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# Discriminations based on differential responding

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City University of New York, 1989

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# DISCRIMINATIONS BASED ON DIFFERENTIAL RESPONDING

by

ELIZABETH RAMIREZ

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1989

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# Abstract

## Discriminations based on differential responding

by

Elizabeth Ramirez

Adviser: Professor Brett K. Cole

In a conditional discrimination paradigm, a pigeon's choice of a red side key was reinforced if the animal had completed a single peck (FR 1) requirement on the center key; choice of a green side key was reinforced when the animal completed a probabilistic (p), or random ratio (RR), requirement on the center key. Eight values of p were investigated, from p=.025 to p=1.0. With FR 1 and p responding as discriminative antecedents to choice, a gradual decline was obtained in overall accuracy of choice, eventually to a chance level, with increases in p value. The values of p sampled variations of behavior differences between components. Discriminability of the component run length (RL) values of the p requirement were analyzed. Although accuracy as a function of RL value decreased with increases in p value, the effect was small, and for some animals, differential responding to RL> 1 was not eliminated. The systematic decrease in overall accuracy was accounted for in terms of an increasing frequency of

abolishment trials that resulted from the increasing overlap, with increases in p value, between the single peck (FR 1) requirement, where red choices were reinforced, and the single peck (RL 1) from the p requirement, where green choices were reinforced. The RL discriminability data showed an increase in errors at a given RL> 1, with increases in p. This was viewed, first, as a 'context' effect, since at each value of p, any RL was embedded in a different distribution of other RL values. Second, increasing the p value not only increased the frequency of possible non-differential reinforcement, it also represented a decrease in the opportunity for differential responding. These reinforcement based changes were viewed as responsible for the abolishment of discriminative performance on single peck trials, and for the incidental reinforcement of position based choices. Such abolishment also accounted for the generalization of position preference to RL> 1 trials, producing an error gradient wherein RL values closest to a single peck produced the most errors.

# Dedication

This dissertation is dedicated to Dr. George DeLeon, an extraordinary man, without whose advice, encouragement, and continuous support, this work would not have been completed. My deepest gratitude goes to him, for his compassion, and for his willingness to see me through a most painful journey. The enduring truths he has taught me remain as a guiding light in my life.

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Dr. Robert Lanson, for his generosity and support, for allowing me inconditional access to his laboratory and equipment, and for his help with the computer-generated materials that were essential to conducting the present experiment.

John Leong, for always being there, with expert computer advice to solve every conceivable problem; and not least, for his always kind, and much needed, friendly support during the long, data processing phase of this study.

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Organisms can learn to discriminate between stimulus events, that is, they can exhibit a given probability or a given distribution of responses in the presence of a stimulus S1, which will differ from the probability of responding in the presence of a second stimulus, S2, even if S1 and S2 are physically similar. One way to accomplish this differential responding to stimuli is through a differential reinforcement procedure. In one form of such procedure, a specified response R1, is reinforced only in the presence of S1, whereas a different response R2, is reinforced in the presence of S2. Stimulus control of behavior is then obtained to the extent that the change of stimulus, say, from S1 to S2, brings about a change in the organism's response pattern from R1 to R2. The study of a discrimination is usually carried out over time, for responding to S1 and S2 may show fluctuations, and even a temporary reversal, before the behavior patterns to these stimuli become reliable.

Once stimulus control is established, however, specific behavior patterns emerge in the presence of their controlling stimuli. If, on the other hand, the organism were required to reverse a previously established discrimination and to produce behavior pattern R2 in the presence of S1, while producing R1 in the presence of S2, the previously learned discrimination would have to undergo extinction for the reverse discrimination to be acquired.

In such a procedure, acquisition of the reverse discrimination effectively means the elimination of the previous discrimination. There is, however, an experimental procedure that allows for a given discrimination and its reversal to coexist in the organism's repertoire. This is made possible by bringing the opposing discriminations themselves under stimulus control; such is the conditional discrimination paradigm.

In a conditional discrimination, the prevailing discrimination at any given time is conditional on an additional event. For instance, in a two choice conditional discrimination, the presentation of an antecedent stimulus, A1, on one trial brings about one discrimination like S1-R1 vs. S2-R2; whereas the presentation of a different antecedent stimulus, A2, on another trial brings about the reverse discrimination, in this case, S1-R2 vs. S2-R1. In other words, the control of an entire discrimination by each antecedent stimulus makes it possible to alternately obtain reversed discriminations without the need to retrain either discrimination after extinguishing its alternative. A familiar example is the conditional discrimination by pigeons in a three-response key situation, where a red-green discrimination may be required on the side keys. One discrimination, where responses to the red side key are reinforced and responses to the green key are not, prevails, for instance, when the center key is red. The reverse discrimination where responses to the green side key are reinforced and those to the red are not, prevails when the center key is green. Since the prevailing discrimination and the "correct" stimulus on any given trial depends on the nature of the antecedent stimulus, the animal's performance on the side key discrimination (i.e., its accuracy of choice of side key stimulus, over trials) is a measure of the extent to which the animal discriminates the antecedent center key stimuli. The successful acquisition and maintenance of accurate discriminations of this type has been repeatedly reported with different kinds of stimuli, including hues and geometric patterns, as the antecedent stimuli controlling subsequent discriminations (Cumming & Berryman, 1961; 1965).

Although the study of simple and conditional discriminations has dealt extensively with the discriminability of exteroceptive stimuli and their ability to control behavior, the study of events that are found to control behavior has often pointed to the organism's own behavior as a source of stimulation. That is, behavior is a measurable, physical event, and it has stimulus properties like any other event. This fact has often been acknowledge in the literature by ascribing discriminative properties to behavior shown to determine  subsequent behavior (Keller & Schoenfeld, 1950; Ferster & Skinner, 1957). Sequences of responses, for instance, as in chained responding, are said to be possible by the stimulus function of the organism's own responses. Response sequences can be experimentally established by having one response produce the discriminative stimulus for the next response, and so on. However, when a similar sequence of responses is observed in the absence of identifiable exteroceptive stimulus change following each response, the responses in the sequence might appear to constitute a response chain. As stated by Keller (1966), "...the chaining concept involves the assumption that each response in the sequence of operant responses either functions as or produces the discriminative stimulus for the responses that follows". However, research on the discriminative properties of behavior has been scarce compared to that on the discriminability of exteroceptive stimuli, and only recently has this area generated considerable experimental work.

Some early work on the stimulus properties of behavior has been concerned with response sequences. An often cited observation, in this context, is that reported by Ferster and Skinner (1957) of performance by pigeons on mixed fixed ratio (FR) schedules of reinforcement. In a mixed schedule, two or more schedules are presented to the animal alternately, with no exteroceptive stimulus change accompanying a schedule change. Pigeons were trained on a mix FR50-FR250. When under the FR250, the animals were observed to show a pause in responding after about 50 responses, which suggests that some aspect of the organism's own responding is different at the completion of each FR size and that the animal discriminates this difference.

The search for variables determining this pause in responding in the absence of an exteroceptive stimulus change was approached in a different way by Mechner (1958). He introduced the idea of "internal cohesion" of successive responses or response 'runs' observed in FR responding, and stated that run termination occurs at points of low cohesion within the run. A method was needed, however, to investigate what aspects of responding influenced the probability of run termination. With rats as subjects, Mechner's (1958) technique made termination of a run of responses on lever A a requirement for reinforcement of a response on lever B. The response on lever B provided an index of run termination and, thus, the probability of switching to lever B represented a measure of the internal cohesion of runs on lever A. By manipulating the minimum number of responses required on lever A before a response could be reinforced on lever B, Mechner's procedure represented a major procedural innovation. That is, it was able to show how behavior, a conventional dependent variable, can become an independent variable whose effects on subsequent behavior may be determined. Mechner's results showed that, the median number of responses made on lever A before switching to lever B increased as a function of the value of the FR required on lever A. The author suggested that the effect that the number of responses made on lever A had on the probability of run termination might be accounted for by the discriminative function of the animal's own behavior. Mechner (1958) stated: "As the animal continues responding on lever A, the response-produced stimulus situation becomes increasingly favorable, that is, an ever stronger [discriminative stimulus], for switching to lever B."

It has been suggested that the study of the discriminative functions of behavior can be approached in the same way as that of exteroceptive stimuli. That is to say, just as it is possible to establish a discrimination based on differences between stimuli, so can a discrimination based on differences in behavior be arranged. This was the approach followed in a study by Rilling and McDiarmid (1965), involving an innovative use of the conditional discrimination paradigm. The procedure essentially manipulated behavior in place of exteroceptive stimuli as the antecedents to choice. Moreover, in the conventional paradigm, accuracy of choice is a measure of discriminability of the antecedent stimuli; thus, in the context of Rilling and McDiarmid's procedure, choice is a measure of discriminability of the antecedent behavior. In the three-key situation of their study, pigeons were required to complete either of two fixed ratio (FR) requirements alternating on the center key, initially FR50 and FR5. Choice of the right side key was reinforced after completion of the larger FR, and a choice of the left side key was reinforced after completion of the smaller FR. By then keeping FR50 constant while gradually increasing the value of the smaller FR, these investigators were able to obtain a discrimination function for pairs of FR's, showing the percentage of correct side key choices as a function of the antecedent FR value. Accuracy of choice was near 90% when the correct choice was cues by either an FR50 or an FR35. However, as the difference between the antecedent ratios decreased, accuracy of choice showed a gradual decline and fell below 60% when the ratios alternating on the center key were FR50 and FR47. These results indicate that pigeons can base their choice of the side key stimulus on their antecedent behavior on the center key. Equally significant, the conditional discrimination paradigm has become, since Rilling and McDiarmid's (1965) study, one of the most frequently used procedures to investigate the stimulus function of behavior and its discriminative control of subsequent behavior.

Further research on the discriminability of FR patterns has supported and extended Rilling and McDiarmid's

(1965) results. When no other cues to choice are provided, pigeons are, in effect, able to base their choices on their prior behavior, as demonstrated in a study by Pliskoff and Goldiamond (1966). Unlike Rilling and McDiarmid (1965), these investigators introduced a control condition to investigate the effects of non-differential behaviors as antecedents to choice. They alternated two equal FR values in a situation where birds' choices of the right side key had been previously reinforced after completion of the larger of two ratios, and left key choices had been reinforced after completion of the smaller ratio. In their two-response key situation, accuracy of choice was determined also for other pairs of fixed ratios by decreasing the difference between the two FR values. Pliskoff and Goldiamond (1966) found that when the animals had no differential behavior on which to base their subsequent choice of side key (i.e., FR50 vs. FR50 condition), accuracy of choice fell to 50%; that is, the animals' choices did not depend on their previous behavior and in that situation, accuracy was not better than chance level. However, as the difference between the pair of FR values increased, so did choice accuracy. These results indicate that the animals had no cue for correctly choosing a side key other than differences in their antecedent behavior.

Although the use of FR behavior requirements allows for a precise manipulation of the antecedent behavioral event along the number of responses continuum, research has been conducted on the discriminative properties of behavior along other response dimensions. For instance, classes of interresponse times on the center key have been shown to function as the antecedent stimuli on a conditional discrimination (Nelson, 1974 ; Pliskoff & Tierney, 1979; Reynolds, 1966; Shimp, 1981). Similarly, pigeons have been found to discriminate the duration of their prior key pecks, since different center-key peck durations controlled different side key color discriminations (Ziriax & Silberberg, 1978). In addition, and in support of procedures of this type, it has been argued that the stimulus control evidenced by the conditional discrimination is a more accurate measure than, for instance, response rate, to determine the discriminable properties of response-reinforcer relations and their stimulus function (Lattal, 1981). Within this context, Lattal(1981) has shown that animals can make accurate choices of the reinforced stimulus in color discriminations when the only differential condition on which to base their choice of stimulus is whether their antecedent behavior was under a DRL or a DRO response requirement.

A psychophysical question has also been asked regarding the extent to which behavior patterns must differ to serve a discriminative function. A study by Hobson (1975), was designed to investigate this question, using FR patterns as the antecedent stimuli for a spatial discrimination. In a three-key situation, pigeons were required to complete either of two FR values on the center key; which choice of side key was reinforced, depended on whether the smaller or larger of two ratios had just been completed. The animals were divided into three groups, each distinguished by the size of the larger FR value and which remained constant at FR10, FR20 and FR30. Within each of these groups, animals were exposed to several pairs of fixed ratios to a criterion of stability at each pair. Once stable accuracy of choice was obtained at a given FR pair, the smaller ratio was increased by one or two responses, and stable performance was obtained at the new pair before increasing the smaller ratio again. In general, for only one bird in each group was the value of the smaller ratio increased until it equalled that of the larger ratio. For other birds, the smaller ratio was increased until the difference between values was just below or equal to 10% of the larger ratio. Hobson (1975) found that for all animals the probability of choosing the correct side key decreased systematically as the difference between the two FR values became smaller. That is, as the ratios that alternated on the center key became increasingly similar in value, the animals' accuracy of choice approached chance responding, i.e., 50% accuracy level.

Hobson's (1975) data also extend previous findings by showing the effects on choice of establishing a non-differential requirement, i.e., by having two identical ratio values as the antecedents to choice. Under these circumstances, all animals showed chance performance. This, and similar reports by Pliskoff and Goldiamond (1966), support the interpretation that the accuracy above chance level that was obtained when there was a difference between the two ratio values ia a measure of the animal's discrimination of some aspect of their antecedent ratio behavior. Furthermore, such discrimination was exhibited at differences as small as that represented by 10% of the larger FR value of a pair. For the three groups of animals in Hobson's study, this means that accuracy above chance levels was obtained at FR10 vs. FR9, FR20 vs. FR18, and FR30 vs. FR27. An additional finding in that study was that, at the same relative difference between ratio values, the FR30 group generally showed higher accuracy levels than the FR10 group. Thus, even though the nature of the discrimination functions was essentially the same for all groups of animals, in addition to the relative differences between ratios, accuracy levels were affected by the 'background' ratio level, that is, by the size of the larger ratio.

The experimental findings thus far reviewed indicate that differential response patterns can serve as effective discriminative stimuli for subsequent responding. It has also been noted that beyond FR requirements, some of the response patterns that have been investigated have laid either along orthogonal dimensions, such as DRL vs. DRO responding, or along a single continuum, such as response duration. The most desirable strategy of the two could be the single dimension approach. Just as one would study stimulus discriminability within a single stimulus dimension by systematically varying the stimulus along that dimension, it would be desirable to systematically vary behavior along a continuous dimension. One response dimension along which differences can be established to form a continuum is that of the number of responses emitted by the organism. One way of identifying points along the number of responses continuum is by identifying a succession of responses as a response run and the total number of responses as the response run length (Mechner, 1958; Schoenfeld & Cole, 1972). In other words, the emission of a topographically specified response, which can be repeated _n_ times, can be enumerated and becomes the run length of that class of responses. The term 'run length (RL), will thus be used here to denote a relatively continuous sequence of responses (a "run"), with the total number of responses emitted representing the length of the run or RL value. In this way, a continuum of behavior differences, in number of responses, can also be identified as points along the run length (RL) dimension.

Representative studies which have investigated the discriminative properties of behavior by varying behavior along the dimension of number of responses have typically required the completion of two FR requirements as the antecedents to choice. Accuracy of choice is subsequently determined at a few arbitrary points along the continuum (Pliskoff & Goldiamond, 1966), or more systematically, one value is "anchored" at one point and then different pairs are formed by contrasting this constant value with another value. Most frequently, the changing ratio is a lower FR value that is gradually increased and made to approach the constant. In those cases, the lower value has been increased either daily (Rilling, 1965), or until stable performance is obtained at a given pair (Hobson, 1975). In either case, the number of FR pairs that has been investigated is small, e.g., six pairs, while the range of values is typically narrow and generally constrained to the lower end of the RL continuum. In addition, once an accuracy of choice function has been determined, Hobson's (1975) data show that the obtained accuracy levels will also depend on the 'background' ratio level, that is, on the value of the larger ratio. Even though Hobson provided data on three such 'background' levels, i.e., FR10, FR20 and FR30, the fact that each level was contrasted only with equal or lower FR values, restricts the functions to the lower end of the continuum. In other words, a comprehensive investigation of the RL continuum is lacking.

For a more comprehensive study, therefore, of the discriminative properties of differential behavior patterns, it is desirable to study many values along the selected response dimension. One way of manipulating the run length dimension in a comprehensive fashion can be accomplished by generating the different run length values in a probabilistic fashion. That is, within a conditional discrimination paradigm, different probabilities can be assigned to the presentation of the side key stimuli, given a response on the center key. For instance, when a probability of 1.0 is assigned to the stimulus change, every center key response will produce the side key stimuli, i.e., the center key requirement will be an FR 1 requirement. If, however, the stimulus change is assigned a probability value less than 1.0, a run of responses on the center key may occur before the side key stimuli are produced. In addition, the length of the required run, or run length (RL) will vary, randomly, from trial to trial. According to the rules of probability, with a sufficient number of trials an entire distribution of RL values will be generated on the center key, and an extensive number of RL values will occur within a session. Furthermore, because the nature of the RL distribution will depend on the probability value that is assigned, by setting the probability of stimulus change to different values, different RL distributions can be investigated, and the relative discriminability of selected RL values can be determined as a function of that probability.

To better understand some of the implications of using a probability variable, some of the properties of this variable must be emphasized. For instance, once a probability value p has been selected, that p value applies to each and every peck the animal makes on the center key. For example, consider an FR10 requirement in contrast to a p manipulation. In the FR10 case, the probability of the 10th center key peck producing the side key stimuli is 1.0, whereas the other nine responses within the run have a probability of zero of producing the side key stimuli. In the probability manipulation, on the other hand, each center key peck is equally likely to produce the side key stimuli. That is, any response within a run will be selected, with the given probability, to produce the stimulus change. Under these conditions, a response is selected independently of previously made responses or independent of previous outcomes, i.e, the probability of a key peck producing the stimuli on the side keys does not increase or change in any way as the animal keeps pecking on the center key. As a result, the cardinal position of the effective response within a run will vary probabilistically; that is, will vary randomly. When using a probability manipulation, therefore, any RL value may be produced on the center key on any given trial (the only exception to this rule is $\underline{p}=1.0$, the value at which every center key peck will produce the side key stimuli,i.e., RL 1 results in all trials. In effect, the probability manipulation results in a known, random distribution of RL values, where all the parameters of the distribution are entirely determined by the probability value $\underline{p}$ that is assigned to center key pecks. That is, at all probability values $0< \underline{p} < 1$, every possible RL value has a nominal probability of occurring within the random distribution. Furthermore, it is possible to determine the proportion of a given probability distribution that any given RL value will occupy. The relative frequency distribution of RL values at a given $\underline{p}$ value can be obtained by the formula for the geometric distribution in probability theory, as applied to stimulus schedules in the t-T system (Schoenfeld & Cole, 1972): $\text{prob. } N = p \cdot q^{(N-1)}$, where prob. N is the probability of any given RL value, $\underline{p}$ is the assigned probability of stimulus change, and $\underline{q}$ is the probability of non-stimulus change, or $(1 - \underline{p})$. All other parameters of the RL distribution, its mean RL, standard deviation, etc., can therefore, be obtained. The mean RL value, for instance, is equal $1/\underline{p}$. However, the order or sequence in which the different RL values will occur from trial to trial is not known in advance; that is, the RL values will be randomly distributed.

To illustrate some of the distributional properties that are associated to manipulating the probability that a center key peck will produce the side key stimuli, the expected frequency of occurrence of a few selected RL values under different probability values is shown in Table 1 below. By examining this table, the following basic properties of the probability manipulation can be noted: 1) at all p values, the RL that has the highest probability of producing the stimulus change is RL 1 (a single peck) and its relative frequency is equal to p; 2) within each probability distribution, the larger the RL value, the lower its relative frequency; 3) large RLs have a higher relative frequency at small p values; 4) short RLs (e.g. RL 3), increase in frequency with increases in p, up to the middle range of p values. With further increases in p, the frequency of short RLs begins to decrease; and 5) since the proportion of the distribution that is occupied by the RL 1 value is equal to p, the complement of the p value represents the proportion occupied by all RL> 1 values.

The probability variable has been selected as the independent variable in this experiment and it will be introduced in the following way. In a three-response key situation, pigeons will be required to peck at a center key. A given number of pecks on the center key is to be followed by a stimulus change in which the animal will be presented with a discrimination situation between two side key stimuli. Reinforcement of a response to either side key stimulus will be conditional on the antecedent RL on the center key. The variable to be manipulated, therefore, is the probability value, $p$, that a center key peck will produce the side key stimuli.

The basic design will consist of opposing two components as the alternating response requirements on the center key, One component will be 'anchored' at the beginning of the run length continuum, consisting of a fixed ratio (FR) requirement of a single peck, or FR 1. Under this component, a single peck will produce the side key stimuli, i.e. a red and a green side key. The FR 1 component will be kept constant throughout the experiment, alternating with a probability component at selected $p$ values. Under the $p$ component, different RL values will be required to produce the side keys. Once the side key stimuli are presented, which choice of stimulus is reinforced will depend on the animal's antecedent behavior on the center key. Red choices will be reinforced after completion of the FR 1 requirement, and green choices will be reinforced after completion of the $p$ requirement. The animal's accuracy of choice of side key stimuli will then

## Table 1

### Relative frequencies

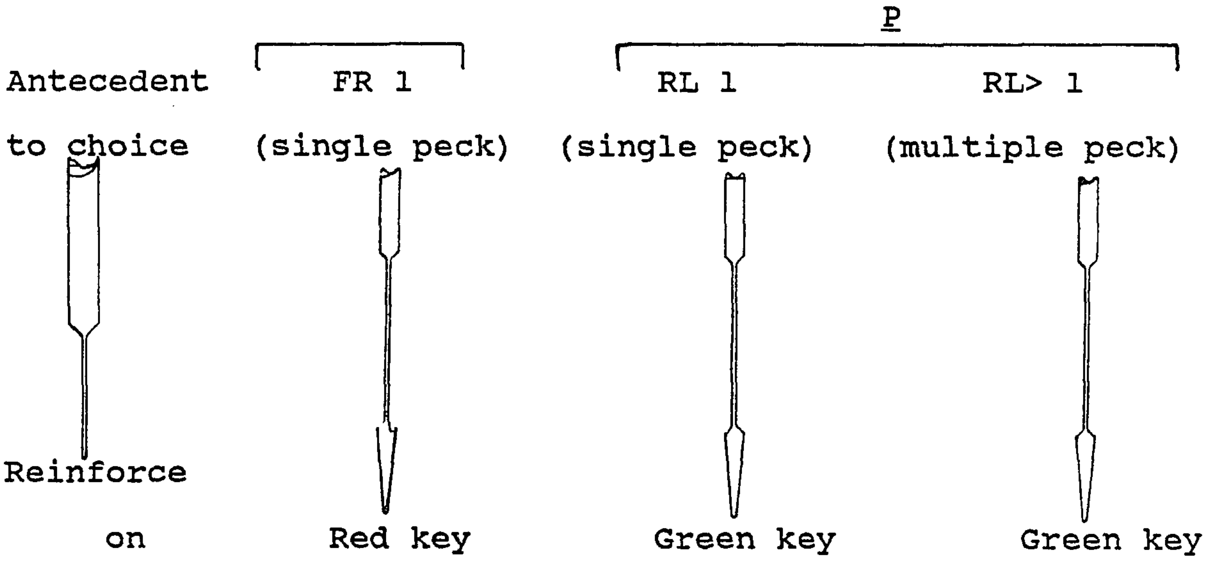
| p | RL 1 | RL 3 | RL 20 | RL 200 | RL> 1 |
|---|---|---|---|---|---|
| .025 | .025 | .023 | .015 | .00016 | .975 |
| .10 | .100 | .081 | .013 | 7.8E -11[a] | .900 |
| .25 | .250 | .140 | .001 | 3.4E -26[a] | .750 |
| .75 | .750 | .046 | | | .250 |
| .90 | .900 | .009 | | | .100 |
| 1.0 | 1.0 | 0 | 0 | 0 | 0 |

[a] Floating point notation. The negative exponent (E), after the fraction, indicates the number of places the decimal point must be displaced to the left.

be determined at different values of the probability component, while holding the FR 1 component constant.

