance of two trees was taken as a still larger unit and placed under an intermittent schedule of 50 per cent reinforcement, or what might be termed a random ratio of 2. Conceivably, the blackout would act as a conditioned reinforcement to hold together the tree, the feeder light would provide conditioned reinforcement for the FR performance of two trees, and the feeder presentation occasionally combined with the other two stimulus events would maintain the total performance.

The bird was trained on this new procedure for approximately a month. The FI within the tree was 2 minutes, as in previous experiments, and the FR in the blue was at first 75 and then was increased to 150 in an attempt to equalize the preference between branches of a tree. Although the preferences were finally equalized by this larger ratio, the bird's weight eventually declined to approximately 70 per cent of free feeding since twice as much behavior, on the average, was required for each reinforcement with the addition of the random ratio of 2. In order to obtain a larger sample of the performance and to allow a higher body weight, the contingencies in the blue were reduced to an FR of 75, and the FI in the green was reduced to 1 minute. Training was then continued for another month and the experiment terminated. A 5-hour sample of the performance after 16 days' training on this final procedure is shown in Fig. 48. Examination of this typical performance shows that the emission of trees still occurs in pairs in spite of the intermittent reinforcement of such a performance. Further examination shows an over-all preference of approximately 3 to 1 for the FR branch of the tree over the FI branch. It will be observed that within a given pair of trees the occurrence of either the FR or FI branch largely follows two patterns. In one case, the FR branch is selected on both completions of the tree; and in the other case, the FI branch is selected on the first tree and the FR branch on the second. In only one instance is the FI branch selected during the second emission of the tree, *i.e.*, the one which completed the FR 2 requirement and might be accompanied with grain. During the latter days of the experiment, from which the record in Fig. 48 was taken, the bird would typically complete the tree more than 400 times each 24-hour period, maintaining a weight level approximately 85 per cent of free feeding.

In general, then, the manipulations with this bird again suggested the feasibility of treating the tree as a unit of analysis subject to empirical manipulation, and again demonstrated that given the proper procedures, far more complex samples of behavior than a simple tree could be brought under good experimental control. The critical features of the procedures employed in these latter experiments would seem to be the generous use of explicit stimulus control and the use of continuous experimental sessions. Thus, the implied technology for the exploration of extensive multi-operant repertoires presumably may be found in the amplification of those features. The relevance of explicit stimulus control follows not only from its well-proven usefulness in establishing discriminations, but as well from the conceptual simplification which it allows the experimenter when combined with equally explicit manipulations required by the organism. The relevance of continuous sessions, on the other hand, largely follows from the increased experimental time and flexibility which they allow the experimenter. Thus, by the use of the continuous sessions, the experimenter is able to employ strenuous contingencies over a longer period of time, may more readily use diverse kinds of rein-

forcement, gain an enhanced control over extraneous factors, rear organisms from birth, or, in principle, duplicate experimentally any relevant condition that may be assumed necessary in the natural world for the establishment of complex repertoires.

CONCLUSION

It has been suggested throughout this paper that the building and exploration of complex repertoires is likely to enhance our general understanding of behavior. As a final support of this argument, it is suggested here that the relative ease with which trees were established and subjected to involved stimulus control, in contrast with the difficulties of establishing long serial chains, reflects more than changes in methodology. It perhaps reflects a general property of multi-operant behavior. That property formalized into a hypothetical law might be stated as follows: The maintenance of any operant in a sequence of operants is a function of the reinforcing properties of the alternative operants to which it may lead. Thus, in a strictly serial sequence of operants, the maintenance of each operant depends primarily upon the available reinforcing properties of the subsequent one. In a tree or branching-type sequence, however, where one operant may produce the conditions for several alternative or concurrent behaviors, the available reinforcement for the early operant is likely some combination of the reinforcing properties of each possible operant. The ease with which rather complex trees were maintained, together with the results of the several experiments reported in which operants reinforced even with food were found to be partially under the control of their eventual consequences, are generally taken as evidence supporting the above notion. A further implication of this hypothetical law is in terms of its relevance to the general problem of partial reinforcement and the concept of strength. Although the intermittent reinforcement of an operant or tree may well lead to an increased frequency of its occurrence, as was demonstrated in the case of trees, such a result does not necessarily imply that the occasion for such behavior will be more reinforcing or adequate to maintain some more remote behavior by which it is produced. The results of several experiments reported above would rather suggest its reinforcing properties to be less. The principle of partial reinforcement then is perhaps overly hedged in the ambiguous concept of strength and in the vagueness of reference as to which units of behavior in fact are strengthened. In a real sense, therefore, these more general problems in the analysis of behavior await the exploration of explicit and well-controlled multi-operant repertoires more deserving of their consideration.

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