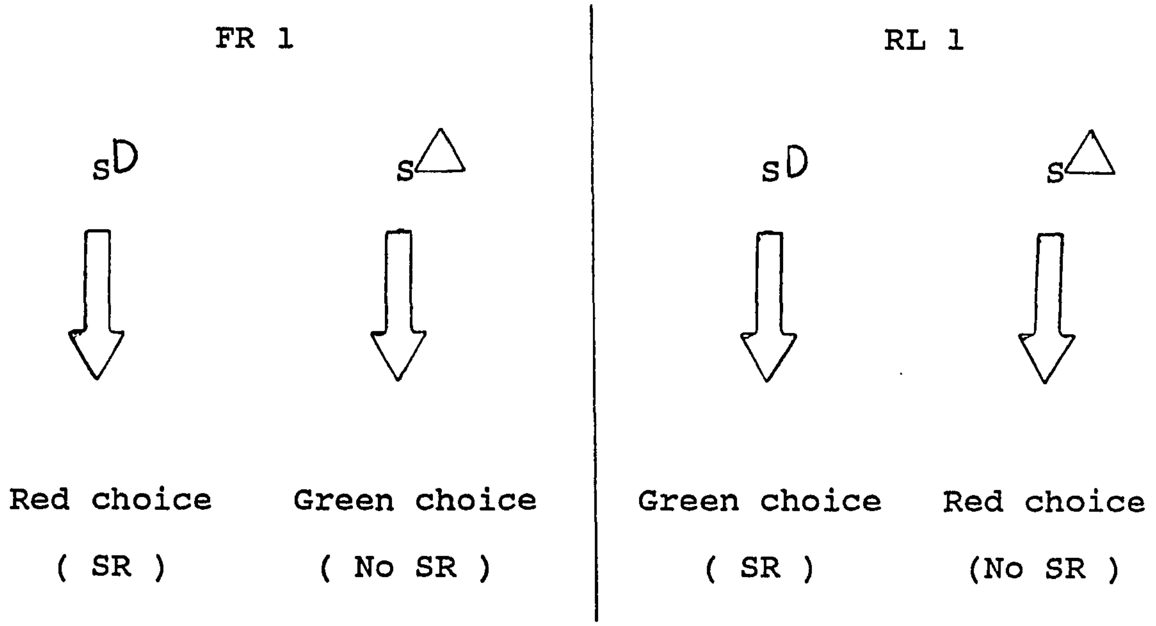
In a general way, then, it can be said that the animals in this study will be required to complete two differential response requirements on the center key, as antecedents to choice. Differential requirement here refers to the alternation of a single peck requirement, FR 1, with a multiple peck requirement (RL> 1 trials of the p component). However, in dealing with the probability variable, one must contend with the fact that as part of the p component, there will also be trials requiring a single peck (RL 1 trials); these trials constitute a non-differential requirement from that on the FR 1 component, introducing an element of ambiguity in the training of the conditional discrimination.

For purposes of illustration, the stimulus-response relations that will be reinforced within this design can be represented schematically by subdividing the p component in two sub-components, namely, RL 1 and RL> 1, as well as their reinforcement relation in comparison with the FR 1 component.



As this scheme shows, one consequence of alternating an FR 1 and a probability component is their overlap when both require a single peck on the center key. On those trials, the animal is presented with a situation in which whether the red or the green choice is reinforced depends on which center key requirement was in effect, even though the requirement is identical in the two cases. Thus, red choices will be reinforced after a single center key peck (FR 1 trials), and green choices will also be reinforced after a single center key peck (RL 1 trials of the p component).

To further clarify this important implication to be drawn from the use of a probability component, an analogy can be made with discrimination procedures which utilize exteroceptive stimuli. Within the conditions of this experiment, FR 1 responding can be identified as the discriminative stimulus ($S^D$) correlated with reinforcement of red choices and as the discriminative stimulus ($S^\Delta$) correlated with non-reinforcement of green choices; within the same analogy, an inverted set of $S^D$ - $S^\Delta$ relations would apply to RL 1 responding. As the diagram below shows, the $S^D$ - $S^\Delta$ relation that is prescribed by the reinforcement contingencies prevailing on FR 1 trials can be undermined by scheduling reinforcement of green choices on single peck trials (RL 1 ) of the p component.



In effect, a conventional procedure to undermine a well established discrimination between two stimuli, known as the abolishment procedure, consists of equalizing the reinforcement conditions in $S^D$ and $S^\Delta$ (Keller & Schoenfeld, 1950); this can be done by reinforcing responding not only to $S^D$, but also to $S^{\Delta}$. Therefore, the arrangement of the reinforcement contingencies on single peck trials from the FR 1 and the *p* component is reminiscent of previously reported arrangements known to effect the abolishment of a discrimination (Skinner, 1933; Stoddard & Sidman, 1971). Skinner (1933), for instance, reduced the difference in responding to two stimuli, light and dark, by introducing reinforcement for responses to $S^{\Delta}$. In the present study, the presence of RL 1 trials represents, then, the potential abolishment of the red-green discrimination that is intended for the single peck (FR 1) component, where the red side key is the $S^D$ stimulus associated with reinforcement (SR), and the green side key is the $S^{\Delta}$ stimulus associated with non-reinforcement (No SR).

Notwithstanding its similarity to an abolishment procedure, a major difference in this study is that at probability values of *p* less than 1.0, the *p* component contains RL values other than RL 1. That is, the present procedure also involves differential reinforcement contingencies associated to a multiple-peck (RL> 1) requirement of the *p* component, and one which is expected to form the basis of a conditional discrimination, when alternated with the FR 1 component. Nevertheless, abolishment of the FR 1 discriminative relations could take place, and could conceivably result in the abolishment of the entire conditional discrimination. This latter effect, if it were to take place, would be different from a conventional abolishment, since it would be effected via abolishment of the discriminative relations of only one of the two components. Moreover, the potential for abolishment would be expected to relate to the value of p. Compare, for instance, the training situation at a p=.025, where most p trials are RL> 1 trials, which represent differential responding from FR 1, and the situation at p=.50, where one half of p trials is identical to FR 1 trials (see Figure 2). The limiting case would, of course, be represented by a p=1.0, where single pecks would be required on every trial and red and green choices would be equally reinforced.

Because the proportion of RL 1 trials, relative to the proportion of differential RL> 1 trials can be manipulated by varying the probability value, the present design allows for the simultaneous determination of conditions associated with the establishment of a discrimination, and of the conditions associated with its potential abolishment. In other words, the design permits the determination of the extent to which the conditional discrimination coexists with different, and controlled, proportions of 'abolishment trials'.

What we are referring here to as the coexistence of discrimination trials with abolishment trials is an arrangement which finds a parallel in some studies investigating the discriminability of signals, usually exteroceptive stimuli, with methods stemming from a signal detection theory (SDT) approach (Green & Swets, 1966). Thus, there are signal detection studies which utilize a conditional discrimination paradigm with two stimuli, two mutually exclusive responses and two possible outcomes, either reinforcement or non-reinforcement. Typically, reinforcement of each of the two responses occurs in correlation with only one of the two stimuli, establishing two discriminative stimulus- response relations. More recently, however, some studies have begun to investigate the effects on signal detectability when reinforcement of one of the responses is scheduled, some of the time, in the presence of the other stimulus -the $S^{\Delta}$ for that response. In such studies, the reinforcement of responses to $S^{\Delta}$ is identified as the reinforcement of 'errors', whereas reinforcement of responses to $S^{D}$ is identified as the reinforcement of 'correct' responses. Maintaining $S^{D}$ and $S^{\Delta}$ constant, the introduction of reinforcement for errors has resulted in decreases or near abolishment of discriminative responding to the two stimuli (Nevin, Olson, Mandell, & Yarensky, 1975). The introduction of the reinforcement of errors has, in turn, been identified as one way of weakening the reinforcement contingencies that maintain a base line discrimination, and as one that reduces discriminative responding (Nevin, Jenkins, Whittaker, and Yerensky, 1982). These reports increase the expectation about the extent to which the present conditional discrimination can be maintained at the various probability values that will be investigated, since each p value generates a given proportion of reinforcement of 'errors' or abolishment trials.

It is proposed that the probability variable of this study provides for a comprehensive manipulation of behavior differences along the run length dimension. To the extent that discriminative responding can be established based on such differences as the antecedent stimuli, the present design may also provide information needed in other areas of research. For instance, the results from this study could be usefully related to those studies which investigate the role of differential responding as discriminative stimulus, when used in combination with an exteroceptive stimulus. In those conditional discriminations procedures,- sometimes labeled as arbitrary, symbolic or non-identity matching- for each of two exteroceptive (sample) stimuli, there is a behavior pattern the animal must complete in their presence, i.e., sample specific behavior. Both, the exteroceptive stimulus, and its associated behavior pattern, become a compound sample stimulus which antecede subsequent choice responding between two stimuli, each of which has been arbitrarily assigned as the match for each of the two samples. It has been reported that requiring a different behavior in the presence of each exteroceptive stimulus greatly facilitates the acquisition of a matching task (Eckerman, 1970), and of several non-identity matching tasks, as compared to acquisition when either the samples are exteroceptive stimuli only, or when the behavior required in their presence is non-differential (Cohen, Looney, Brady, & Aucella, 1976). One interpretation of these findings suggested that sample-specific responding increased the discriminability of the exteroceptive stimuli, facilitating their control over subsequent choice behavior, much in the same way differential reinforcement increases stimulus control when compared to non-differential reinforcement. More recently, however, some studies have questioned the mere facilitating role attributed to differential behavior in the various matching tasks, and suggest, instead, that the discriminative stimulation generated by the behavior alone can become the effective sample stimulus in the control of subsequent choice behavior (Urcuioli & Honig, 1980). Moreover, Cohen, Brady, and Lowry, (1980), reported that, when opposed to each other, the sample specific behavior exhibited relatively larger discriminative control, over subsequent behavior, than the exteroceptive stimulus. From these results, Cohen et al. questioned whether the differential behavior that is generated by differential reinforcement in discrimination procedures does in fact enhance stimulus control, or whether such behavior acquires control that overrides exteroceptive stimulus control. Partial support for this interpretation has been reported by Urcuioli and Honig (1980). It must be noted, however, that these studies utilized only two behavior patterns or two values of a behavior dimension. It would appear that further treatment of this issue of relative control by the stimulus sample or the behavioral sample would benefit from a comprehensive assessment of the discriminative control by some behavior dimension alone, i.e., with no associated exteroceptive stimulus. Such assessment, as proposed for the present study, could provide a referent against which to evaluate the added contribution of some stimulus dimension to a conditional discrimination.

The purpose of the present study is to explore the methodological adequacy of introducing a probability manipulation as a comprehensive way of dealing with the dimension of differences in behavior as discriminative stimuli along the run length continuum.

From the preceding discussion it should be apparent that the probability variable generates a wide range of RL values (see also Table 1), and that it should provide for a comprehensive treatment of the RL dimension. At the same time, by manipulating the $p$ value, it should be possible to determine the discriminative properties of a given RL under the context or 'background' of different RL distributions and thus determine the extent of such contextual effects, if any, on RL discriminability. Finally, given that a fixed behavior value, FR 1, will alternate with a variable, sometimes overlapping, probability value p, the present design will provide data on the extent to which the discriminability of these behavior patterns is affected when abolishment trials and conditional discrimination trials are combined in controlled proportions.

## Method

### Subjects

The subjects were six White Carneaux pigeon hens ranging in age from 5 to 7 years. Following arrival in the laboratory the birds' flight feathers were cut back to the first feather line and housed in individual home cages. Trimming of the feathers was repeated periodically throughout the experiment. From arrival, the animals were maintained on a free-feeding schedule of Standard Purina grain mix, by keeping the grain constantly available in their food cups throughout the day. Fresh water and grit were continuously available in the animals' home cages. Each bird's weight was taken daily for several weeks to determine its *ad libitum* weight; thereafter, each bird was reduced to 80% of its *ad lib* weight and maintained at that level throughout the experiment.

### Apparatus

The experimental chamber was a standard three-key Lehigh Valley Electronic Model #132-02 with the interior painted off-white. A minimum force of 20 ± 5 g of static mass was required to operate each key.

Three IEE inline display projectors Model #00010-01-XXXX-1820 (with hues and geometric shapes available), were used to transilluminate the response keys with hues only, nominally white, red and green hues. A ventilation fan inside the chamber provided masking noise.

The experimental contingencies were programmed automatically by relays, timers and a paper-tape reader. Electromechanical counters provided separate cumulative records of correct and incorrect responses to both the left and the right side key, as well as recording the number of reinforcers delivered. A Sodeco five-digit parallel entry printer counter (Type PN-117) provided a trial by trial record of both, the number of center key responses that were required to produce the side key stimuli, and the side key that was chosen. In addition, two Lehigh Valley probability gates (Model 235-11) were used to generate the probability values to be investigated in this study.

## Procedure

Magazine training and center key shaping. All animals were first trained to eat from the hopper with the house light on, the center key illuminated with a white light, and the side keys dark. During the next session, the birds were trained to peck at the illuminated white center key by the method of successive approximations. Once an animal had pecked at the center key, a trial by trial procedure was introduced. For each trial, a single peck at the white center key turned the key light off, produced a 3.0 s access to grain, and terminated that trial. Access to grain was followed by a 0.5 s intertrial interval (ITI), during which the house light remained on and all keys were dark. Responses to the white center key were reinforced under this continuous reinforcement schedule (CRF) for a total of 100 trials.

White-side key training. On the following day, a two-link response chain was introduced. In order to gain access to food it was necessary that a single peck on the white center key be followed by a single peck on the white side key. A trial began with the illumination of the white center key. A peck on this key simultaneously turned off the light and presented the animal with a white light on one of the side keys. The side key remained illuminated until the animal pecked at it. A single peck turned off the illuminated side key and produced 2.5 s access to grain. Pecks at either the dark side key or the dark center key had no scheduled effect. Each presentation of grain was followed by an ITI during which the house light was on and the keys were dark. During this session, the ITI was gradually increased from 0.5 to 3.0 s. The right and left keys were illuminated equally often in a Gellerman (1931) sequence for a total of 100 trials.

On the next day, either a red or a green light was substituted for the white light on the side keys.

Color-side key training. In this session, a peck on the white center key simultaneously turned off the light and presented either a red or a green light on one side key. A peck on the colored side key produced access to grain, whereas pecks at the dark center and side key had no scheduled consequence. The animals were given 100 trials; 50 consecutive trials with the red light followed by 50 trials with the green light. Each set of 50 trials followed a different Gellerman (1931) sequence and each color appeared equally often on the left and the right. Within this session, the ITI was gradually increased from 3.0 s up to the final value of 10 s for all animals. The latter value remained in effect for the rest of the experiment.

Conditional discrimination training. In this procedure, specific response requirements were introduced on the center key as the antecedent stimuli to choice responding on the side keys. Before the stimuli correlated with reinforcement could be presented on the side keys the animal had to complete a behavior requirement on the center key.

On a trial-by-trial procedure, two response requirements alternated on the center key, a fixed ratio (FR) requirement and a probability (p) requirement. Each of these two requirements was correlated with one of two colors on the side keys. On a given trial, after the animal had completed the center key requirement assigned for that trial, it was presented with two side keys simultaneously, one illuminated with a green light the other with a red light. The animal's choice of side key was then reinforced with access to grain, only if the chosen key was the one correlated with the response requirement the animal had just completed on the center key.

Under one response requirement, the FR component, a single peck (FR 1) was required on the center key; this component was constant throughout the experiment. Under the alternating response requirement, the p component, the probability that a center key peck would produce the side key stimuli was manipulated as the independent variable of this study. Once assigned, the probability value p applied to each response the animal made on the center key under the p component. In this fashion, a given random distribution of required run length (RL) values was associated to each of the p values investigated. On any trial in which the p component was in effect, the RL value that was effective to produce the side key stimuli was determined by the momentary input/output ratio of the probability gates which were set at a given p value. The probability value was changed by simply moving the dials of these gates to a different p setting. Because of its probabilistic nature, the p component required any number of responses on the center key, from a single peck (RL 1), to a multiple peck (RL> 1). As a result, some proportion of trials of the p requirement were identical, along the number of responses continuum, to trials of the FR 1 requirement. However, even though an FR 1 and a RL 1 are identical response requirements, the contingencies of reinforcement associated to each were different. Therefore, it may be convenient to distinguish, at times, between these two types of single peck trials by referring to them respectively as Type I and Type II trials.

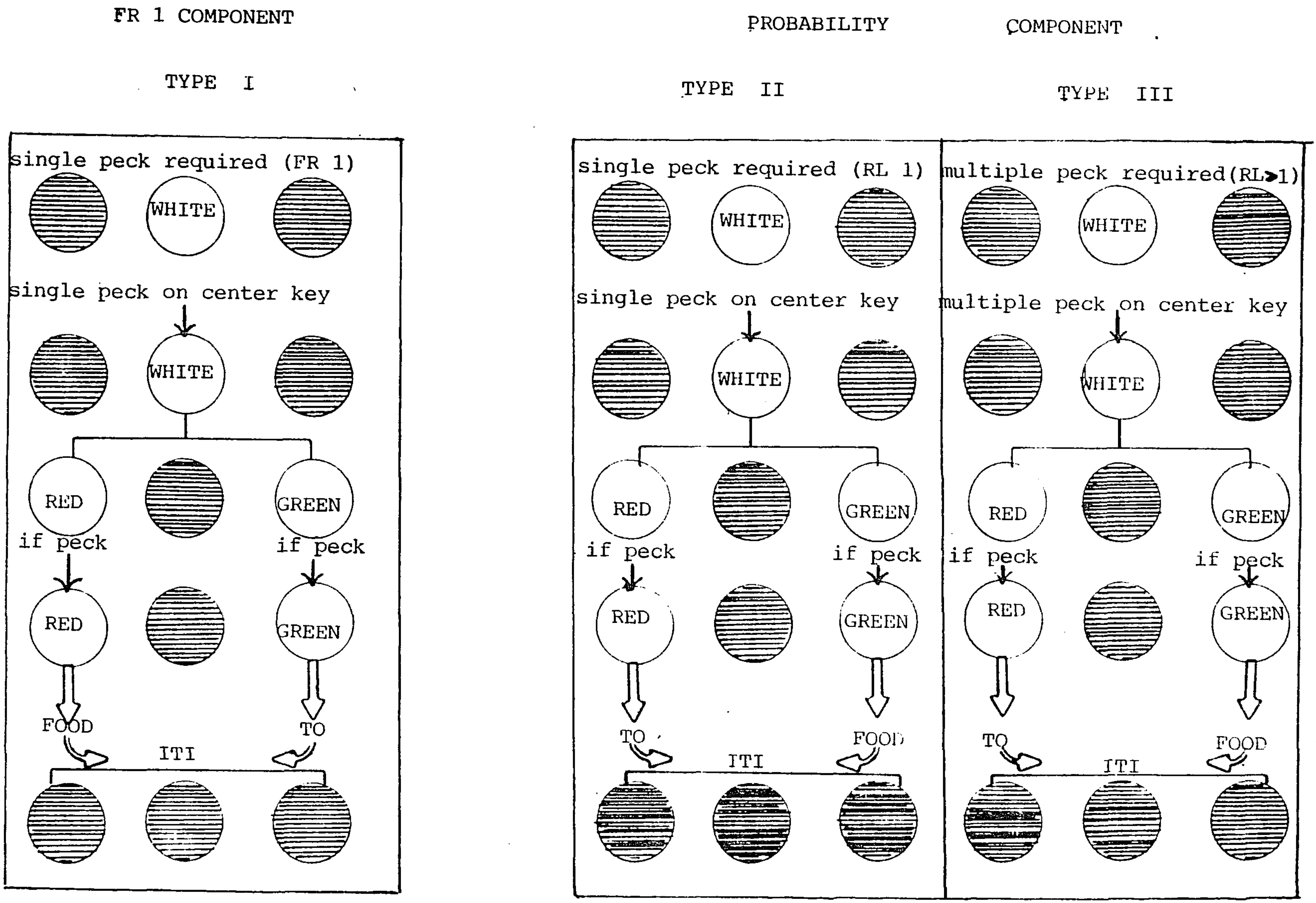
Figure 1 is a schematic representation of the flow of events in trials corresponding to the FR 1 component (Type I trials), and in trials corresponding to the p component (Type II and Type III trials). It will help explain how the choice of side key color was reinforced given the center key requirement, as well as the nature of the run length overlap of FR 1 and p trials.

A trial was initiated with the illumination of the white center key. Completion of either the FR 1 or the p center key requirement simultaneously turned off the white center key light and presented the animal with a simultaneous red - green discrimination situation on the side keys. The positive side key color in this side key discrimination was conditional on the animal's antecedent behavior on the center key. The red side key was arbitrarily designated positive after FR 1 responding (Type I trials in Figure 1). The green side key was designated positive after p responding (Type II and Type III trials). Figure 1 illustrates the two types of trials which

Figure 1. Schematic representation of the flow of events on each of the different types of trials. The circles represent the three response keys. The lines across the circles indicate that the key is dark; otherwise, its color is indicated.

The representation of each trial type includes the following events in their order of occurrence: the center key response requirement at the beginning of the trial, the completion of the response requirement on the white center key which produces the side key stimuli, and the consequence -either reinforcement ($S^R$ ), or time out (TO) from reinforcement- for each choice of side key. An intertrial interval (ITI) follows either $S^R$, or TO, at the end of which a new trial begins.

Figure 1



FR 1 COMPONENT
TYPE I
single peck required (FR 1)
WHITE
single peck on center key
WHITE
RED
GREEN
if peck
if peck
RED
GREEN
FOOD
TO
ITI
PROBABILITY COMPONENT
TYPE II
single peck required (RL 1)
WHITE
single peck on center key
WHITE
RED
GREEN
if peck
if peck
RED
GREEN
TO
FOOD
ITI
TYPE III
multiple peck required (RL>1)
WHITE
multiple peck on center key
WHITE
RED
GREEN
if peck
if peck
RED
GREEN
TO
FOOD
ITI

constituted the p requirement. On Type II trials, a green choice was reinforced after a single peck, or RL 1 requirement. On Type III trials, a green choice was reinforced after a multiple peck or RL> 1 requirement. Also illustrated in Figure 1 is the overlap of the FR 1 and the p components on Type I and Type II trials; both trials required the same behavior, i.e., a single peck, but the consequences of choice were different for each type. Red choices were reinforced on Type I trials and green choices were reinforced on Type II trials.

A single peck to the "correct" side key stimulus turned both side key lights off and produced access to grain. A single peck to the "incorrect" side key stimulus produced a time out (TO) period, i.e., turned off both the house light and the side key lights, leaving the bird in a darkened box for 3.0 s. An ITI of 10 s, with the house light on and all keys dark, followed either a TO or period of food presentation.

A session consisted of 204 trials; 102 were FR 1 trials, the other 102 were p trials. Since the correct side key color associated to a center key requirement must occur equally often on both side keys, four center-side key configurations are possible. A punched tape controlled a computer generated sequence of quasi-random permutations of the configurations in blocks of four; since each configuration appeared only once within each block, the two center key components occurred equally often within a session. Another consequence of this blocking was that a given configuration did not occur on more than two trials in succession. To further preclude any learning of the stimulus sequence, there were as many punched tapes as experimental sessions; the tape was replaced once it had been used with all six animals. Thus, each bird was exposed to a given 204-trial sequence only once.

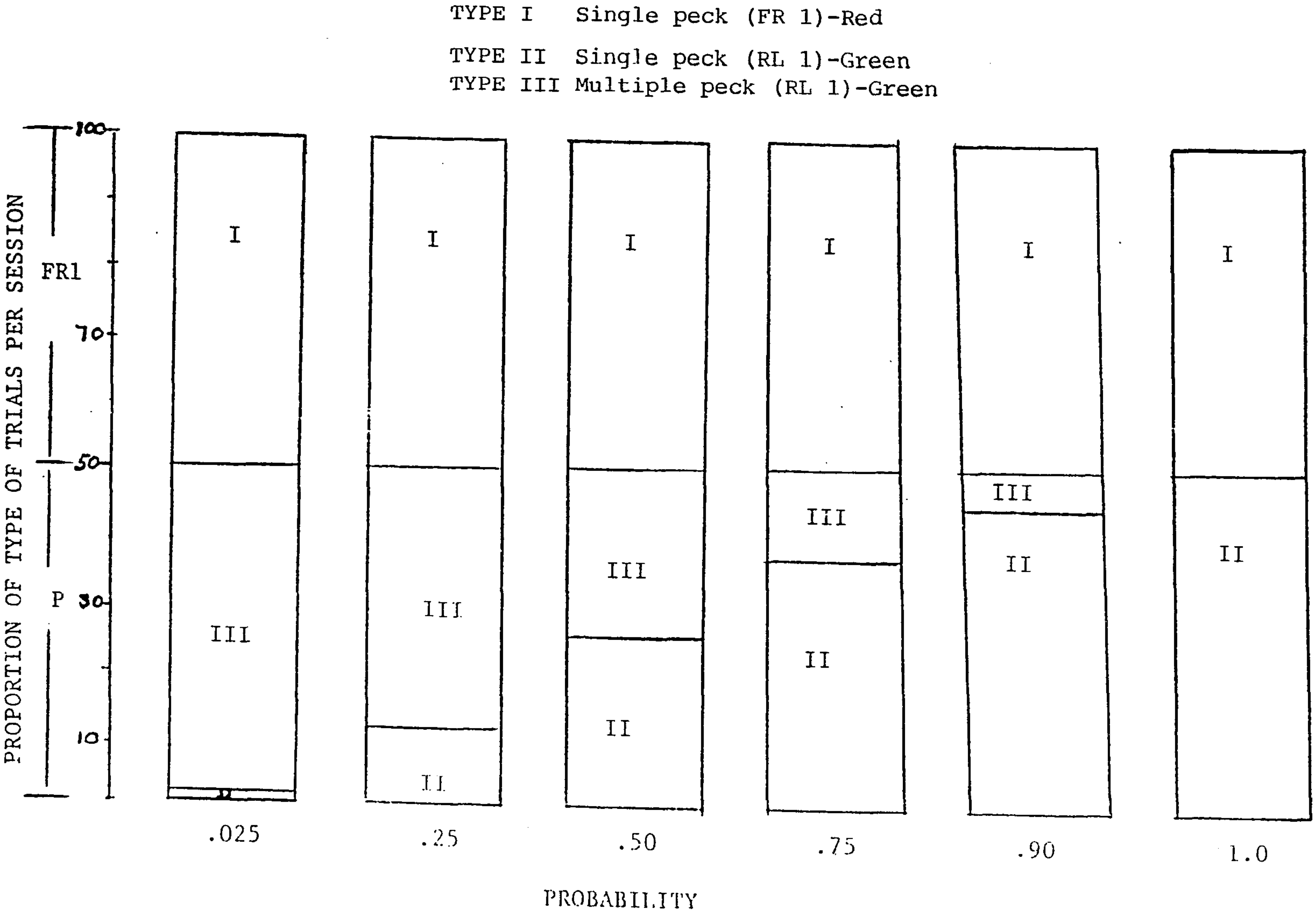
For a representation of the expected distribution of the different types of trials per session, at a given probability value, the bar graph in Figure 2 was constructed to show the percentage of each type of trial at selected probability values. Thus, the proportion of Type I trials of the FR 1 component was constant at 102 trials throughout the experiment and constituted 50% of total trials in a session. In contrast, the relative frequency of Type II and Type III trials of the p component changed with the probability value. Thus, in a session at p=.025, Type II trials constituted only 1% of the session's trials, and Type III the remaining 49%. At p=.50, 25% of the session's trials were Type II and the other 25% were Type III. At a p=1.0 value, on the other hand, all p trials were Type II trials, and constituted 50% of the session's trials. Note that, when the proportion of Type II and Type III trials are considered, not with respect to total trials, but with respect to trials in the p component, the value of p alone

Figure 2. Percentage of each type of trial in the FR 1 and the p components, relative to the total number of trials in a session (204 trials). Percentages are presented as a function of probability value.

The FR 1 component is constituted by Type I (single peck) trials only -where red choices were reinforced-, and their frequency remains constant at 102 trials, throughout the experiment.

The p component is represented by two types of trials, Type II (single peck) trials, and Type III (multiple peck) trials -where green choices were reinforced-, and their relative frequency changes with the probability value.

Figure 2


TYPE I Single peck (FR 1)-Red
TYPE II Single peck (RL 1)-Green
TYPE III Multiple peck (RL 1)-Green
PROPORTION OF TYPE OF TRIALS PER SESSION
FR1
P
100
70
50
30
10
I
III
II
I
III
II
I
III
II
I
III
II
I
III
II
I
II
.025
.25
.50
.75
.90
1.0
PROBABILITY

specifies the proportion of Type II trials, whereas its complement, 1-p, specifies the proportion of Type III trials. For instance, at p=.25, Type II trials constitute 25% of all p trials, and Type III the remaining 75%; at p=.50, Type II trials are 50% of p trials, and Type III trials the other 50% , and so on.

The probability values that were selected for study were presented in sequence. A few p values were presented in a descending sequence, starting at p=1.0; subsequently, the same values and several other were presented in an ascending sequence, terminating at p=1.0.

Descending sequence. The values investigated in this sequence were p=1.0, p=.95, and p=.90. Each of these values was in effect for a predetermined number of sessions before changing to the next value. The reinforcement contingencies under the p=1.0 condition were scheduled similarly as for any other p condition, with punched tapes randomly assigning reinforcement of red choices on 50% of the sessions' trials (FR 1) component, and for green choices on the other 50% of the trials (p component). It is important to emphasize that the p=1.0 value results in total overlap of the p and FR 1 components Therefore, this value provided a control condition to asses the effects of requiring differential center key behavior at $p < 1$ values.

Ascending sequence. Following the last session at p=.90 of the descending sequence, the animals were switched to an ascending sequence of probability values, starting at $p=.025$. Thereafter, the value of $p$ was increased after a criterion of 25 sessions at a given $p$ values had been met. The values and their order of presentation were as follows: $p=.025$, $p=.10$, $p=.25$, $p=.50$, $p=.60$, $p=.75$, $p=.90$, and $p=1.0$. The last two values within this sequence represent redetermination points. Table 2 summarizes the exposure to descending and ascending $p$ values given each bird, and the number of sessions at each value.

Because only the value of the $p$ component was changed, whereas the FR 1 component was constant, the different conditions of the experiment will often be identified by reference to the $p$ value only. For instance, reference to the results from alternating an FR 1 center key requirement with a $p$ requirement at a $p=.25$ value will be referred to as the results under the $p=.25$ condition.

Experimental sessions were conducted 7 days a week, whenever the birds were within ±15 g of their ad lib weight. During the early part of the ascending condition, 5 of the 6 birds were frequently overweight and were run every other day. Reinforcement duration was then adjusted for these birds, so that their 80% weights were maintained daily. Under these conditions, supplemental food was required by most birds at the end of the session. A summary of the reinforcement durations that were used with each bird is also included in Table 2.

Table 2. Probability values in the order given to each bird. Reinforcement (SR) duration (in seconds) for different sessions is indicated.

| B147 | | | B128 | | | B145 | | |
|---|---|---|---|---|---|---|---|---|
| P | SESSIONS | $S^R$ | P | SESSIONS | $S^R$ | P | SESSIONS | $S^R$ |
| 1.0 | 1 - 10 | 2.5 | 1.0 | 1 - 10 | 2.5 | 1.0 | 1 - 10 | 2.5 |
| .025 | 1 - 3 | 2.5 | .95 | 1 - 9 | 2.5 | .95 | 1 - 10 | 2.5 |
| | 4 - 13 | 3.0 | .025 | 1 - 9 | 2.5 | .90 | 1 - 7 | 2.5 |
| | 14 - 17 | 2.5 | | 10 - 15 | 2.0 | .025 | 1 - 9 | 2.5 |
| | 18 - 25 | 1.75 | | 16 - 25 | 1.75 | | 10 - 17 | 2.0 |
| .10 | 1 - 16 | 1.75 | .10 | 1 - 25 | 1.75 | | 18 - 25 | 1.75 |
| | 17 - 25 | 2.0 | .25 | 1 - 3 | 1.75 | .10 | 1 - 25 | 1.75 |
| .25 | 1 - 10 | 2.25 | | 4 - 25 | 1.85 | .25 | 1 - 25 | 1.75 |
| | 11 - 25 | 2.75 | .50 | 1 - 25 | 1.85 | .50 | 1 - 25 | 1.75 |
| .50 | 1 - 25 | 2.75 | .60 | 1 - 25 | 1.85 | .60 | 1 - 25 | 1.75 |
| .60 | 1 - 25 | 2.75 | .75 | 1 - 25 | 1.85 | .75 | 1 - 25 | 1.75 |
| .75 | 1 - 25 | 2.75 | .90 | 1 - 15 | 1.85 | .90 | 1 - 25 | 1.75 |
| .90 | 1 - 25 | 2.75 | | 16 - 25 | 1.89 | 1.0 | 1 - 25 | 2.5 |
| 1.0 | 1 - 25 | 2.75 | 1.0 | 1 - 25 | 1.89 | 1.0 | 1 - 25 | 2.5 |

| B146 | | | B127 | | | B150 | | |
|---|---|---|---|---|---|---|---|---|
| P | SESSIONS | $S^R$ | P | SESSIONS | $S^R$ | P | SESSIONS | $S^R$ |
| 1.0 | 1 - 10 | 2.5 | 1.0 | 1 - 10 | 2.5 | 1.0 | 1 - 3 | 2.5 |
| .95 | 1 - 10 | 2.5 | .95 | 1 - 8 | 2.0 | | 4 - 10 | 3.0 |
| .90 | 1 - 9 | 2.5 | .90 | 1 - 6 | 2.0 | .95 | 1 - 10 | 3.0 |
| .025 | 1 - 9 | 2.5 | .025 | 1 - 10 | 2.5 | .90 | 1 - 6 | 3.0 |
| | 10 - 16 | 2.0 | | 11 - 18 | 2.0 | .025 | 1 - 11 | 3.0 |
| | 17 - 19 | 1.7 | | 19 - 25 | 1.75 | | 12 - 25 | 2.25 |
| | 20 - 25 | 2.0 | .10 | 1 - 25 | 1.75 | .10 | 1 - 25 | 2.25 |
| .10 | 1 - 25 | 2.0 | .25 | 1 - 10 | 1.75 | .25 | 1 - 25 | 2.25 |
| .25 | 1 - 3 | 2.0 | | 11 - 25 | 2.0 | .50 | 1 - 25 | 2.25 |
| | 4 - 16 | 2.25 | .50 | 1 - 25 | 2.0 | .60 | 1 - 25 | 2.25 |
| | 17 - 25 | 3.0 | .60 | 1 - 25 | 2.0 | .75 | 1 - 25 | 2.25 |
| .50 | 1 - 25 | 3.0 | .75 | 1 - 25 | 2.0 | .90 | 1 - 25 | 2.25 |
| .60 | 1 - 25 | 3.0 | .90 | 1 - 25 | 2.0 | 1.0 | 1 - 25 | 2.25 |
| .75 | 1 - 25 | 3.0 | 1.0 | 1 - 25 | 2.0 | | | |
| .90 | 1 - 25 | 3.0 | | | | | | |
| 1.0 | 1 - 25 | 3.0 | | | | | | |

## Results and Discussion.

For an overall view of the effects of the probability manipulation on the animals' discriminative performance, it will be convenient to show the data in the form of Receiver-Operating-Characteristic (ROC) plots, used in studies of the detectability of signals (McNicol, 1972). In such studies, given a discrimination task which involves two different stimuli, S1 and S2, two different responses, R1 and R2, and two different outcomes, reinforcement and non-reinforcement, the ROC plot shows the conditional probability of R1 given that S1 was presented (a "hit"), against the conditional probability of R1 given that S2 was presented (a "false alarm"). Similar conditional probabilities can be calculated for R2 given S1 and S2, and are the complement to those for R1 given S1 and S2. At each value of the variable under study, the proportion of hit and false alarm responses is determined, to yield one point of the ROC curve. With several such points, an ROC plot can indicate changes in either discrimination level, response bias, or both, with changes in the independent variable.

For this experiment, the FR 1 component will be arbitrarily identified with S1, and the p component with S2, whereas red, and green choices will be identified with R1, and R2, respectively. In ROC plots like those in

Figures 3 through 5, the positive diagonal is represented by a straight line connecting the points with coordinates (0,0) and (1,1). Points along this diagonal represent no discrimination, or chance responding with respect to S1 and S2. The negative diagonal is represented by the straight line connecting the points with coordinates (1,0), and (0,1). Points along this line indicate the absence of bias, which is the tendency for one choice response to occur more frequently given either S1 or S2.

For instance, when the proportion of hits, or red choices given FR 1 [P(red/FR 1)], is plotted against the proportion of false alarms, or red choices given p [P(red/p)], at each probability value of the p component, points along the positive diagonal will indicate that the likelihood of choosing the red side key was the same after the FR 1 or the p component, e.g., chance responding. Points above the positive diagonal represent above chance accuracy levels. Therefore, the discrimination between the FR 1 and the p component will increase to the extent that the data points depart from the positive diagonal, toward the upper left corner. Perfect discrimination is represented by a point with (1,0) coordinates. With respect to bias, points along the negative diagonal will represent equal likelihood of correct choices after the FR 1 and the p component, that is, equal bias toward either side key color. Response bias increases to the extent that the data points depart from the negative diagonal. Total bias toward the red side key is indicated by (1,1) coordinates; total bias toward the green side key is represented by (0,0) coordinates. Note that, under the conditions of this experiment, an animal may also exhibit a bias toward either the left or the right side key. Such bias is not precisely indicated in the ROC plots that will be presented. However, position preferences will be examined in a later portion of the results section.

The ROC plots in Figure 3, show the proportion of hits in FR 1, e.g. correct responses in the FR 1 component [P(red/FR 1)], against the proportion of false alarms, e.g., errors in the p component [P(red/p)]. The figure shows that the discrimination with respect to the FR 1 component was at the highest level at $p$=.025, with very slight, or no associated bias. For all animals, the proportion of hits is at or above 90% and for some animals the point falls near perfect discrimination, e.g. B127 and B145. However, with increases in the probability value, all subjects showed a decrease in the discrimination. For most animals, discrimination fell at, or near, chance level at probability values larger than $p$=.60, although some animals, like B127 and B128, show points at a relatively larger distance from chance responding at $p$ values as high as $p$=.75 and $p$=.90.

Figure 3. Receiver Operating Characteristic (ROC) plots with respect to FR 1, at different p values, for each animal. The conditional probability of choosing the red side key given that an FR 1 trial was presented [P(red/FR 1)], was plotted against the conditional probability of a red side key choice given that a p trial was presented [P(red/p)].

Each point in these plots represents the mean from the last 10 sessions at a p value. The value of p is indicated next to each point.

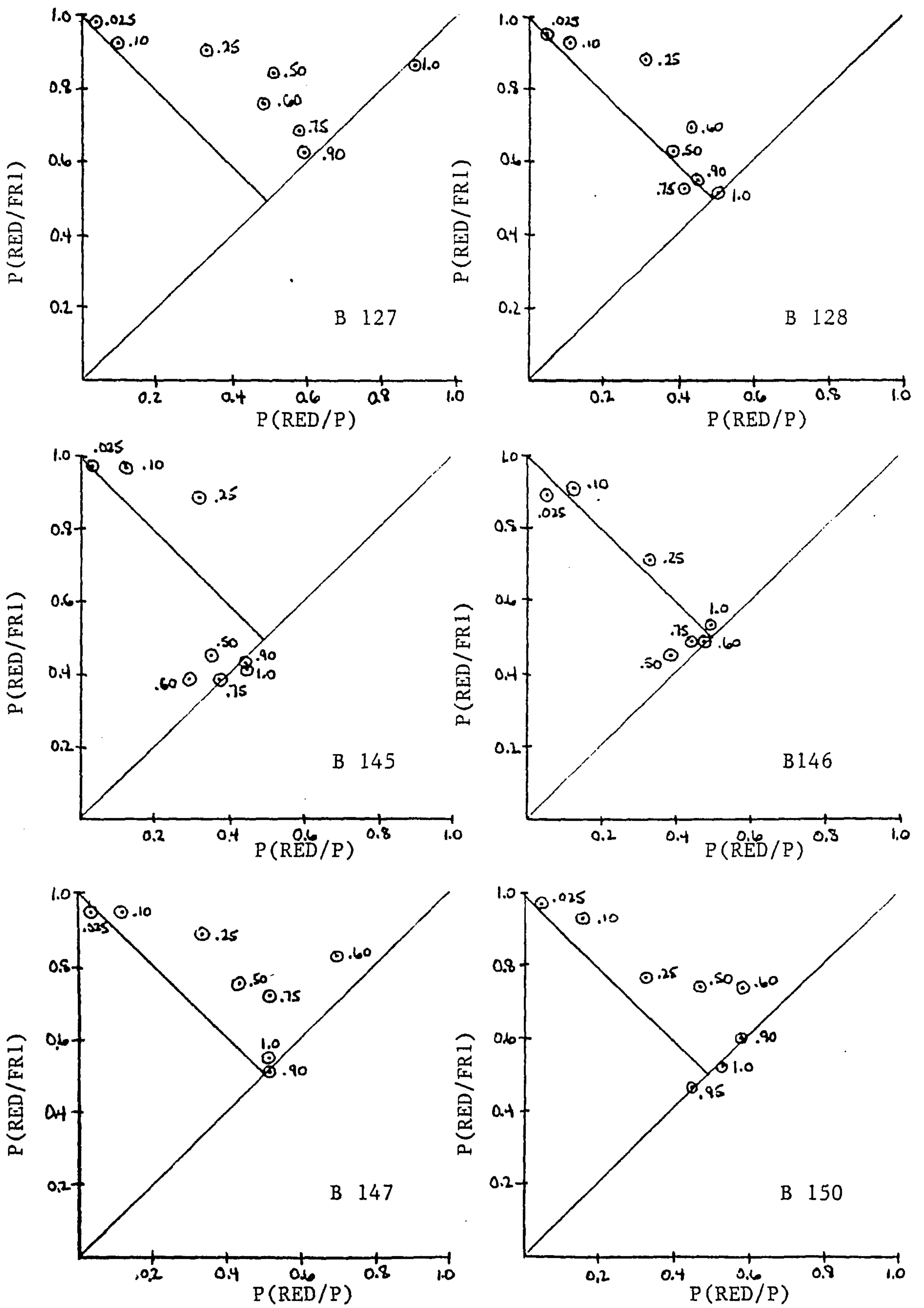

B 127
B 128
B 145
B146
B 147
B 150
P(RED/FR1)
P(RED/P)
1.0
0.8
0.6
0.4
0.2
.025
.10
.25
.50
.60
.75
.90
.95
1.0

Figure 3

In addition, the plots in Figure 3 also show that all animals exhibited an increase in bias, with increases in p value. Five animals showed an increase toward the red side key. This color bias tended to decrease at values above p=.60, toward an equal probability of choice of either the red or the green side key, at the larger p values. Only B145 and B146 showed a bias toward the green side key at p=.50, and subsequent p values. For B145, the shift in color bias represented a large change, from a red bias at p=.25 - where the proportion of hits was near 90% - to a green bias, and a hit rate below 50%. For B146, it represented a change from virtually no color bias and a hit rate of 70% at p=.25, to a green bias and a drop to below 50% hit rate. Therefore, these two birds exhibited the largest drop in discrimination level at an earlier value in the sequence of p values.

The discrimination with respect to the p component was also examined in the ROC plots shown in Figures 4 and 5. Note that the plots in Figure 3 showed the FR 1 discrimination against all types of trials in the p component. However, since the p component contained both, an indiscriminable requirement from FR1, i.e., RL 1 trials, as well as a discriminable requirement, i.e., RL> 1 trials, therefore, the discrimination with respect to the p component was examined in separate plots. First, the ROC plots in the right column of Figures 4 and 5 show data for

Figure 4. Receiver Operating Characteristic (ROC) plots for birds B127, B128 and B145, with respect to the p component broken down into two run length (RL) categories: single peck (RL 1), and multiple-peck (RL> 1).

Left-column ROC plots show the conditional probability of a green side key choice given that a RL 1 trial was presented [P(green/RL 1)], against the conditional probability of a green side key choice given that an FR 1 trial was presented [P(green/FR 1)].

Right-column ROC plots show the conditional probability of a green side key choice given that a RL> 1 trial was presented [P(green/RL> 1)], against the conditional probability of a green side key choice given that an FR 1 trial was presented [P(green/FR 1)].

Each point in these plots represents the mean from the last 10 sessions at a p value. The value of p is indicated next to each point.

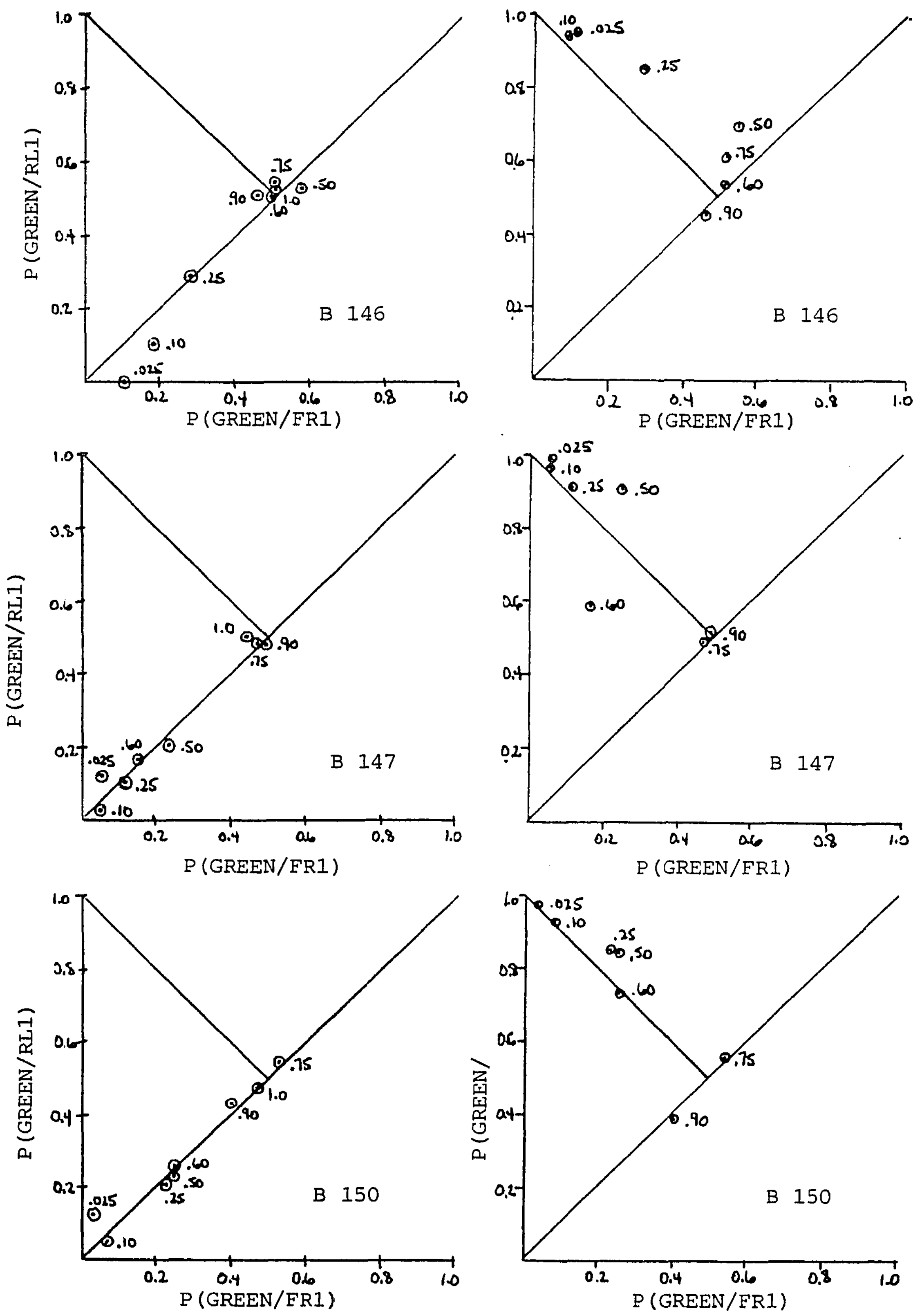

P(GREEN/RL1)
P(GREEN/FR1)
1.0
0.8
0.6
0.4
0.2
B 146
.75
.90
1.0
.60
.50
.25
.10
.025
.10
.025
.25
.50
.75
.60
.90
B 147
1.0
.90
.75
.60
.50
.25
.10
.025
.025
.10
.25
.50
.60
.90
.75
B 150
.75
1.0
.90
.60
.50
.25
.025
.10
P(GREEN/
.025
.10
.25
.50
.60
.75
.90

Figure 4

Figure 5. Receiver Operating Characteristic (ROC) plots for birds B146, B147 and B150, with respect to the *p* component broken down into two run length (RL) categories: single peck (RL 1), and multiple-peck (RL> 1).

*Left-column ROC plots* show the conditional probability of a green side key choice given that a RL 1 trial was presented [P(green/RL 1)], against the conditional probability of a green side key choice given that an FR 1 trial was presented [P(green/FR 1)].

*Right-column ROC plots* show the conditional probability of a green side key choice given that a RL> 1 trial was presented [P(green/RL> 1)], against the conditional probability of a green side key choice given that an FR 1 trial was presented [P(green/FR 1)].

Each point in these plots represents the mean from the last 10 sessions at a *p* value. The value of *p* is indicated next to each point.

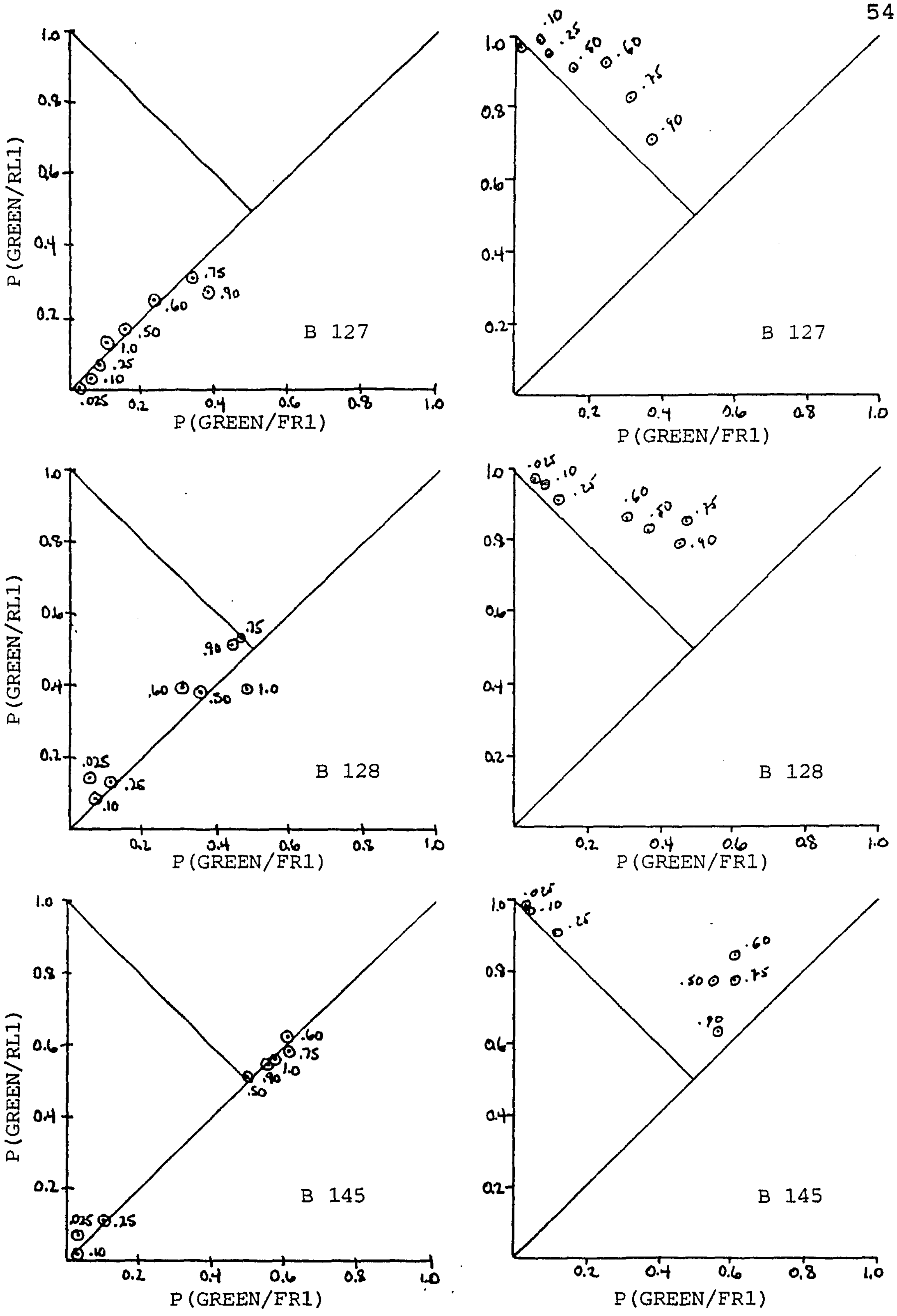

P (GREEN/RL1)
P (GREEN/FR1)
1.0
0.8
0.6
0.4
0.2
B 127
.025
.10
.25
1.0
.50
.60
.75
.90
B 128
.025
.10
.25
.60
.50
1.0
.90
.75
B 145
.025
.10
.25
.50
.90
1.0
.75
.60

Figure 5

multiple peck trials in the form of hit rate, or the proportion of green choices given RL> 1 trials, against the false alarm rate, or the proportion of green choices given FR 1 trials, across *p* values, for each animal; second, the ROC plots in the left column of Figures 4 and 5 show data for single peck trials in the form of hit rate, or the proportion of green choices given RL 1 trials, against the false alarm rate, or the proportion of green choices given FR 1 trials, across *p* values, for each animal. Every point in the ROC curves in Figures 3 through 5 represents the mean of the last 10 sessions, at each *p* value of the *p* component. The results shown in the left column of Figures 4 and 5 for the identical center key requirements, e.g., a single peck from the FR 1 requirement, and a single peck (RL1) from the *p* requirement, will be discussed first.

In looking at the ROC plots in the left column, it is worth remembering the reinforcement conditions. On single peck trials, if the single peck was generated by the FR 1 component, a red choice was reinforced; whereas a green choice was reinforced if the single peck was generated by the *p* component. The ROC plots in Figures 4 and 5 show that, for each animal, all points lie at, or near the positive diagonal. That is, at a given value of the *p* component, the likelihood of choosing the green side key was nearly equal after either an FR 1 trial or a RL 1 trial. That is, no animal showed evidence of discrimination between the RL 1 requirement of the p component, and the FR 1 component. On the other hand, the changing locus of the points along the positive diagonal also indicate that changes in p value resulted in a systematic shift in color bias on single peck trials. That is, whereas at small p values red choices were highly likely after either FR 1 or RL 1, with increases in p value the proportion of red choices decreased for all animals; the points in most animals' ROC plots approach the negative diagonal, or equal bias line, where the green side key is chosen equally often as the red side key. However, the plots for B145 and B146 show a further decrease in red choices with a bias toward green choices; this shift in bias is shown at p component values of p=.50 and above. Therefore, even though no discrimination was exhibited between types of single peck trials (FR 1 and RL 1), the likelihood of a green or a red choice, given a single peck, was not random, e.g. it was not equal 50% at all p values. Rather, after FR 1 or RL 1 trials the most likely choice was a red choice - above 90% of the trials - at small p component values, e.g., p=.025, p=.10. The likelihood of a red choice decreased with increases in p value, and for most animals tended to approach equality with green choices, e.g., approach the 50% level, at the larger p values, particularly at p=1.0. Only B145, and to a lesser extent, B146, showed an earlier shift (at p=.50), toward a greater proportion of green choices; B145 remained biased toward green choices, even at p=1.0, where reinforcement was scheduled with equal frequency for red and green choices. B146, on the other hand, approached random responding on single peck trials at the p component value of p=.60.

The ROC plots on the right columns of Figures 4 and 5 plot the proportion of hits, or green choices on RL> 1 trials, against the proportion of false alarms, or green choices on FR 1 trials. The figures show that discrimination of the RL> 1 portion of the p component was near perfect at p=.025, and that for all six animals increasing the p value in the p component resulted in decreases in the discrimination of RL> 1 trials. Unlike the FR 1 discrimination shown in Figure 3, however, three animals did not reach chance responding on RL> 1 trials even at the largest p value of p=.90; whereas those animals who reached chance responding show that their proportion of correct choices on RL> 1 was generally higher than that on FR 1. Compare for instance the plots for B150 at p=.50 in Figures 3 and 5. There are indications, therefore, that the likelihood of correct choices on RL> 1 trials was generally at a higher level than that exhibited on FR 1. With respect to bias, performance in RL> 1 showed lower levels relative to those in FR 1. For instance, most animals were essentially unbiased to color, at probabilities up to p=.25. With further increases in p value, moderate increases in bias are seen for all animals, the largest green bias was exhibited by B145 at values above p=.25.

In summary, the conditional discrimination that was prescribed by the contingencies of reinforcement, was established within the lower range of probability values of the p component. That is, the likelihood of red choices was high after a single peck (FR 1 and RL 1), as shown in Figure 3 and left column of Figures 4 and 5; whereas the likelihood of green choices was high after a RL> 1, as shown in the right column of Figures 4 and 5. However, increases in the value of the p component resulted in both, a decrease in all animals' discriminative performance on the colored side keys, and an increase in color bias, particularly the red side key, e.g., larger proportion of red choices after both, FR 1 and p trials. The only two birds who exhibited a shift toward a green bias early in the sequence of p values, also exhibited the largest decrease in discrimination levels.

The plots in the left column of Figures 4 and 5 also show that, as expected, the animals did not discriminate between a single peck from the FR 1 component, and a single peck from the p component.

To examine how changes in the probability value of the p component resulted in the decline of the animals discriminative performance, as well as to determine the possible sources of the obtained bias, a detailed analysis of the animals' performance at each p value will be presented next.

### Descending sequence

Figure 6 and Figure 7 present three measures of the animals' performance under the descending sequence of probability values. The top panel of these figures shows the obtained overall accuracy at the various probability values as a function of sessions. Each point in the overall accuracy function is the mean of two values, the percentage of correct choices associated to the FR 1 component (Type I trials), and the percentage of correct choices associated to the p component (Type II and Type III trials combined). Accuracy of choice was also plotted, separately, for each center key component in the middle panel of Figures 6 and 7, which contains two functions for each animal,at the various p values as a function of sessions. The triangles represent the percentage of Type I trials in which correct (red) choices were made after the FR 1 center key component; the circles represent the percentage of Type II and Type III trials, combined, in which a correct (green) choice was made after the p center key requirement. Perfect conditional control of choice by center key behavior is indicated when the accuracy functions for both response requirements, FR 1 and p, reach 100%. On the other hand, accuracies simultaneously close to 100% for one component and close to 0% for the other component, represent color preference; i.e., indicate that one color is being chosen regardless of the antecedent behavior on the center key. The functions in the bottom panel of Figures 6 and 7 are plots of the percentage of Type I trials in which an animal made a left key choice (triangles), and the percentage of Type II and Type III trials in which a left key choice was made after the p requirement (circles). In these plots, deviations above or below 50% represent a position preference; i.e., indicate that one key position is being chosen- the left and the right key, respectively- regardless of center key behavior.

On the p=1.0 condition, only Type I (FR 1) and Type II (RL 1) trials occurred in each session (see Figures 1 and 2). Therefore, the pattern of choice that emerged under this condition cannot be related to the differences between the antecedent center key requirements. Thus, if accuracy of choice under the p=1.0 condition were at higher than chance level, i.e, higher than 50%, it would indicate that the experimental arrangement provided cues to the animals other than center key requirement, as a basis for correct choice responding.

The functions on the top panel of Figures 6 and 7 show, instead, that overall accuracy of choice was below 50% for all animals on the first session at p=1.0. On

Figure 6. Daily data for B128, B150 and B146.

The <u>top panel</u> shows one function for each animal. The mean percent correct choices in all types of trials (overall accuracy), as a function of sessions.

The <u>middle panel</u> shows two accuracy functions for each animal, one for each center key component (FR 1 and p). The points connected by triangles represent the mean percent correct choices on Type I trials (FR 1 component), and the points connected by circles represent the mean percent correct choices on Type II and Type III trials combined (<u>p</u> component).

The <u>bottom panel</u> shows two left- key functions for each animal, one for each center key component (FR 1 and p). The triangles represent the mean percent choices of the left side key on Type I trials (FR 1 component), and the circles represent the mean percent choices of left side key on Type II and Type III trials combined (<u>p</u> component). See text for details.

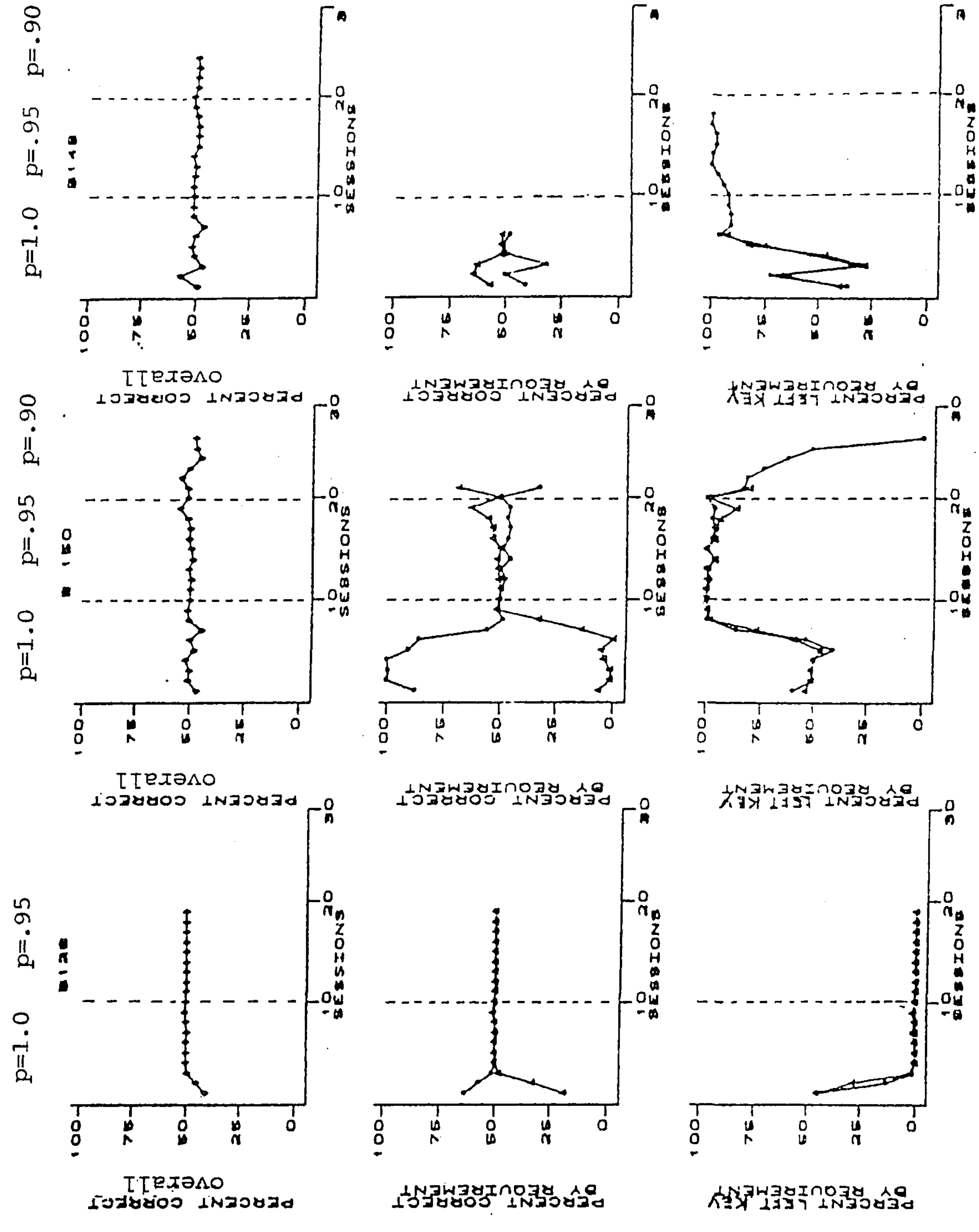

p=1.0 p=.95
p=1.0 p=.95 p=.90
p=1.0 p=.95 p=.90
PERCENT CORRECT overall
PERCENT CORRECT BY REQUIREMENT
PERCENT LEFT KEY BY REQUIREMENT
SESSIONS
0
10
20
30
25
50
75
100

Figure 6

Figure 7. Daily data for birds B145, B127 and B147.
The top panel shows one function for each animal. The mean percent correct choices in all types of trials (overall accuracy), as a function of sessions.

The middle panel shows two accuracy functions for each animal, one for each center key component (FR 1 and p). The points connected by triangles represent the mean percent correct choices on Type I trials (FR 1 component), and the points connected by circles represent the mean percent correct choices on Type II and Type III trials combined (p component).

The bottom panel shows two left-key functions for each animal, one for each center key component (FR 1 and p). The triangles represent the mean percent choices of the left side key on Type I trials (FR 1 component), and the circles represent the mean percent choices of left side key on Type II and Type III trials combined (p component). See text for details.

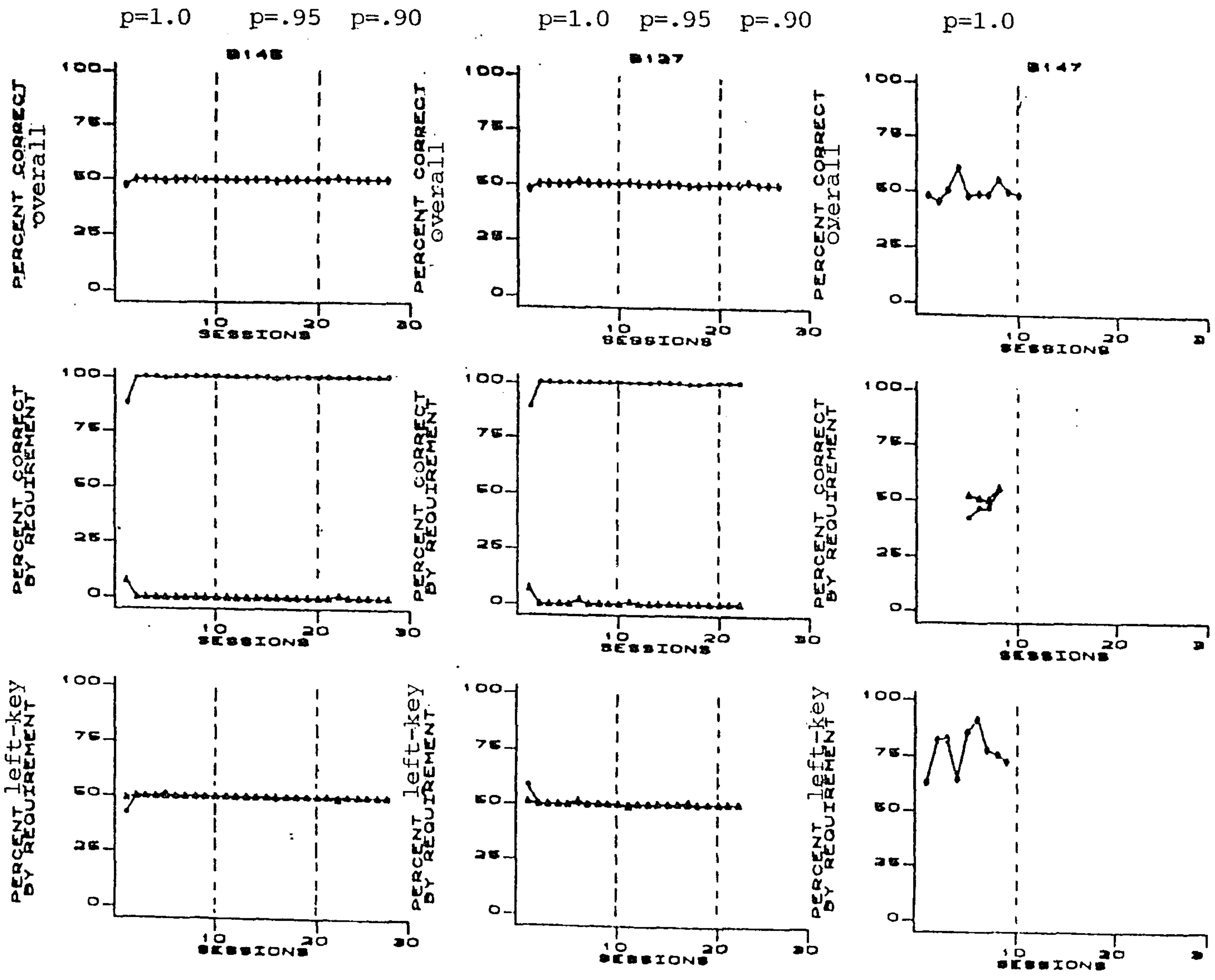

p=1.0
p=.95
p=.90
B148
p=1.0
p=.95
p=.90
B127
p=1.0
B147
PERCENT CORRECT overall
PERCENT CORRECT BY REQUIREMENT
PERCENT left-key BY REQUIREMENT
0
25
50
75
100
10
20
30
SESSIONS

Figure 7

subsequent sessions, accuracy remained at, or near the 50% level. The only observed increases above this level were of a transient nature, such as those occurring during the fourth and eighth session for B147 and during the second session for B146to a failure on the trial advancement mechanism, B146 was reinforced for a red choice on the right side for 104 successive trials on the third session, producing a temporary increase in this bird's percentage of right key choices (Figure 6, bottom panel). However, this bird's accuracy on the following sessions did not differ from that of the other animals. In addition, B146 suffered from a respiratory infection and was removed from the experiment between the seventh and the eighth session for 18 days.

On the other hand, the plots of correct and left-key choices by component shown in the bottom panel indicate that, at $p=1.0$, color and position preferences were developed by all animals; this is indicated by either exclusive responding to one color (middle panel), to one side key position (bottom panel), or a combination of both. Thus, B145 and B127 (Figure 7, middle panel) chose exclusively the green side key on 9 out of the 10 sessions. Birds B128, B150, and B146 (Figure 6), showed initial color preference; in subsequent sessions, preference for color decreased in favor of near total preference for one key position. Bird B147, on the other hand, exhibited a combination of preferential responding to color and key position (see Figure 7).

Therefore, the functions for p= 1.0 in Figures 6 and 7 indicate that in the absence of a differential center key requirement on which to base their choices, all animals adopted preferences, where side key choices were governed either by key color or key position, resulting in the observed 50% accuracy level.

The introduction of a differential requirement on the center key was accomplished by contrasting the FR 1 component with decreased values of the p component, one at p=.95 and the other at p=.90. For birds B146 and B147, per component data were lost for some sessions at these p values. For these animals, only overall data functions are shown in Figure 6. At p= .95 and p= .90, the p component generates a small proportion of trials requiring a RL > 1 (Type III trials); these, represent a differential requirement with respect to Type I trials of the FR 1 component (see Figure 2 at p=.90). However, at those p values, the differential requirement failed to acquire discriminative control over subsequent choice behavior. Overall accuracy remained at 50%, indicating that the behavior required under p=.95 and p=.90 did not provide sufficient differential stimulation, from that on FR 1, to develop such control. Instead, the animals' side key choices remained under the control of color or position preferences.

### Ascending sequence

The day after the last session of the descending sequence of p values, the birds were switched to an ascending sequence of probability values, starting at p=.025. Since large changes in accuracy levels occurred on the initial sessions at p=.025, the accuracy obtained during the first seven sessions at this p value was plotted separately in Figure 8. In this figure, the unconnected points represent overall accuracy for individual birds; each point is the mean percentage of correct choices on the FR 1 and the p components combined, for each animal, as a function of sessions. The solid function represents the grouped median overall accuracy.

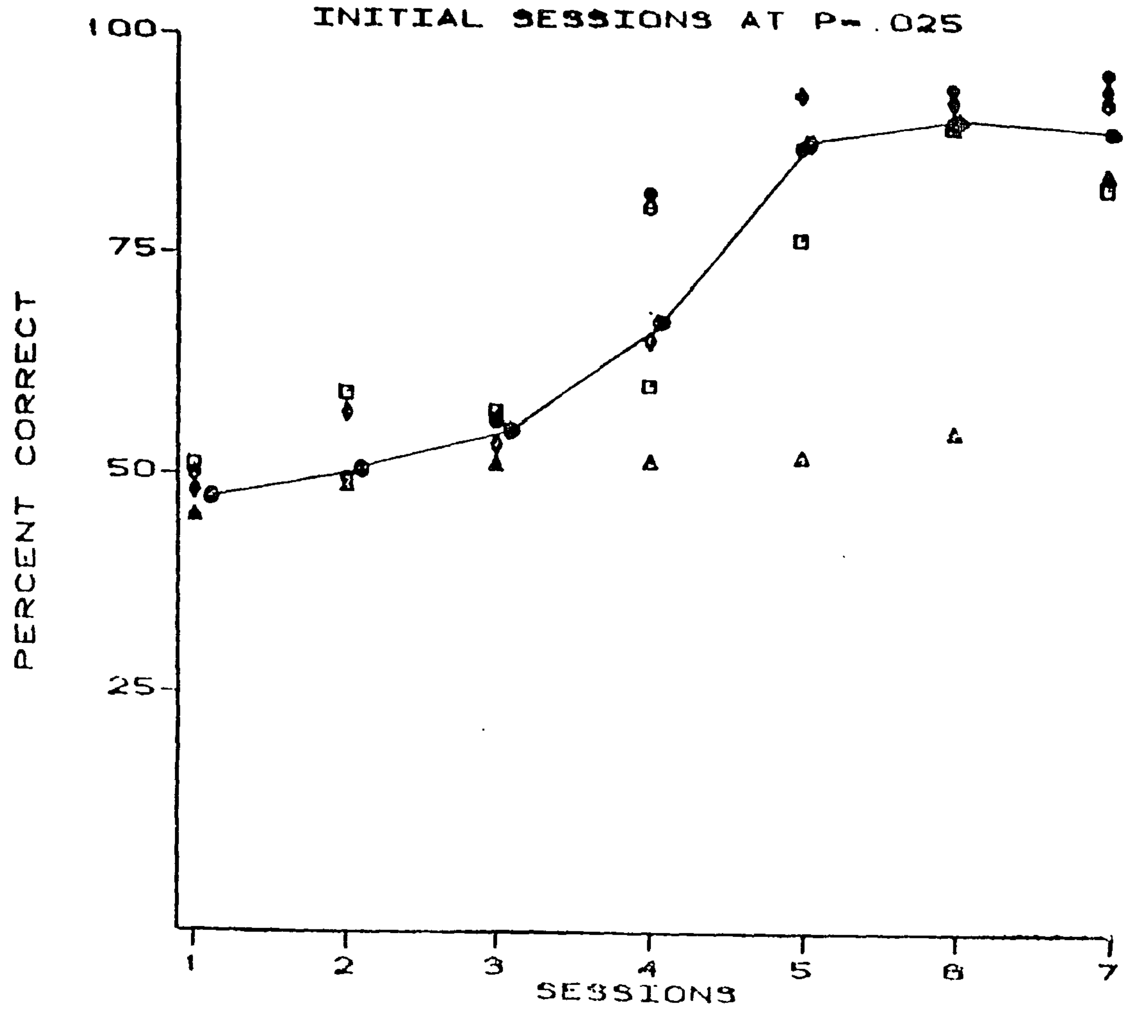
The plot for the initial sessions at p=.025 shows that overall accuracy was at, or below, 50% on the first session, followed by a moderate increase over three subsequent sessions. Thereafter, accuracy showed a steep increase for most animals, reaching an over 85% level by the fifth session. At that point, only B150 and B146 were below that level. By the seventh session B127, B128, and B145 were over 90% accurate, and B150, B146, and B147 were above 80% levels. These results indicate that the center key behavior that was generated by contrasting the FR 1 requirement with a p requirement set at p=.025, acquired discriminative control over choice behavior. Furthermore, this control was in agreement with the reinforcement contingencies. All animals learned to make highly accurate choices of side key color at levels they could have only reached by basing their choices on their antecedent behavior on the center key.

Because overall accuracy is the traditional measure reported in previous relevant studies, the effects that changing the p value had on the animals' discrimination of center key behavior will be first examined in terms of that measure. Furthermore, and even though a decrease in the animals' accuracy of choice is expected, the overall accuracy functions will provide a general answer to the question of what level of accuracy can be maintained when various proportions of discrimination and abolishment trials are combined. As indicated earlier, the frequency of abolishment trials increases as the value of p increases, and they are represented by the RL 1 trials of the p component; they schedule the reinforcement of "errors" with respect to the FR 1 component, i.e., schedule the reinforcement of green choices after a singe peck on the center key.

The changes that were obtained in overall accuracy with changes in the value of the probability component are

Figure 8. First seven sessions of exposure to *p*=.025. The unconnected points represent the individual mean percent correct choices per day. The solid function represents the grouped median overall accuracy, per day.

Figure 8


INITIAL SESSIONS AT P=.025
PERCENT CORRECT
100
75
50
25
SESSIONS
1
2
3
4
5
6
7

first shown in plots of daily accuracy levels as a function of p value. Figure 9 shows the group function at each of the eight p values in the ascending sequence; each function represents the daily median percentage of correct choices in all types of trials, across animals, at a given p value.

Figures 10 through 15 are plots of individual overall accuracy, showing each animal's daily mean percentage of correct choices at each p value. The portion of the function for $p=.025$ that was shown in Figure 8 was omitted in Figures 9 through 15. In addition, the overall accuracy data for $p=.90$ and $p=1.0$ in these figures represent a replication and an extension of those obtained earlier, at these p values, in the descending sequence condition. Future reference to the $p=.90$ and $p=1.0$ data will, henceforth, mean the replication data within the ascending condition, unless otherwise stated.

The group functions in Figure 9 show that changes in the value of the probability component had an orderly effect on the animals' accuracy. Overall accuracy was highest at the smallest p value, $p=.025$; at this value, the function reached an over 95% level and stabilized around a 94% - 96% accuracy range. It is clear that no animal can reach 100% accuracy level, because maximum accuracy at each

Figure 9. Grouped (N=6) median percent correct choices, per day, at each p value. For each animal in the group, correct choices in the FR 1 component were combined with correct choices in the p component (overall accuracy).

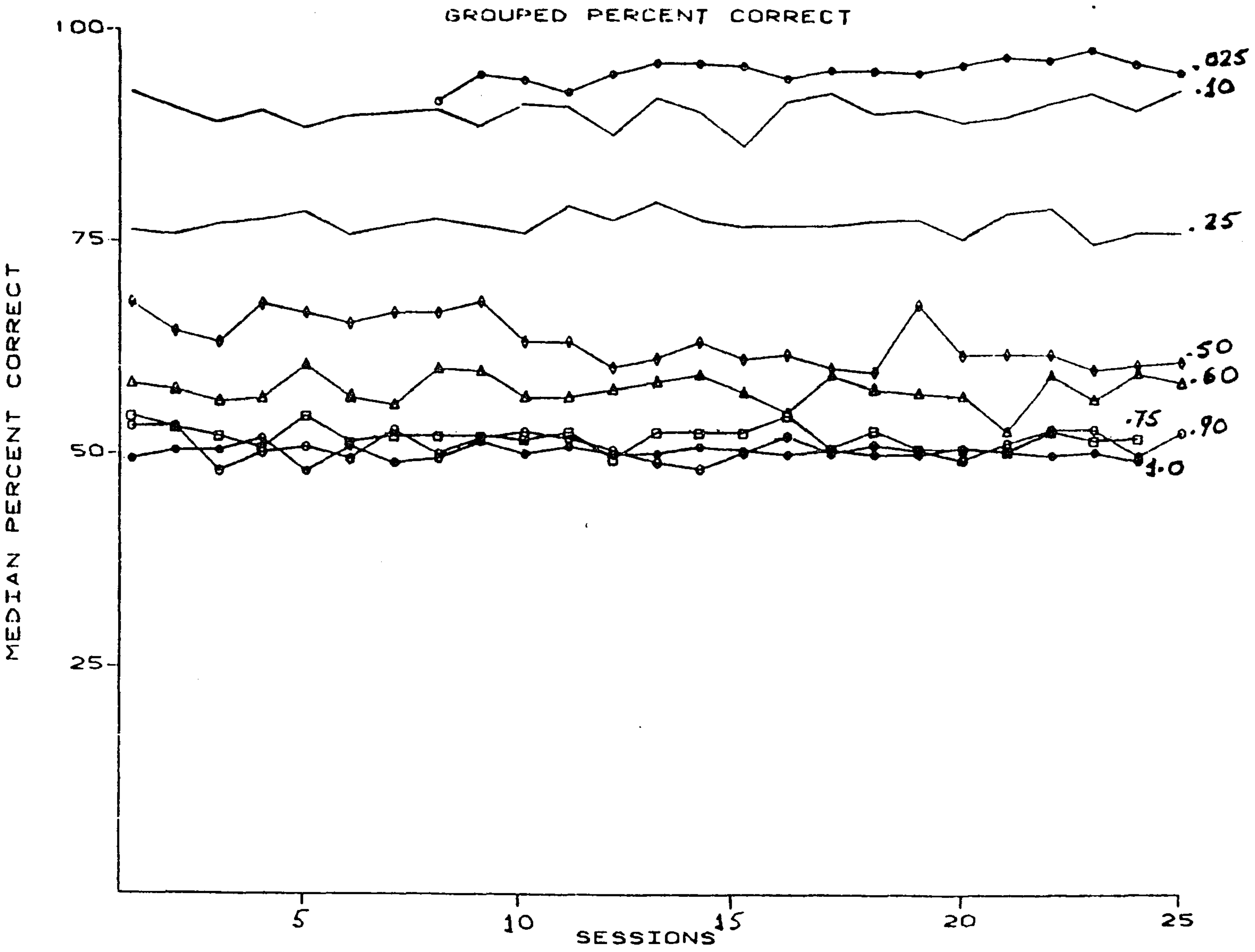

GROUPED PERCENT CORRECT
MEDIAN PERCENT CORRECT
100
75
50
25
5
10
15
20
25
SESSIONS
.025
.10
.25
.50
.60
.75
.90
1.0

Figure 9

p value is limited by the RL 1 element of the p component. Nevertheless, the accuracy levels reached at the smallest p value indicate that, under the circumstances, the animals were performing at, or near, maximum accuracy. As expected, increases in the probability value from $p=.025$ to $p=.60$ resulted in a decrease in overall accuracy for all animals. With further decreases in the p value accuracy decreased even further, with the percentage of correct choices falling to 50% at $p=.75$, $p=.90$ and $p=1.0$. With the exception of the data at these large p values, no overlap was obtained, across p values, in the functions shown in Figure 9. Therefore, the selected p values effectively sampled distinct accuracy levels.

On the other hand, the individual functions in Figures 10 through 15 show that the overall accuracy levels that were attained at the various p values varied across animals. For some animals accuracy fell to 50% late in the sequence of p values, and for others, it deteriorated earlier. In addition, the increasing day to day variability that was observed with increases in p value might suggest some reversals and obscure the trends shown by the group functions. However, when the individual daily mean percentage of correct choices in all types of trials (overall accuracy), is averaged over the last 10 sessions of each p value and plotted as a function of probability, as shown in Figure 16, overall accuracy remained essentially a monotonic function of probability. These individual functions, although not identical, show some striking similarities across animals. For instance, the limits of the functions, that is, the accuracy range covered by the different functions was virtually identical. Thus, at $p$=.025, accuracy was above 95% for five animals, whereas at $p$=1.0 all functions fell to 50%. Also, most animals reached very similar accuracy level for $p$ values below $p$=.50. On the other hand, greater individual differences were obtained in the slope of the functions at the larger $p$ values. The functions are seen to differ, for instance, in the rate at which the animals approximated the asymptotic level. That is, some animals showed a gradual decreasing function, but others exhibited a rather abrupt fall in accuracy. For instance, B146 reached the 50% accuracy level at an earlier point in the sequence of $p$ values than most other birds, which, for B146 resulted in a flat accuracy function for nearly half of the p range. Other animals, like B127, reached the final accuracy level only at the end $p$ value, resulting in a gradual decreasing function. In spite of these differences in reaching an asymptote, no animal reached such asymptote before the probability value was set at $p$=50. Thus, for some animals the asymptote was reached at $p$=.60, and for others a decreasing function was still observed across the upper range of $p$ values, i.e., between $p$=.50 and $p$=1.0. It is

Figure 10. Daily mean percent correct choices for bird B145, in the FR 1, and the _p_ components combined (overall accuracy), at each value of the _p_ component.

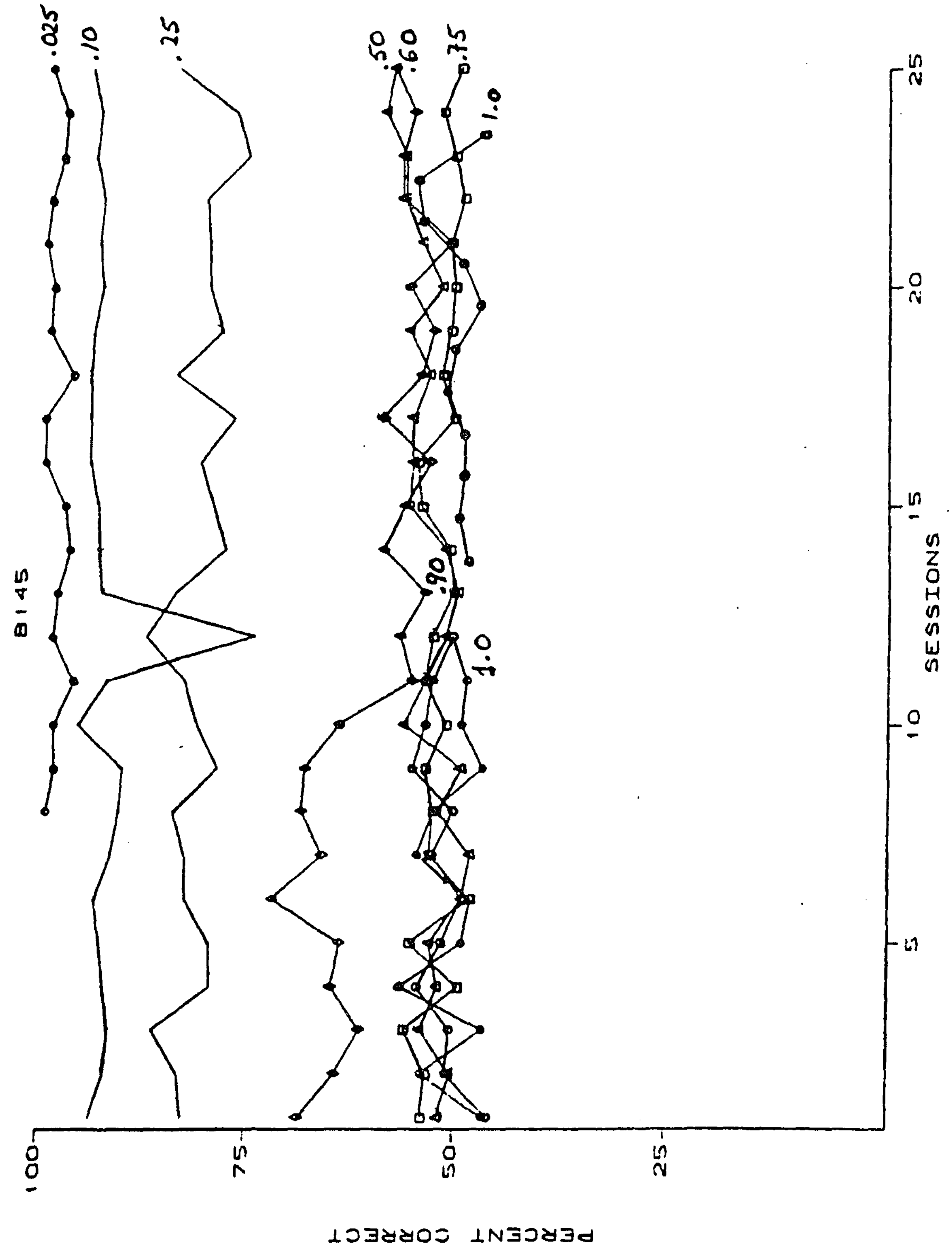

PERCENT CORRECT
100
75
50
25
SESSIONS
5
10
15
20
25
B145
.025
.10
.25
.50
.60
.75
1.0
.90
1.0

Figure 10

Figure 11. Daily mean percent correct choices for bird B127 in the FR 1, and the p components combined (overall accuracy), at each value of the p component.

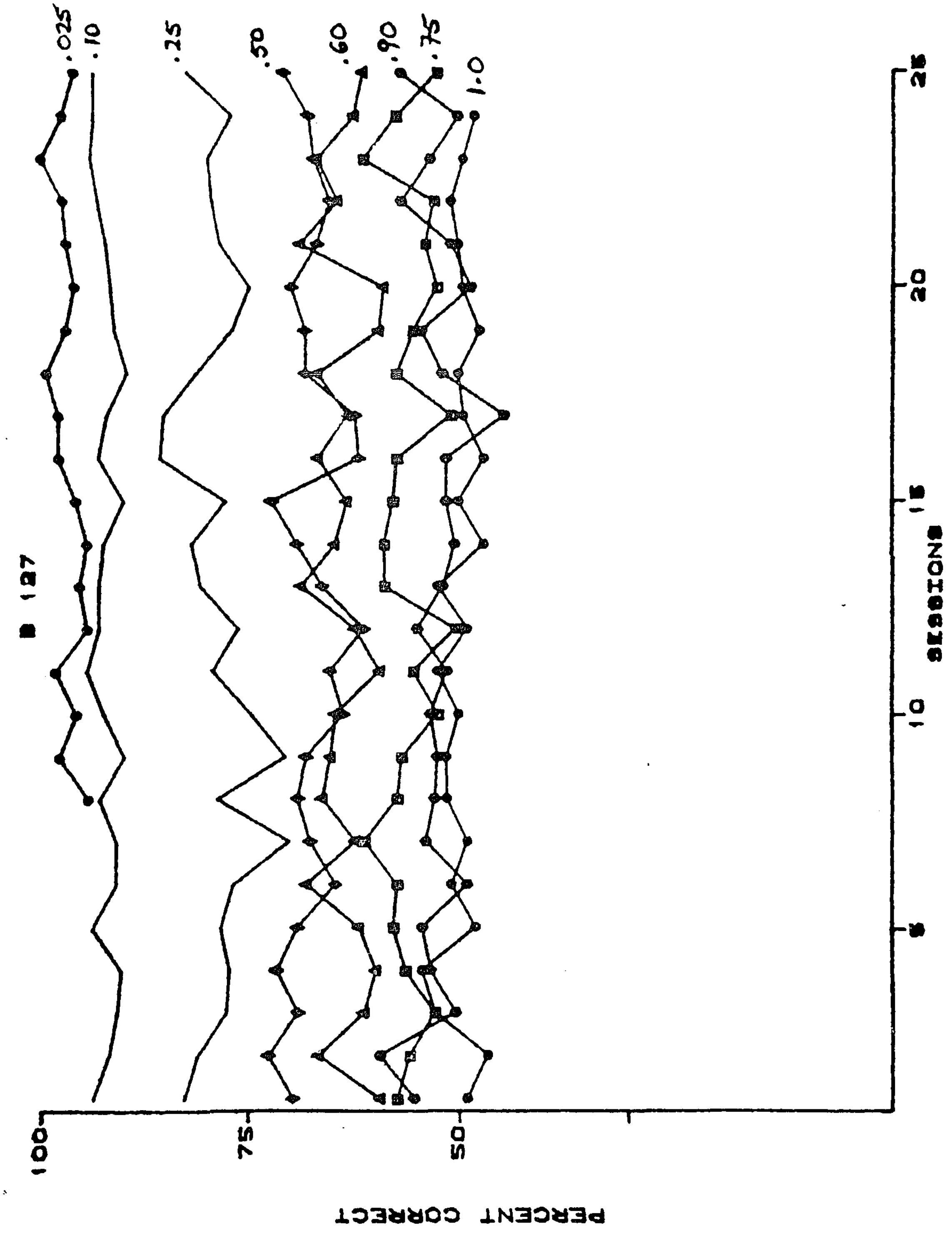

PERCENT CORRECT
100
75
50
SESSIONS
5
10
15
20
25
B 127
.025
.10
.25
.50
.60
.90
.75
1.0

Figure 11

Figure 12. Daily mean percent correct choices for bird B147 in the FR 1, and the *p* components combined (overall accuracy), at each value of the *p* component.

Figure 12

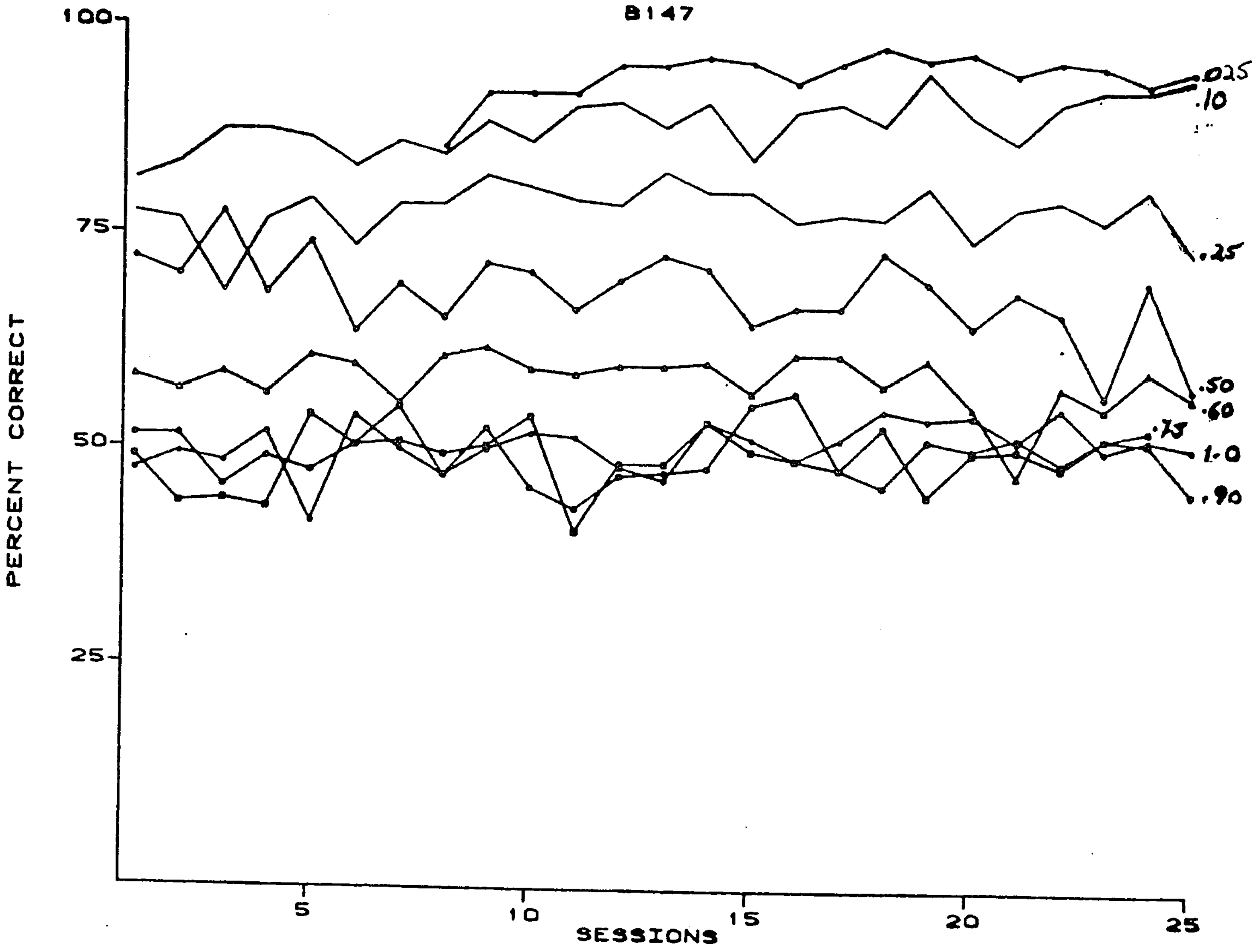

B147
100
75
50
25
PERCENT CORRECT
5
10
15
20
25
SESSIONS
.025
.10
.25
.50
.60
.75
1.0
.90

Figure 13. Daily mean percent correct choices for bird B128 in the FR 1, and the p components combined (overall accuracy), at each value of the p component.

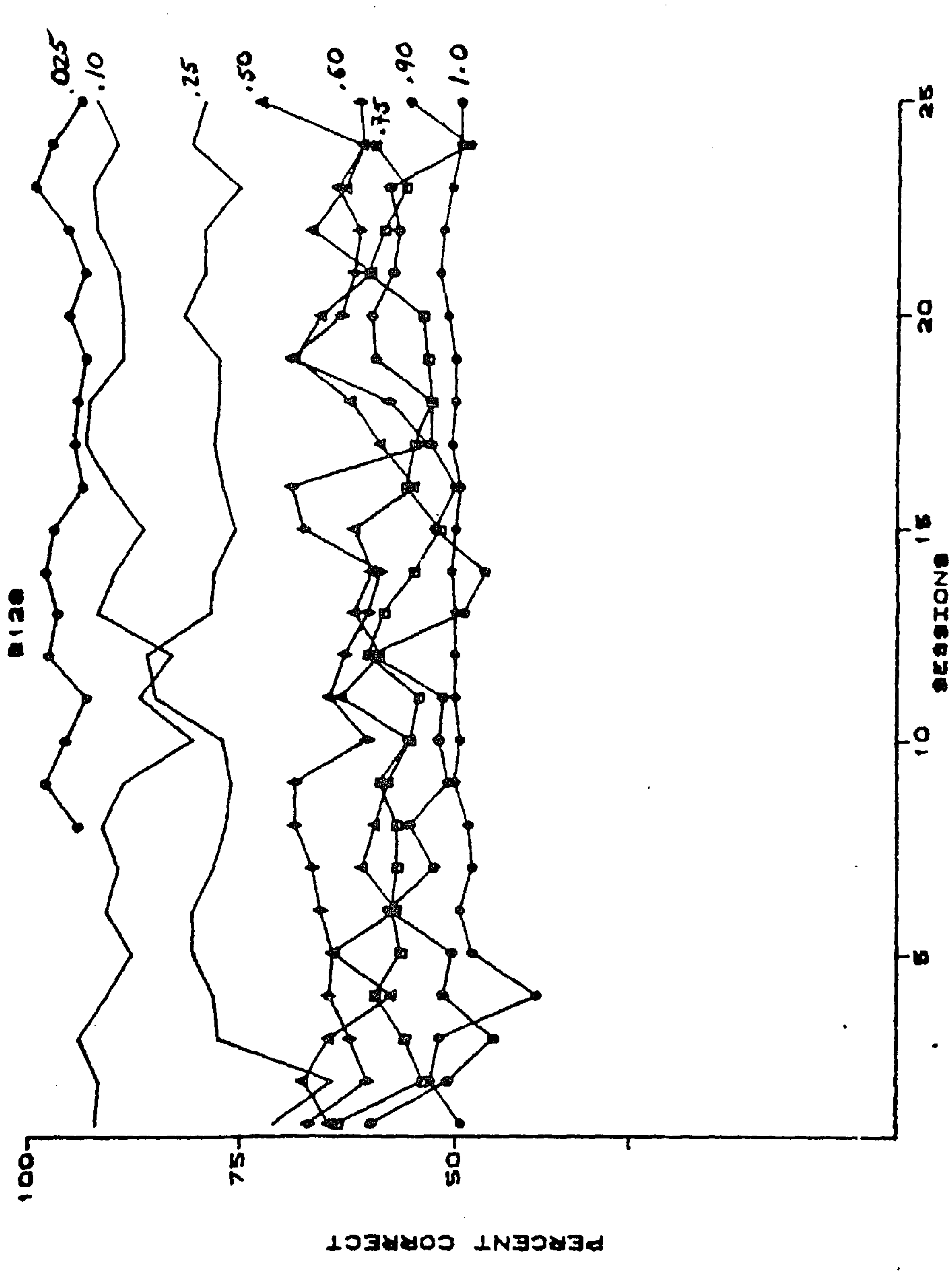

B128
PERCENT CORRECT
100
75
50
SESSIONS
5
10
15
20
25
.025
.10
.25
.50
.60
.75
.90
1.0

Figure 13

Figure 14. Daily mean percent correct choices for bird B150 in the FR 1, and the p components combined (overall accuracy), at each value of the p component.

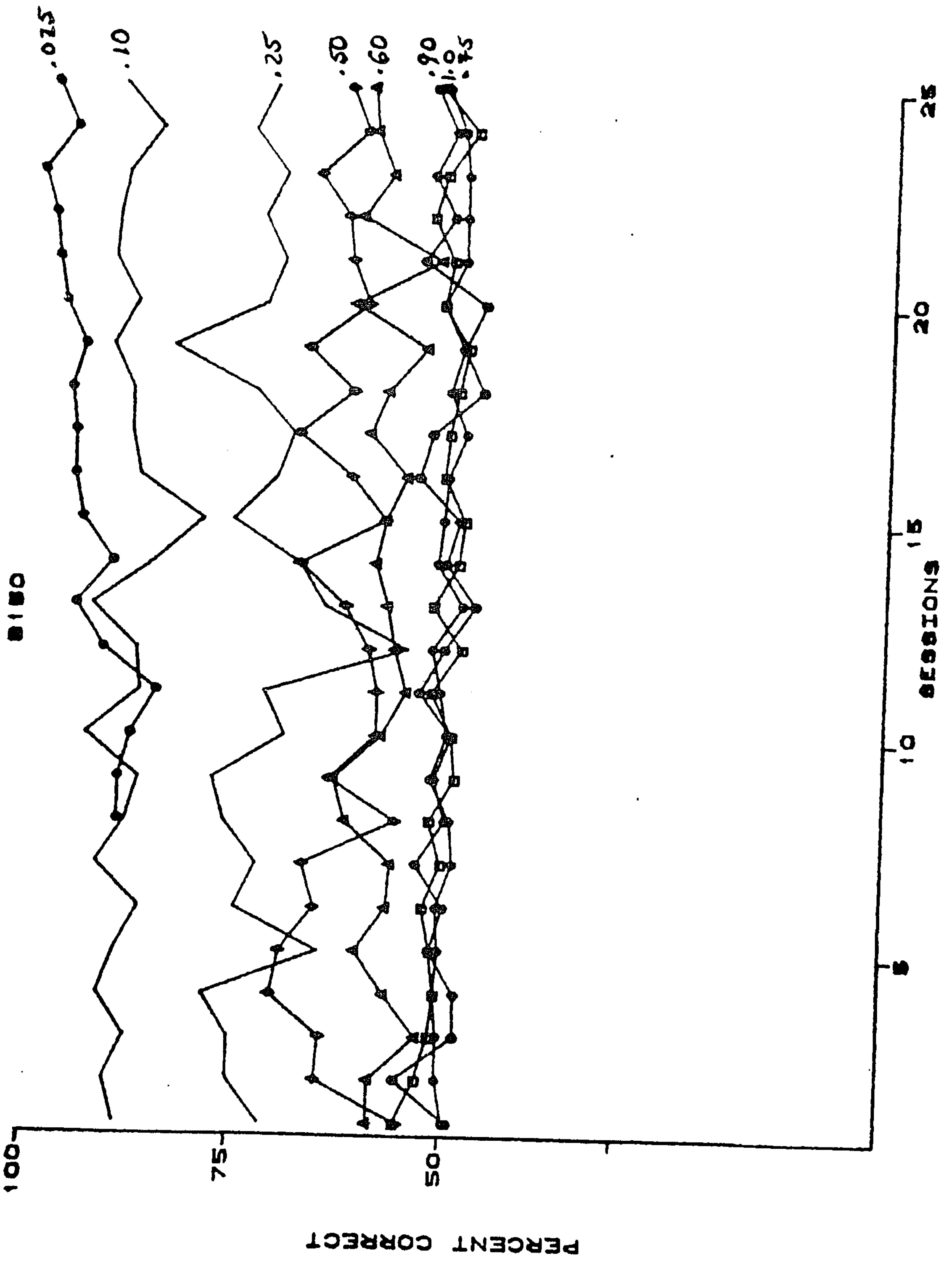

B180
.025
.10
.25
.50
.60
.90
1.0
.75
100
75
50
PERCENT CORRECT
5
10
15
20
25
SESSIONS

Figure 14

Figure 15. Daily mean percent correct choices for bird B146 in the FR 1, and the p components combined (overall accuracy), at each value of the p component.

Figure 15

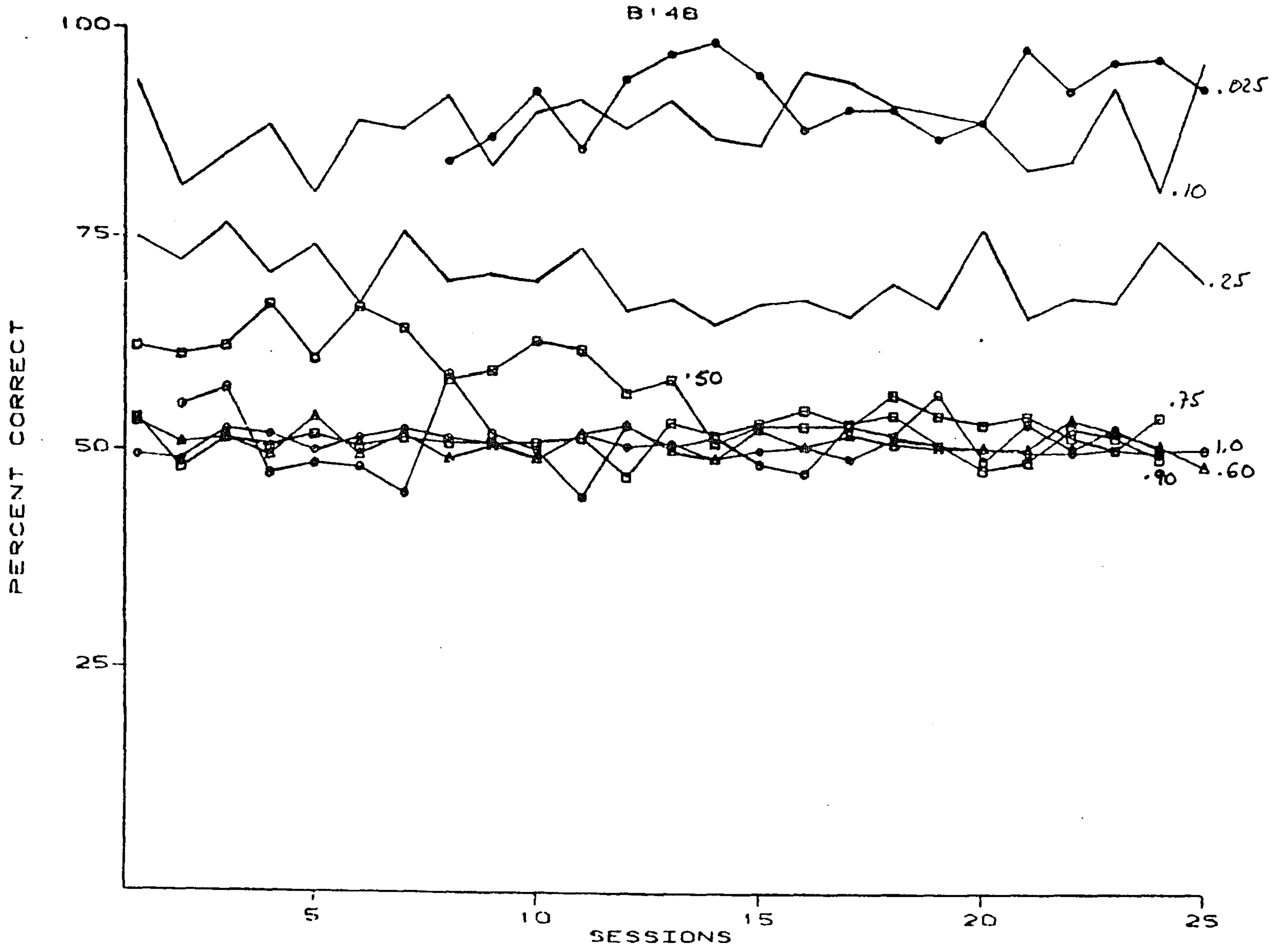

B'48
100
75
50
25
PERCENT CORRECT
5
10
15
20
25
SESSIONS
.025
.10
.25
.50
.75
1.0
.90
.60

Figure 16. Mean percent correct choices in FR 1 and *p* components combined (overall accuracy), as a function of *p* value, for each animal. Each point in a function represents the mean overall accuracy over the last 10 sessions at a given *p* value.

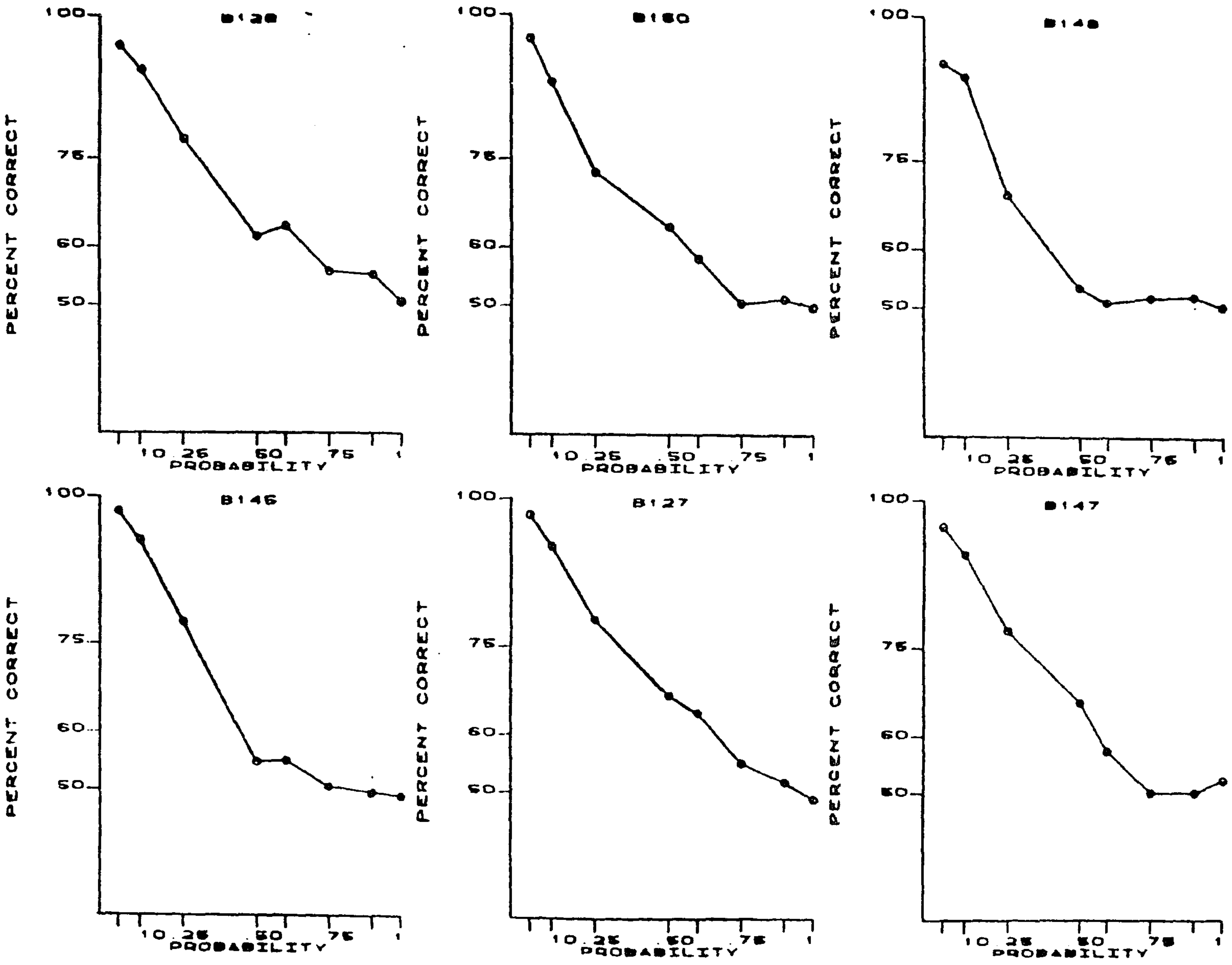

B128
B160
B148
B146
B127
B147
PERCENT CORRECT
100
75
60
50
PROBABILITY
10
25
50
75
1

Figure 16

also evident that, regardless of whether a function reached asymptote gradually or abruptly in the sequence, the slope of the functions in Figure 16 showed a decrease within the upper range, relative to the slope at probabilities below $\underline{p}$=.60.

In addition to their replicability across animals, the functions in Figure 16 also appear to be representative of the animals' performance, not only on the final days at a $\underline{p}$ value, but across sessions as well. The stability of the grouped overall accuracy functions shown in Figure 9 suggests that for most of the probability values studied, the level of accuracy that is reached on the first or second day of exposure is a good predictor of the average function at a given $\underline{p}$ value. Accordingly, plots of accuracy functions that arbitrarily select the last 10 days at a $\underline{p}$ value -such as those shown in Figure 16- would not be thereby distorted.

One way of looking at the stability of the overall accuracy measure across sessions for a given $\underline{p}$ value is provided by a difference score, which subtracts the mean percentage of correct choices on the last 10 days from the mean percentage of correct choices on the first 10 days. Table 3 shows these scores, indicating the positive or negative deviation of the mean accuracy in the last 10 days, form that on the first 10 days, at the various $\underline{p}$ values for each animal. Also shown in Table 3 is the mean difference score for each animal, which represents the algebraic sum of the animal's difference scores at the various p values, divided by the number of scores. These data show that, in general, the mean accuracy reached in the last 10 sessions at a given p value remained essentially constant from the level reached in the first 10 sessions. The difference between initial and final accuracy was slight at most p values and the mean difference score did not exceed a 4% accuracy difference.

The most notable exception to accuracy stability was the function at $p$=.50. The comparatively larger accuracy changes at this p value can also be seen across sessions in the individual daily plots in Figures 10 through 15. These plots show a decrease over the last sessions at $p$=.50 for four out of six birds, especially for birds B145 and B146 (Figures 10 and 15, respectively), whose initially higher than 60% accuracy fell near a 50% level on the last days at this p value. The large drop in B145's accuracy, as shown in Figure 10, was also preceded by a disruption in this animal's behavior. Between sessions eight and eleven of the $p$=.50 condition, this bird did not complete the intervening sessions on several days, even when allowed three times the usual session time. After removal from the experiment for five days, B145 then completed the session, although at a marked lower accuracy which it maintained on the subsequent

Table 3
Difference score between mean percent accuracy on first, and last 10 sessions, at each *p* value. The mean difference score (X) is also shown.

| P | B127 | B128 | B145 | B146 | B147 | B150 |
|---|---|---|---|---|---|---|
| .10 | 1.07 | -0.59 | 2.65 | 0.83 | 0.39 | 5.69 |
| .25 | 2.45 | -0.49 | -2.84 | -2.74 | 3.08 | 0.53 |
| .50 | -2.69 | 0.56 | -9.02 | -9.08 | -1.81 | 4.17 |
| .60 | 1.33 | -0.04 | 0.15 | 3.58 | 0.25 | 1.42 |
| .75 | -1.77 | -1.13 | 0.83 | -1.91 | -1.42 | 1.23 |
| .90 | 2.40 | 0.19 | 1.77 | -1.81 | -1.57 | 0.73 |
| 1.0 | 1.52 | -0.54 | -0.54 | -1.27 | -1.17 | 3.18 |
| X = | 0.62 | -0.29 | -1.08 | -1.77 | -0.32 | 0.82 |

sessions at $p$=.50. Interruption of the experiment alone did not seem to affect this bird's accuracy. During the final sessions at $p$=.75, for instance, B145 was removed from the experiment for 40 days due to a head injury. This animal resumed responding on its first returning session; in addition, it did not show any significant change in accuracy from the previous sessions.

Beyond the comparatively larger differences exhibited at the $p$=.50 value, the regularity of the overall accuracy data that was obtained with the use of a probability manipulation deserves special attention, for this regularity sheds some light on the nature of probability as an independent variable in this study. The orderliness of the daily accuracy functions shown in Figure 9 is particularly relevant to the question of variability in the $p$ component and the effects of such variability in the animal's performance.

Specifically, in the probability component the required RL was unpredictable from trial to trial and from session to session. Thus, each animal was exposed to a different set of RL values. However, in spite of random sequencing, in the long run, all animals will be exposed to the same distribution of RL values. What is obtained, then, is a day to day, animal to animal variability in the composition of the $p$ requirement, while uniformity across animals is obtained in the long run.

Regarding these general characteristics of the probability variable, the question can be asked, then, whether its use will generate parallel characteristics of performance. Namely, large day to day, within, and between subject variability, with possible similarity among subjects only after sufficient exposure, i.e., in the long run. However, the obtained results indicate that the animals' choice behavior did not parallel these p characteristics, but, rather, that reliable changes in accuracy occurred long before the nature of the entire distribution unfolded. That is, it would appear that the animals responded to some immediate characteristic(s) of the probability distribution, rather than to its long term characteristics, such as the mean RL value. At the same time, the narrow variability in most accuracy functions suggests that the unpredictability of the RL sequences within the p component did not affect the orderliness of the choice behavior.

One element of the distribution that can readily be anticipated to have an immediate effect on the conditional discrimination is the RL 1 element of the p requirement. The RL 1 value, being the most prominent value of the p distribution, sets the upper limit of accuracy level that can be attained at each p value. Under the conditions of this experiment, and given that the FR 1 and the RL 1 center key requirements are indiscriminable, the occurrence of RL 1 trials could have forced the decrease in the animals' accuracy of choice in two ways. In one case, the scheduled reinforcement of green choices on RL 1 trials of the p component may have not only increased the probability of green choices on RL 1 trials, but could have also induced errors on other single peck trials, i.e., induce green choices on FR 1 trials. In this case, greater accuracy can be achieved in the p component at the expense of errors in the FR 1 component. In the other case, 100% accuracy in FR 1 can be achieved at the expense of decreasing accuracy in the p component. In the latter case, two considerations must be made. First, the highest accuracy level that was achieved at $p$=.025 indicates that the animals made the initial conditional discrimination FR 1 - red, multiple peck(RL> 1) - green. The second consideration involves the possibility of the animals not making 'contact' with the scheduled contingencies of reinforcement. In relation to these contingencies, it will be remembered that the p value alone specifies the frequency of single peck (RL 1) trials, whereas the complement of this value (1 - p), specifies the proportion of RL> 1 trials. Thus, at $p$=.10, a RL 1 is present on 10% of p trials, and on the remaining 90% of the trials, RL> 1 values are required; at $p$=.25, single peck trials constitute 25% of all p trials, while RL> 1 constitute 75% of the p component, and so on. Therefore, with the increases in p value there is a concomitant increase in the frequency of available reinforcement for a single peck(RL 1)-green relation. Lack of contact of this contingency with the animal's behavior, i.e., failure of the contingency to produce an increase in the likelihood of green choices on RL 1 trials, would be indicated by a lack of change in the animal's choice strategy, which would result in predictable overall accuracy levels. That is, in terms of overall accuracy, the initial response strategy that was reinforced at $p$=.025, was that of choosing the red side key if a single peck had been required on the center key, and choosing the green side key if a RL> 1 had been required. The data in Figure 9, for instance, show that increasing the probability value of the p component resulted in a decrease in choice accuracy. Since only the RL> 1 portion of the p component was discriminable from the FR 1 component (see also ROC curves in Figures 4 and 5), and since such discriminable portion decreases with increases in p value, the question may be raised as to whether the obtained accuracy decrease represents a change in the animals' choice strategy after each center key requirement, or whether the initial strategy was maintained across changes in the p value, and the accuracy decrease was then only the result of a procedural feature, i.e., the decrease in the RL> 1 portion of the p component.

Under the view that the animal's initial strategy does not change with changes in p value, the likelihood of a red choice would be highest after a single peck at all p values, which could result in 100% accuracy in the FR 1 component, and 100% errors in RL 1 trials of the p component. Since FR 1 trials constituted only half of a session's trials, perfect accuracy in FR 1 would represent 50% accuracy with respect to total trials. On the other hand, if discrimination in the p component was limited to RL> 1 trials, accuracy in the p component would be equal 1 - p. For instance, 90% of the p component is constituted by RL> 1 trials when p is at p=.10. Since the p component constitutes half of a session's trials, 90% accuracy in this component will represent 45% accuracy with respect to total trials. Therefore, the overall accuracy level expected at a p=.10 would be equal 50% (from FR 1), plus 45% (from p), which would equal 95%. Similarly, overall accuracy at p=.25 would be 87.5%; at p=.50 would be 75%, and so on.

The overall accuracy data in Figures 9 through 15 for both, the group and the individual subjects, fall below those hypothetical levels, and show an even greater departure from them the larger the p value. At p=.50, no animal reached as high an accuracy as 75%, nor 70% at p=.60 (see also Figure 16). Instead, the data suggest that the animals' choice behavior did change, with changes in p value.

Therefore, an attempt was made to determine which of the above mentioned constraints operated on maximum accuracy of choice. For this purpose, the animals' performance was further analyzed by obtaining separate measures for the FR 1 and the p component; the measures of interest were accuracy and position preference per component. In addition to the ROC plots from Figures 4 and 5, behavior on single peck trials was also analyzed, by obtaining the separate proportion of errors on FR 1 and on RL 1 trials, and the percentage of green choices on these two types of single peck trials.

### Conditional control and stimulus preferences.

In addition to the overall accuracy functions at each p value, the animals' choice behavior was analyzed in other ways. One way involved the animal's behavior as a function of component type. In this analysis, the FR 1 and the p components can each be identified as constituting a stimulus-response relation. Because in this study the reinforcement of the choice of a given colored side key was conditional on a given antecedent center key behavior, the contingencies of reinforcement required the establishment of two stimulus-response relations. In one relation, FR 1 responding provided the occasion for reinforcement of red choices: an FR 1 - red relation. In the other relation, p responding provided the occasion for reinforcement of green choices: a p - green relation. A measure of the likelihood of occurrence of each of these two relations constitutes a more analytical measure- compared to overall accuracy -of the extent to which the animals' choices represented conditional control by center key behavior, and thus agreed with the contingencies of reinforcement.

To determine the extent to which the specified conditional discrimination was maintained as the value of the p component was increased, the frequency of occurrence of the two discriminative relations at the various p values was obtained. These frequencies are represented by the two functions in the upper panel of Figures 17 and 18 for the different animals. The points represented by triangles represent the percentage of FR 1 trials in which a red choice was made, and the points connected by circles represent the percentage of p trials in which a green choice was made. Every point in these functions represents the mean percentage over the last 10 sessions at the given p value. Color preference is indicated when correct choices are simultaneously close to 100% in one function and close to 0% in the other function; in such case, choices are being made to one color regardless of center key behavior. The two functions for each animal in the lower panel of Figures 17 and 18 represent the percentage of left key choices after the FR 1 requirement (triangles), and after the p requirement (circles), as a function of probability value. Each point in the left key functions is also the mean percentage over the last 10 sessions of each p value. Points above and below 50% in these lower panel functions represent a left, and a right key preference, respectively.

The percent correct functions in the upper panel of Figures 17 and 18 show that as the value of the probability requirement increased, there was a general decrease in the frequency of occurrence of the two discriminative stimulus-response relations. However, there was not parallel decrease between component types; at the lower end of the range of p values, i.e., values below p=.50, each increase in p value produced a larger drop in accuracy in the p component than in the FR 1 component, for five animals, and to a lesser extent for another animal (B146). A possible explanation for the difference in frequency among the two relations is that, given that there were rather small increases in position preference in both components -at probability values up to p=.25 - the greater drop in the p -green relation must have resulted from a color bias, i.e., a large proportion of red choices on the p component, presumably, on RL 1 trials. Only for B146 did the decrease in the two relations occur at a comparable rate, and it was largely associated with an increase in position preference

Figure 17. Mean percent correct choices, and mean percent left-key choices associated with each center key requirement (FR 1 and p), as a function of p value, for birds B145, B127, and B147. Each point in these functions is the mean from the last 10 sessions at a p value.

Top panel. Mean percent correct choices per component, as a function of p value. The triangles represent correct choices in the FR 1 component; the circles represent correct choices in the p component.

Bottom panel. Mean percent left key choices, per component, as a function of p value. The triangles represent left-key choices in the FR 1 component; the circles represent left-key choices in the p component.

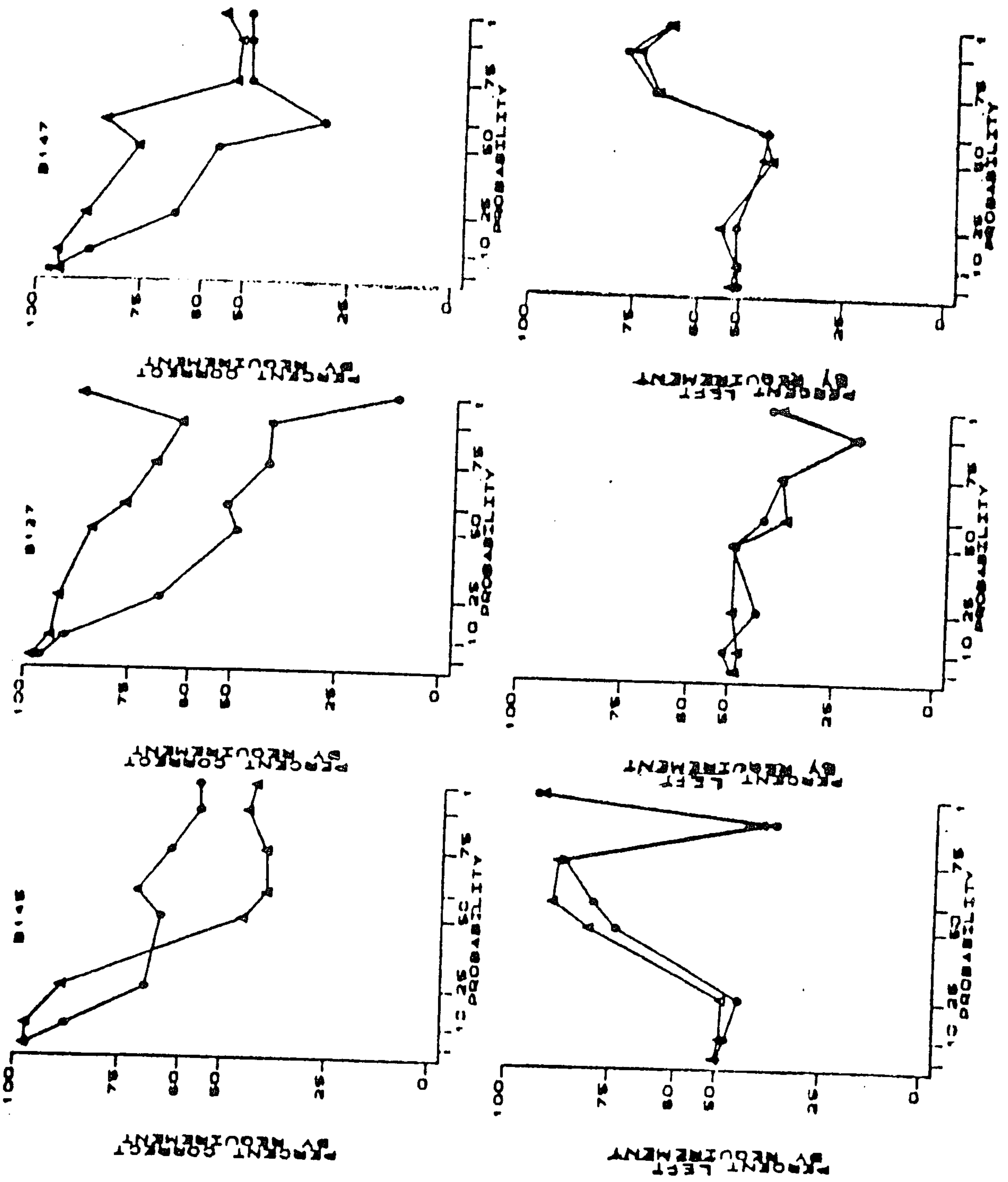

B147
B127
B145
PERCENT CORRECT BY REQUIREMENT
PERCENT LEFT BY REQUIREMENT
PROBABILITY
0
25
50
60
75
100
1
10
25
50
75

Figure 17

Figure 18. Mean percent correct choices, and mean percent left-key choices associated with each center key requirement (FR 1 and p), as a function of p value, for birds B128, B150, and B146. Each point in these functions is the mean from the last 10 sessions at a p value.

Top panel. Mean percent correct choices per component, as a function of p value. The triangles represent correct choices in the FR 1 component; the circles represent correct choices in the p component.

Bottom panel. Mean percent left key choices, per component, as a function of p value. The triangles represent left-key choices in the FR 1 component; the circles represent left-key choices in the p component.

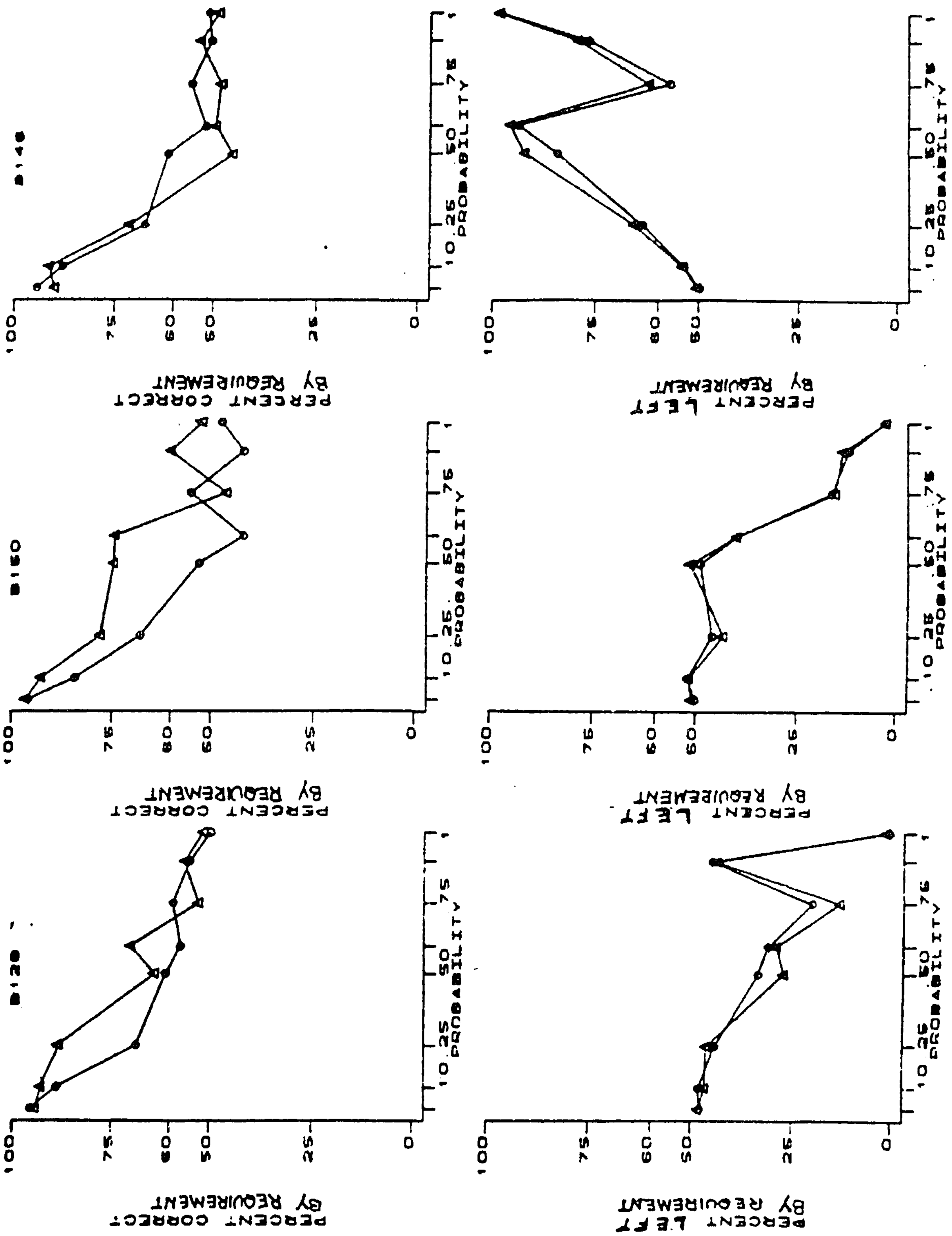

B148
B150
B128
PERCENT CORRECT BY REQUIREMENT
PERCENT LEFT BY REQUIREMENT
PROBABILITY
.10 .25 .50 .75 1
0
25
50
60
75
100

Figure 18

in both component. The possibility of a color bias on RL 1 trials is corroborated by the ROC plots shown in the left column of Figures 4 and 5. These plots show a large bias toward red on single peck trials (both, FR 1 and RL 1), at p values up to p=.25, and for some animals, at an even larger p value, e.g., B147 at p=.60. This suggests that, at p values below p=.50, behavior on RL 1 trials of the p component was largely controlled by the contingencies of reinforcement sustaining the single peck (FR 1) - red relation.

The change to p=.50 had the general effect of further decreasing the probability of occurrence of both relations. For B127, B147, and B150, accuracy in the p component was considerably lower than that for the FR 1 component, with the frequency of the p - green relation falling near 50% levels. Only for two other birds, (B145 and B146), did the FR 1 -red relation show the largest decrement. The functions for these two birds, and to a lesser extent, for B128, also showed a large increase in position preference, especially on FR 1 trials. For instance, on FR 1 trials, B145 and B146 showed a large increase in their proportion of left key choices relative to red choices, resulting in below 50% accuracy on FR 1 trials. For these three animals, B145, B146, and B128, a comparatively lower position preference on p trials resulted in above 60% accuracy in that component. Even though FR 1 and RL 1 trials are identical response requirements and similar responding in these trials can be expected, from the functions in Figures 17 and 18 is not possible to determine the extent to which position preference in the p component was contributed to by single peck trials alone. Considering the available data on those functions, however, and for B145 and B146 in particular, the large decrease in the FR 1 -red relation that was associated with the increase in the FR 1 -left relation under p=.50, points to a slight tendency in these birds to exhibit an unintended form of conditional control, where the controlling relations were p - green and FR 1 - left. Previous studies have reported more consistent conditional control of an incorrect choice than that exhibited by B145 and B146 (Cohen, 1976; Cumming & Berryman, 1965). Nevertheless, the observed changes are associated with the sharp drop in overall accuracy shown by these two animals at p=.50, as shown in Figures 10 and 15. Significantly, B145 and B146 were also the only two animals who reached relatively higher accuracy in the p component, which suggests the existence of a green preference too. This is corroborated by the ROC plots in Figure 5, where B145 and B146 show a bias toward the green stimulus. Furthermore, these birds' discriminative performance deteriorated comparatively faster in the sequence of p values. The role that such color preference may have played will be discussed below.

At probability values above p=.50, all six animals showed preferences. At p=.60, accuracy on p trials decreased further for four animals, whereas color, position preference, or a combination of both were evident in all animals. Another change was observed in the accuracy functions of four animals at p=.75; there was a general decrease in color preference and a prevalence of position preference, reducing the difference in accuracy levels between the two components. For B150, B145, and B147, these changes resulted in the drop to 50% overall accuracy that was shown in Figure 16. At p=1.0, further decreases in color preference resulted in a predominance of position preference for five animals, four of which showed near 100% levels, whereas the other bird, B147, showed a combination of the two preferences. Only B127 exhibited near 100% color preference (for the red stimulus).

The functions depicted in Figures 17 and 18 show that systematic changes in the p value resulted in systematic changes in the frequency of the discriminative relations. At the low end of the range of p values, stimulus choices were under the control of center key behavior. At the high end of the probability dimension, choice behavior fell under the control of stimulus and position preferences; at the intermediate probabilities, center key behavior increasingly shared control of choice with stimulus and position preferences.

The reliability of these effects is increased by comparisons across animals as well as by the replication data at p=.90 and p=1.0. Comparison of the choice levels reached in the final sessions at these values when presented with a descending sequence (Figures 6 and 7), with corresponding levels in Figures 17 and 18 indicate that, regardless of the order of presentation, at these extreme values of p choice behavior falls under the control of color or position discriminations. The only difference between the two exposures at p=.90 was shown by B127 and B145, and was related to the type of preference shown. On their first exposure these animals showed a complete color preference (Figures 6 and 7), while on second exposure they exhibited a combination of color and position preference (Figures 17 and 18).

Regarding the question on the constraints that the RL 1 element of the p component imposed on the animals' discriminative performance, one possibility that was discussed earlier was that the animals' accuracy on the p component would be limited to the proportion of RL> 1 trials. In relation to this, the top panels of Figures 17 and 18 show that for all animals at values below p=.60, the frequency of correct choices in the p component approaches the frequency of RL> 1 trials. However, unlike the hypothesized case, where red choices are made on all single peck trials thus allowing maximum accuracy on FR 1 trials, the functions show instead that, the frequency of correct choices in the FR 1 component increasingly deviated from the 100% level. In other words, there was an increasing loss of control of red choices by single pecks from the FR 1 component. At the same time, whereas the systematic decrease of correct choices on p trials nearly matched the systematic decrease in the frequency of RL> 1 trials, in general, there was no proportional increase in position preference in relation to the p component; instead, four out of six animals showed a red preference (see Figures 3, 17, and 18). This indicates that the drop in accuracy in the p component was the result of some proportion of red bias on p trials. Similarly, errors in the FR 1 component were associated with an increase in position preference only for two birds at p=.50 and p=.60. Instead, what seems to account for the decrease in the FR 1 - red relation as observed for most animals at probabilities below p=.60, is an increase in the frequency of green choices in FR 1 trials; the latter presumably being the result of the increased frequency of reinforcement for such choices on RL 1 trials. Therefore, one result of increasing the probability value appears to have been that, on single peck trials, the animals exhibited an increasing tendency to distribute their choices equally among the red and the green side key. The ROC plots in Figures 3 through 5 show that, in effect, a red bias was exhibited on the p component (Figure 3), particularly on RL 1 trials of the *p* component (Figures 4 and 5, left column). These plots also show that on single peck trials, with increases in p, most animals approached the equal bias line, that is, the point of equal likelihood of either a red or a green choice, on a single peck trial. Notwithstanding this diminished control of choice behavior on single peck trials, accuracy in the *p* component (Figures 17 and 18) approached the expected frequency of RL> 1 trials under a given *p* value, for values up to *p*=.50. This suggests that, at those *p* values correct choices were highly determined by center key behavior on trials where a RL> 1 was required. This level of control by the *p* requirement would not be apparent if absolute accuracy levels were taken at face value. At *p*=.50, for instance, the near 50% accuracy on *p* trials by B127, B147, and B150 might suggest that at this *p* value correct choices were as likely as incorrect choices, i.e., that the *p* component showed no control over choice behavior at this *p* value. But when considered in terms of the properties of the p distribution, these data suggest, instead, a high degree of control by that portion of the distribution represented by RL> 1 trials. In addition, these data support the suggestion that accuracy of choice by component, as shown in Figures 17 and 18, or by type of trials, as will be shown below, represents a more analytical measure of performance on a conditional discrimination, than that provided by the overall accuracy measure (Sidman, 1980).

From the foregoing discussion, the distinct possibility emerges that, at the low and intermediate range of p values, the animals' partitioned the RL continuum into two response categories, with single pecks in one category (FR 1 and RL 1), and multiple pecks, irrespective of RL value, in the other category. To determine the adequacy of this interpretation, the animals' accuracy in the p component can be further analyzed as a function of RL value. Furthermore, since the frequency of red choices was observed to increase on p trials, it remains to be determined whether there was also an increase in the frequency of green choices on RL 1 trials, as previously suggested in connection with the increase of green choices on FR 1 trials.

### Analysis of errors

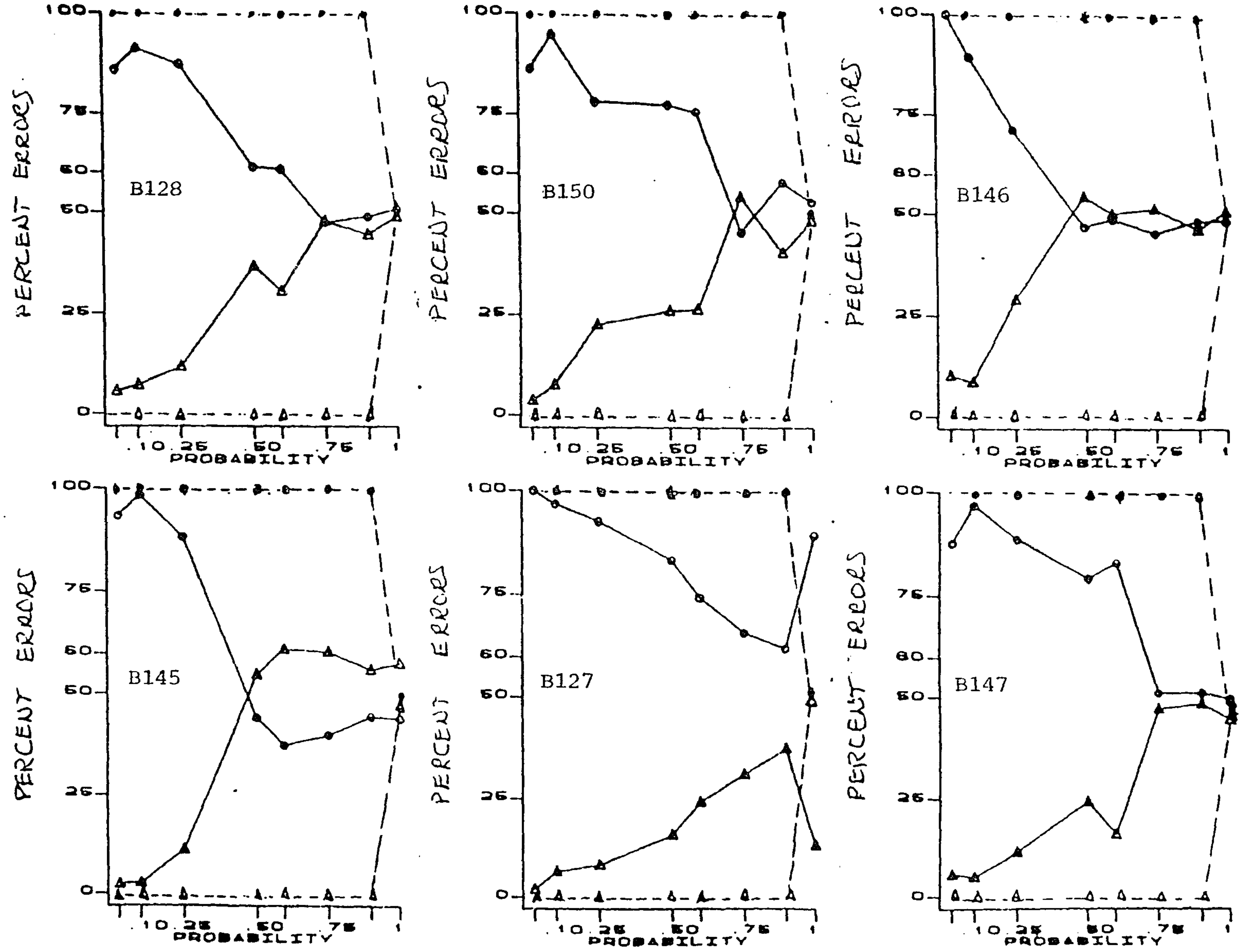
The percentage of errors on FR 1 as well as on selected RL values, as a function of probability, was examined. For comparison across p values, short RLs were selected because they have the highest relative frequency of occurrence, and were thus represented in the probability distribution at most p values. Choice data for large RLs were grouped under the categories RL> 10 and also under RL> 1; in general, the RL> 10 category was available for analysis only at the small p values. Given the random distribution of RLs, where the frequency of occurrence of any given RL varies between sessions, daily percentages of stimulus choices after a given RL were always computed relative to the actually obtained frequency of that RL within a session.

Of immediate interest was the comparison of the animals' errors on the types of single peck trials, FR 1 and RL 1. Figure 19 is a plot of the frequency of errors on RL 1 trials (circles), and on FR 1 trials (triangles), as a function of probability for each animal. Each point in the function represents the mean value over the last 10 sessions at a $\underline{p}$ value. As the functions in Figure 19 show, responding on FR 1 and RL 1 trials it varied systematically with the value of the $\underline{p}$ component. In general, as the $\underline{p}$ value increased, errors on FR 1 trials also increased, whereas errors on RL 1 trials decreased. Although these functions appear to mirror each other, they are not complementary, however. That is, it will be remembered that the number of FR 1 trials (Type I), remained constant at 102 per session, at all $\underline{p}$ values; whereas the number of RL 1 trials (Type II), varied with the $\underline{p}$ value (see Figure 2). Thus, at $\underline{p}$=.50 in Figure 19, for instance, the FR 1 error function plots the percentage of 102 FR 1 trials in which a green choice was made, whereas the RL 1 error function plots the percentage of 51 RL 1 trials in which a red choice was made. The obtained

Figure 19. Mean percent choice errors on single peck trials, as a function of p value, for each animal. Each point in these functions is the mean for the last 10 sessions at a given p value. The solid line connecting the triangles represents the obtained error function for FR 1 trials; the solid line connecting the circles represents the obtained error function for RL 1 trials.

The dashed lines connect the hypothetical proportion of errors on single peck trials, at the different p values, that would result from the animal choosing the red side key on all single peck trials. The dashed line connecting the triangles represents the hypothetical error function that would obtain for FR 1 trials; the dashed line connecting the circles represents the hypothetical error function for RL 1 trials. See text for further detail.

Figure 19


B128
B150
B146
B145
B127
B147
PERCENT ERRORS
100
75
60
50
25
0
.10 .25 .50 .75 1
PROBABILITY

error rates show that, at the smallest p value, all animals were more likely to choose the red stimulus on single peck trials. Increasing p to p=.10 produced an even greater frequency of red choices, i.e., more errors on RL 1 trials, for four animals, whereas the error rate on FR 1 remained at very low levels. With further increases in p, however, errors on RL 1 trials showed a decrease concurrently with the error increases on FR 1 trials causing the functions to meet at the 50% level -the point of equal likelihood of choice of the red and the green stimulus- at the higher p values. The exception to this trend were B127 and B145, whose respective red and green preference prevented the functions from reaching equality.

The decreasing frequency of errors in RL 1 trials supports the suggestion made earlier that, in spite of the overall increase in red choices (errors) on p trials, there was an increase of green (correct) choices on RL 1 trials of the p component. This also indicates that errors in the p component were not limited to the 'ambiguous' RL 1 trials. Nevertheless, at small and intermediate p values, choice errors occurred on more than half of the RL 1 trials. At values as high as p=.60, for instance, where RL 1 trials constitute 60% of all p trials, B127, B147, and B150 made errors on 75% or more of all RL 1 trials, whereas B128 made errors on 60% of those trials. Thus, although the animals' choices on RL 1 trials accounted for a large proportion of errors in the p component, it is clear that as the p value increased, the frequency of errors on other p trials, namely, RL> 1 trials, also increased.

The possibility had also been discussed earlier that the scheduled reinforcement for green choices on RL 1 trials might not be effective to decrease accuracy on FR 1 trials, and, instead, limit the accuracy level in the p component only. Such an outcome would result in the hypothetical dashed functions in Figure 19. As the dashed functions indicate, if red choices are made on all single peck trials at all p values, errors would occur on all RL 1 trials, e.g. the RL 1 function at 100% errors for p< 1, and no errors would occur on FR 1 trials, e.g., FR 1 function at 0% errors for p< 1. At p=1.0, no discrimination is possible, and therefore, the functions would meet at the 50% point. However, and as it will be discussed shortly in terms of an abolishment procedure, it appears that, as expected, the scheduling of reinforcement for green choices on RL 1 trials affected performance on both, FR 1 and RL 1 trials, causing an increasing deviation from the hypothetical accuracy functions for single peck trials (dashed functions, Figure 19). For instance, the consistent decrease in errors in the RL 1 function suggests, that the increasing opportunity for reinforcement for green choices on single peck trials, with increases in p, may have shifted the animals' distribution of choices toward an

Figure 20. Mean percent choices of the green side key on single peck trials (FR 1 and RL 1), as a function of p value, for each animal. Each point in these functions is the mean of the last 10 sessions at a given p value. The triangles represent green choices ("errors'), on FR 1 trials; the circles represent green choices ("correct') on RL 1 trials.

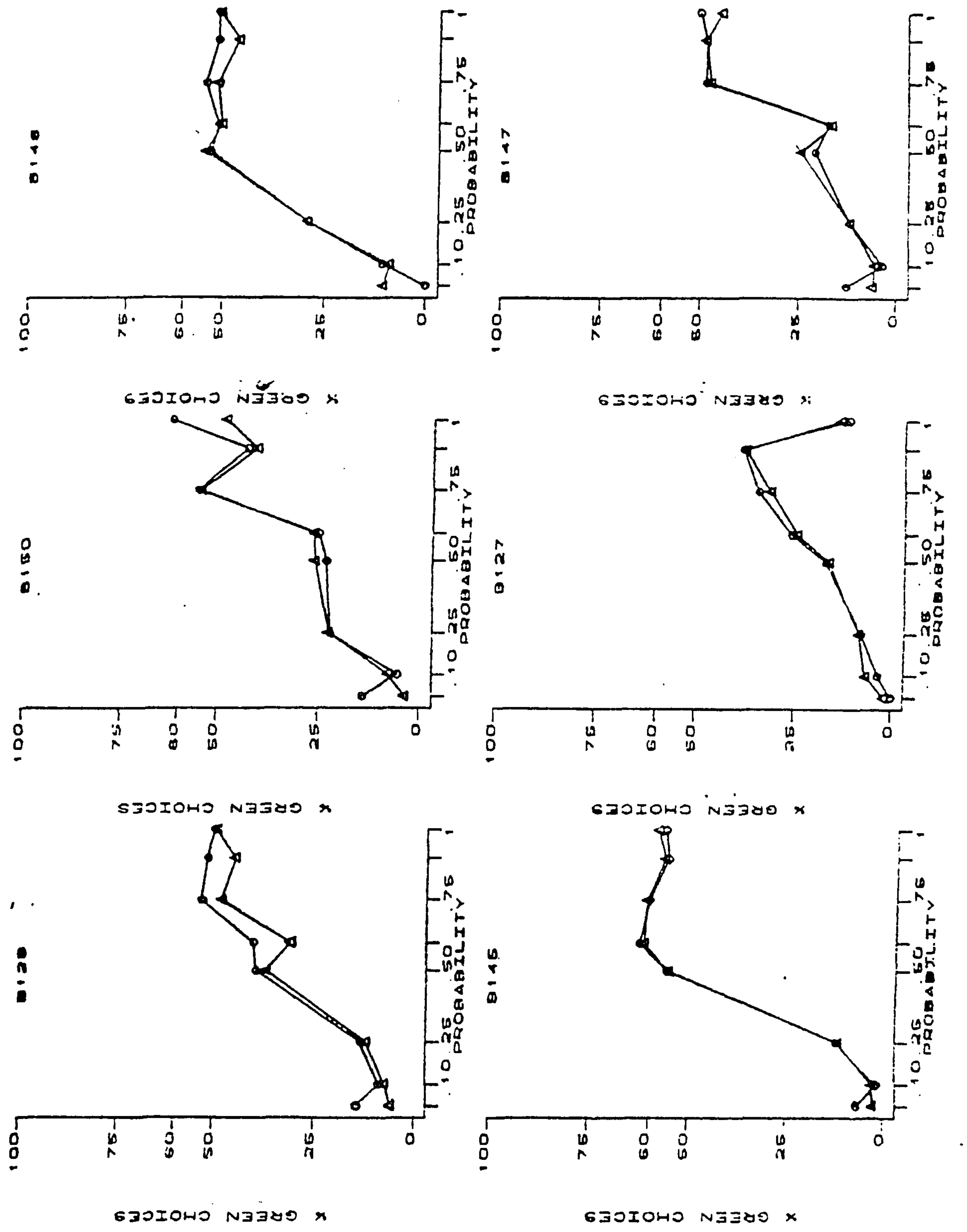

B148
B150
B128
B147
B127
B145
% GREEN CHOICES
PROBABILITY
100
75
60
50
25
0
.10
.25
.50
.60
.75
1

Figure 20

increase in green choices on those trials. This increase can be seen in Figure 20, where the percentage of green choices on FR 1 (circles) and on RL 1 (triangles), was plotted separately. Each point in the functions represents the mean percentage, averaged over the last 10 sessions at each p value. In Figure 20, perfect discrimination between FR 1 and RL 1 trials would be indicated if one function were at 100% (the RL 1) function, and the other at 0%. No animal gave indication of such discrimination. The functions are seen to overlap at all p values; and with the exception of some separation in the functions for B128 within the range $p=.60$ to $p=.90$, the overlap in the functions indicates that the FR 1 and the RL 1 requirement on the center key were indiscriminable. This is in agreement with the ROC plots in the left column of Figures 4 and 5. Nevertheless, as it was indicated before, the animals' behavior on these single peck trials was not random, their likelihood of choosing the green or the red stimulus depended on the value of p. Red choices were highly determined after a single peck when p was at small values; chance levels were reached only at the larger p values.

The above mentioned changes in the animals' behavior on single peck trials can be better understood, as explained below, by noting that the percentage of green choices on RL 1 trials that is shown in Figure 20, also represents the percentage of trials in which the animals were reinforced for choice errors with respect to the FR 1 component. Therefore, the increases in the single peck - green relation that resulted from the increased frequency of reinforcement of such relation, may account for the decrease in accuracy on FR 1 trials, i.e., the decrease in the single peck - red relation. Once again, however, the fact that the animals decreased their frequency of red choices on RL 1 trials shows that the increase in errors on p trials, i.e., the increase in red choices, was not confined to RL 1 trials. That is to say, in spite of the generally high frequency of red choices on single peck trials at small p values, e.g., values below p=.50, the apparent similarity of the p accuracy function to the expected proportion of RL> 1 trials in that component (Figures 17 and 18) would require the frequency of red choices on RL 1 trials to reach 100% across p values for the RL> 1 portion of the distribution to entirely account for the accuracy level on the p component. Instead, the data indicate that, concurrent with the gradual increase in green choices on single peck trials, there was also a gradual increase in red choices, i.e., an increase in errors, on RL> 1 trials. On the other hand, the changes in the functions in Figure 20 are also indicative of growing preferences with increases in probability value. Color preference is indicated to the extent that the FR 1 and RL

1 functions depart from 50%, whereas position preference is evidenced to the extent that the functions approach 50%, which is the point of equal likelihood of choice of either color. Because the frequency of RL 1 trials, and therefore, the frequency of scheduled reinforcement for the single peck -green relation increased directly with the p value, the functions in these figure suggest the possible role that changes in such frequency played on the animals' choices on single peck trials. At small p values, where reinforcement of green choices on single peck trials was relatively infrequent, the animals were more likely to choose the red stimulus on all single peck trials. This likelihood decreased, however, at intermediate p values, where the frequency of reinforcement of green choices increased. With even further increases in the value of the p component, further decreases in red choices toward more green choices were associated with the development of a position preference as well. That is, at the larger p values, the animals showed an increased tendency to distribute their choices equally among the red and the green stimulus. It is possible that, under the present design, this response pattern, along with the reinforcement conditions, favored a position preference. First, given that each color appeared equally often on each side key, equal likelihood of choice of both colors is achieved by exclusive responding to one side key; second, total

position preference allows the animal to obtain 50% of the session's reinforcers, the maximum obtainable when choice responding is not based on RL value. Thus, at the final *p*=1.0 value, for instance, where all *p* trials were RL 1 trials, color preference was eliminated in three animals (B128, B146, and B150) in favor of total position preference, whereas other three animals showed a combination of color and position preference.

With the exception of the results at *p*=1.0, it is also evident that the increasing preferences that were exhibited on single peck trials do not entirely account for the overall increasing preference patterns in the FR 1 and *p* components. Although for each animal the color and position preference pattern shown in Figure 20 tend to covary with those evidenced by the accuracy and left key functions in Figures 17 and 18, there are some differences at the larger *p* values, the values at which single peck trials constitute the largest proportion of the sessions' trials. See for instance, the choice patterns by B145 and B128 at *p*=.90. These animals' proportion of red choices (Figure 20) was near 50%, indicating greater than 90% position preference and low color preference, on single peck trials. On the other hand, their choices on FR 1 and on *p* trials at *p*=.90 (Figures 17 and 18), indicate color preference but do not reveal any appreciable position preference. Similar observations are true for B146 at p=.75, and for B147 at all values above p=.60. Thus, in spite of the covariations between the two sets of functions points to the frequency of RL 1 trials as an important contributor, the fact that the preferential patterns in Figures 17 and 18 do not always match those obtained for single peck trials (Figure 20), suggests that the animals also developed color and position preferences on the RL> 1 trials of the p component.

The extent to which accuracy on RL> 1 trials was affected by changes in probability is shown in Figure 21, which is a plot of the mean percentage of errors made by each animal on all trials requiring a RL> 1 (points connected by circles), averaged over the last 10 days at a p value. For comparison, the corresponding function for errors on FR 1 is also shown (points connected by triangles) -this function is simply a replot of the FR 1 function shown in Figure 20. It will be remembered that errors on RL> 1 trials are constituted by red choices on those trials. Points at 50% would indicate a total position preference, whereas points above 50% would represent a red preference. For all six animals, the frequency of errors on RL> 1 trials increased with increases in probability value. However, the frequency of errors on these trials was lower than that for FR 1 trials, for all animals, at most p values. One reversal was observed at p=.90 for B146 and B150,and was due to an increase in red preference combined with a high position preference, regardless of center key behavior; these animals preferential levels were shown in the ROC plots of Figure 5, and also in Figures 17 and 18. On the other hand, the reversal shown by B147, especially at p=.60, where errors where lower on FR 1 trials, was due to a high red bias on single peck trials (see Figure 5, left column, and also Figures 19 and 20); whereas on RL> 1 trials this bird approached near equal frequency of choice of both colors (see the ROC plots for RL> 1 in Figure 5, right column).

Beyond these exceptions, accuracy on RL> 1 trials was affected less, and later, in the sequence of p values. With lower stimulus and position preferences associated to these trials, the error rates remained below 50% at most p values. For some animals, like B128, choice errors on RL> 1 trials never exceeded the 25% level, and for others, like B127 and B145 it did so only at the highest p value. These data provide some evidence for the interpretation that a discrimination between two response categories, single peck and multiple peck existed at p values as high as p=.90, for some animals. The earliest deterioration of RL> 1 discrimination is shown by B146 at p=.60, at which value this bird exhibited near total position preference in all types of trials (see Figure 18, lower panel).

Figure 21. Mean percent errors on FR 1 trials and RL> 1 trials, as a function of p value, for each animal. Each point in these functions is the mean of the last 10 sessions at a given p value. The triangles represent errors on FR 1 trials; the circles represent errors on RL> 1 trials of the p component.

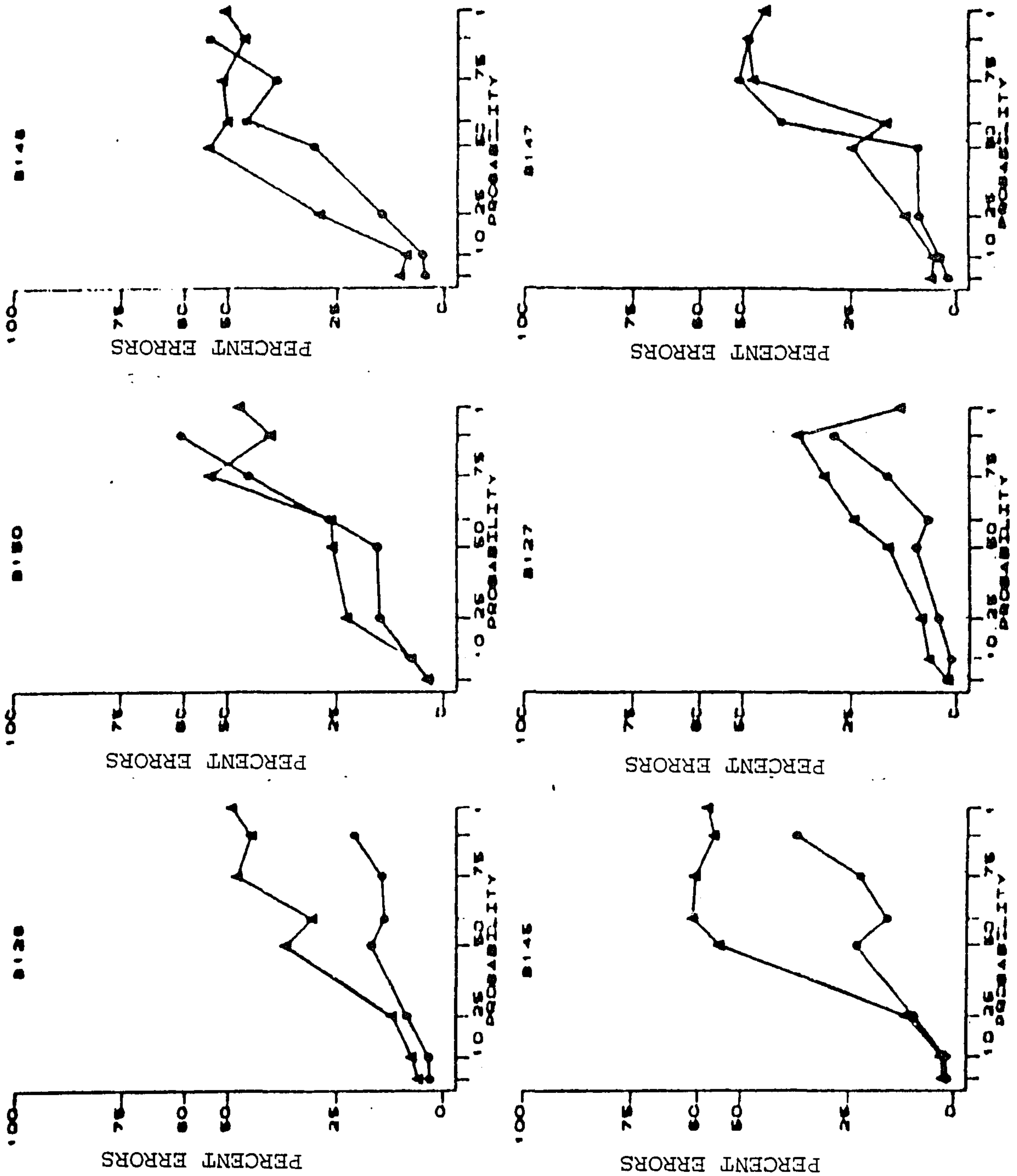

B128
B145
B150
B127
B148
B147
PERCENT ERRORS
PROBABILITY
0
25
50
60
75
100
.10
.25
.50
.75
1

Figure 21

Given that the FR 1 error function overlapped the RL 1 accuracy function (Figure 20), the functions in Figure 21 also allow a comparison of the changes in RL> 1 trials relative to those two functions. This comparison provides additional evidence for the interpretation regarding the development of incompatible stimulus-response relations, with increases in p value. On the one hand, the increase in the single peck-green relation compromised the discriminative relation in which the FR 1 component controlled subsequent red choices. On the other hand, the increase in errors on RL> 1 trials points to an increase in the frequency of an incompatible relation on those trials, namely, a multiple peck - red relation.

### A modified abolishment procedure

The reinforcement conditions which may have resulted in the development of stimulus-response relations that were incompatible with the original discriminative relations, resemble those which operate in an abolishment procedure. To clarify how the present conditions differed from those in a conventional abolishment procedure, it will be convenient to first re-state the current contingencies of reinforcement as well as some of the relevant findings. As Figure 1 shows, on some single peck trials (FR 1) red choices were reinforced (Type I trials). On other single peck trials (RL 1), green choices were reinforced (Type II trials). Type III trials represented a differential requirement (RL> 1), from a single peck, and in which green choices were reinforced. When only the non-differential Type I and II trials were presented to the animal by setting the p component at p=1.0, the animals did not discriminate between these trials and their accuracy of choice was at chance level. However, when other values of p were introduced, thereby introducing the differential Type III trials, the animals' accuracy of choice increased. The small p values generated the highest accuracy levels and the stimulus-response relations which showed the greatest likelihood of occurring were those specified by the contingencies, namely, FR 1 -red and p - green. At those p values, the originally intended discriminative relations, single peck - red and multiple peck - green were thus effectively established and raised to a maximum. However, an inevitable feature of the p component is its comprehensiveness along the number of responses continuum. That is, it generates multiple peck trials and single peck trials as well. This means that, in addition to the multiple peck - green relation, reinforcement was available for a single peck -green relation on RL 1 trials of the p component. Clearly, such relation is directly incompatible with the single peck - red relation of the FR 1 component. Because Type II trials were present in varying proportions at all p values, the animals' behavior on these incompatible Type I (FR 1) and Type II (RL 1) trials was of especial interest.

As discussed earlier in relation to Figure 20, at the small p values the most frequent choice on FR 1 and RL 1 trials was a red choice. At those p values, and from the animal's point of view, any single peck requirement was an antecedent for a red choice. Two factors may account for the decline in red choices on single peck trials with increases in probability. First, as the proportion of RL 1 trials increased with the p value, so did the frequency of non-reinforcement for red choices on single peck trials, i.e., on RL 1 trials. Because the animals did not discriminate between types of single pecks, this operation of non-reinforcement of red choices could conceivably produce a decrease in the probability of red choices on both, FR 1 and RL 1 trials. On the other hand, the operation may not suffice to decrease the probability of such responses; one may turn, in this respect, to those conditional discrimination studies reporting that performance can be maintained well when correct side key choices are reinforced only intermittently (Nevin et al., 1963). Nevertheless, non-reinforcement might suffice to produce a temporary decrease in the probability that the animal will choose the red stimulus after a single peck requirement. Under those conditions, the likelihood of a green choice would also be temporarily increased on those trials. Second, given that the frequency of available reinforcement for green choices on single peck (RL 1) trials increased with p, a temporary increase in green choices on single peck trials is likely to be reinforced. Thus, extinction trials for red choices may not account alone for the functions in Figure 20; rather, it may have been such extinction combined with the reinforcement of the incompatible response, green choices, which resulted in the animals shift in choice behavior on both, FR 1 and RL 1 trials. The function in Figure 20 that corresponds to FR 1, for instance, shows an increase in the frequency of occurrence of an FR 1 - green relation, simultaneous with the increase in the reinforced RL 1 -green relation.

When the base line discrimination is represented by an FR 1 - red, and a p - green relation, the systematic increase in FR 1 - green represents the development of a stimulus-response relation that is clearly incompatible with one of the controlling relations of the base line discrimination. The decline in the discriminative relations that were established at the small p values appears to be due, at least in part, to the development of such incompatible relation. This development was the direct result of a modified abolishment procedure which was generated as the value of the p component is increased. A statement of the conditions that prevail on a conventional abolishment procedure will help clarify what is meant here by a modified abolishment procedure.

In a simple discrimination between two stimuli, responses to one stimulus -the positive stimulus- are reinforced, and the responses to the other stimulus -the negative stimulus- are never reinforced. Eventually, the organism comes to respond to the positive stimulus and respond less, or not at all, to the negative stimulus and a discrimination is said to have been established. One way of altering the effects of discrimination training is known as the abolishment procedure. Under such procedure, reinforcement is introduced for responses to the negative stimulus (Keller & Schoenfeld, 1950); that is, the animal's responses become equally likely to be reinforced under the positive and the negative stimulus. This procedure effectively increases the number of responses to the negative stimulus, decreasing previously established differential responding to the two stimuli, i.e., it abolishes discriminative performance (Skinner, 1938).

In the case of a more complex discrimination, like the conditional discrimination of this study, there were two discriminative relations. Under one relation, FR 1 - red, red is the positive stimulus and green is the negative stimulus. For the other relation, p - green, the opposite is true. The abolishment procedure in this situation would require that a red and a green choice be equally reinforced after both the FR 1 and the p components. In fact, such procedure was in effect under the p=1.0 condition of this study, where single pecks represented both the FR 1 and p components, and, therefore, either a red or a green choice were equally likely to be reinforced. However, at all other values of p, an abolishment procedure was only approximated, where the frequency of abolishment trials was equal to the frequency of RL 1 trials. Because the frequency of RL 1 trials was not equal the frequency of FR 1 trials, except at p=1.0, and because such abolishment trials are effected in relation to only one of the two discriminative relations, i.e, in relation to FR 1, such procedure is identified here as a modified abolishment procedure. Another way of looking at this is to identify the non-differential reinforcement of choice behavior on RL 1 trials as the reinforcement of errors with respect to FR 1. Such procedure is viewed as one way of weakening the reinforcement contingencies between stimulus, response, and consequence and one which results in a decrease in discriminative performance (Nevin et al. 1982). But whether discussed in terms of abolishment, or in terms of the reinforcement of errors, the changes implied by changes in the proportion of RL 1 trials did not alter the differential contingencies of reinforcement in the multiple peck requirement of the p component. That is, red choices (errors), were never reinforced on RL> 1 trials; it is important to remember, however, that the frequency of these multiple peck trials varies with changes in p value.

When errors are reinforced with respect to the two stimulus-response relations of a conditional discrimination, a more systematic decline in discriminative performance is obtained than by reinforcing errors with respect to only one of the two relations (Nevin et al. 1982). The rather systematic decline in discriminative performance which was obtained in the FR 1 and p components when the reinforcement of errors with respect to FR 1 was increased, suggests that the simultaneous decrease in the frequency of RL> 1 trials in the p component may have combined to produce the decline in both components, at least with respect to the overall accuracy measure.

### Preferences and individual differences

The replicability of the accuracy functions across animals was already noted in the description of overall accuracy as a function of probability. However, the functions showing separately the performance on the FR 1 and p components indicated that, although there are striking similarities among the overall accuracy functions for the different animals, the individual functions showed, nevertheless, different profiles. For instance, subjects varied on the rate at which their discriminative performance declined, and the point at which they reached an asymptotic level.

The individual differences that were obtained among the subjects of this study appear to be largely related to the preferential patterns of choice adopted by each animal. As mentioned before, in this experiment, either total preference for a key color or for a key position will result in 50% of all scheduled reinforcers. Under such conditions, animals are equally likely to develop either type of preference. Within the present design, however, the type of preference an animal developed affected the shape of its accuracy function. When the discriminative performance of the different animals is compared in relation to whether they exhibited a green or a red preference, for instance, an adverse effect can be traced on the performance of those which exhibited a green preference. The clearest example is provided by B145 and B146. The functions in Figure 20 show that these two birds exhibited an early green preference in the sequence of $\underline{p}$ values. Thus, at $\underline{p}=.50$, these animals chose the green side key on over 50% of single peck trials (both FR 1 and RL 1); see, for instance, the ROC plots in Figures 4 and 5, left column. These animals' bias toward the green side key after a single peck, allowed them to receive a comparatively higher frequency of abolishment trials than that received by animals showing either a red preference or a position preference. Therefore, an early green preference probably accelerated the loss of discriminative control and probably accounts for the sudden decline that was observed in these animals' discriminative performance on their last sessions at $p$=.50, and accounts as well for the comparatively faster decrease in these birds' accuracy of choice with increase in $p$ value.

The ROC plots in Figures 4 and 5, and the functions in Figure 20 suggest the effects that color bias had on other birds' performance too. For instance, at $p$=.50, B128 chose the green side key on about 40% of single peck trials, whereas other three birds made a green choice on only 25% of those trials. When applied to RL 1 trials, those percentages reflect a lower proportion of abolishment trials, it is not surprising, therefore, that these animals showed comparatively higher accuracy levels at $p$=.50. Similarly, these other animals also showed a slower decline in their overall accuracy. The most extreme example of a "favorable" preference is B127, who exhibited a sustained red preference on single peck trials (ROC plot in Figure 5, left column). This animal's frequency of green choices showed the slowest increases with increases in $p$ value, and were always below the frequency of red choices. Therefore, the frequency of abolishment trials received by B127 at the different $p$ values was maintained at a low level. This may account, then, for this animal's comparatively slowest decline in discriminative performance at the various $p$ values.

In spite of the fact that particular preferential patterns appeared effective to delay or accelerate the decline of the conditional discrimination and hence generate differences in individual profiles, under the conditions of this experiment, the increases in p value ultimately force a decline, and eventual abolishment of discriminative performance. Therefore, the systematic decrease in accuracy as a function of increases in p value is replicable across animals, regardless of individual preferences.

### Discriminative performance on RL> 1 trials

In addition to the decrease in the overall accuracy function, a second general characteristic of all animals' performance was mentioned earlier; namely, the possibility that the animal's basic discrimination was one between single vs. multiple pecks, regardless of RL value. To assess such possibility, choice errors on representative RL values were examined, with data for large RL values combined in the RL> 10 category. The mean percentage of errors per RL, in the last 10 sessions of each p value, were plotted in Figures 22 through 27, for each animal. For comparison, these Figures include the error functions for FR 1 and RL 1. The functions in these figures show that, in general, the frequency of errors an animal made after a given RL value did not remain constant when the probability value was changed. Increases in p resulted in increases in

Figure 22. Mean percent errors made by bird B128 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

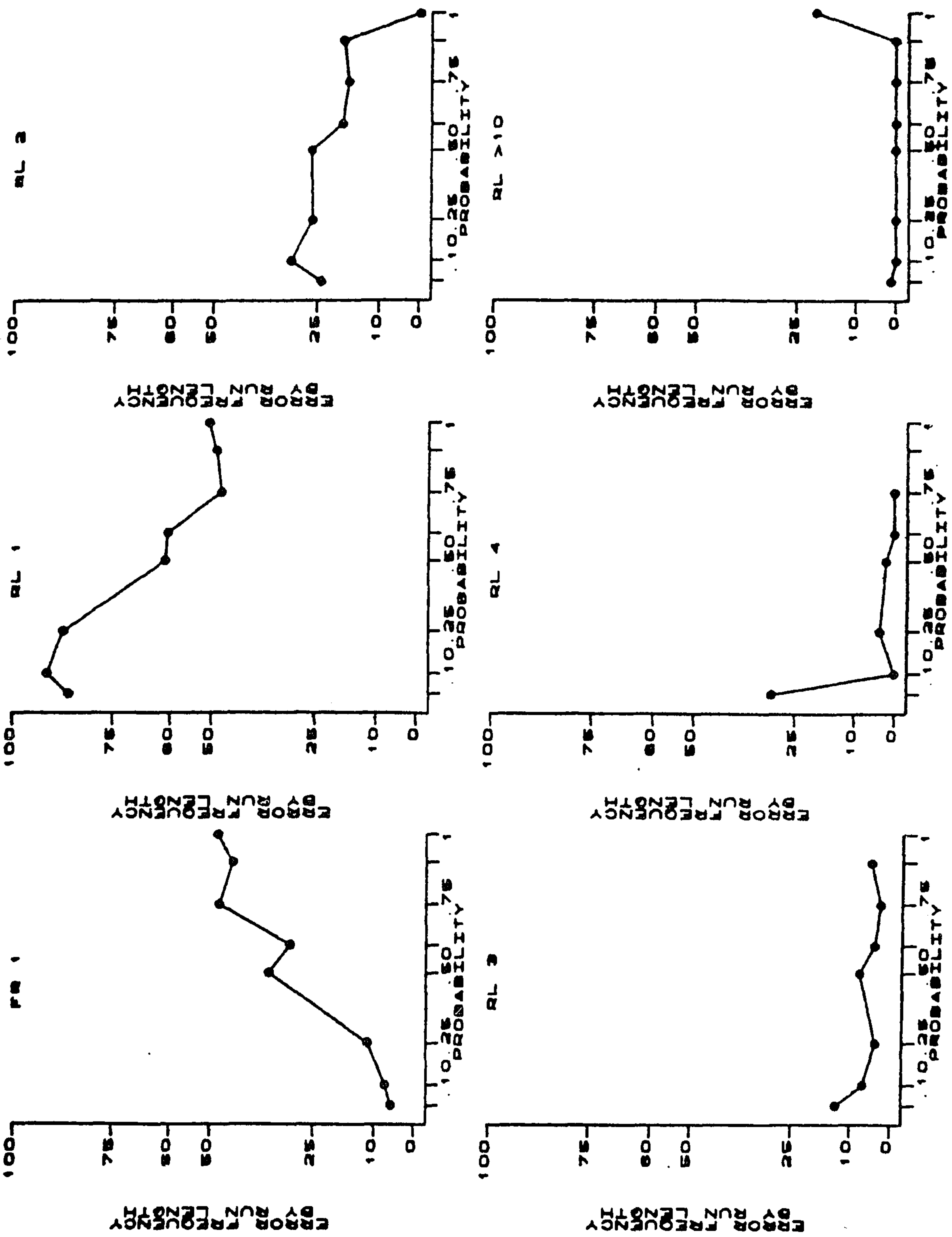

FR 1
RL 1
RL 2
RL 3
RL 4
RL >10
ERROR FREQUENCY BY RUN LENGTH
PROBABILITY
0 .10 .25 .50 .60 .75 1
0
10
25
50
60
75
100

Figure 22

Figure 23. Mean percent errors made by bird B150 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

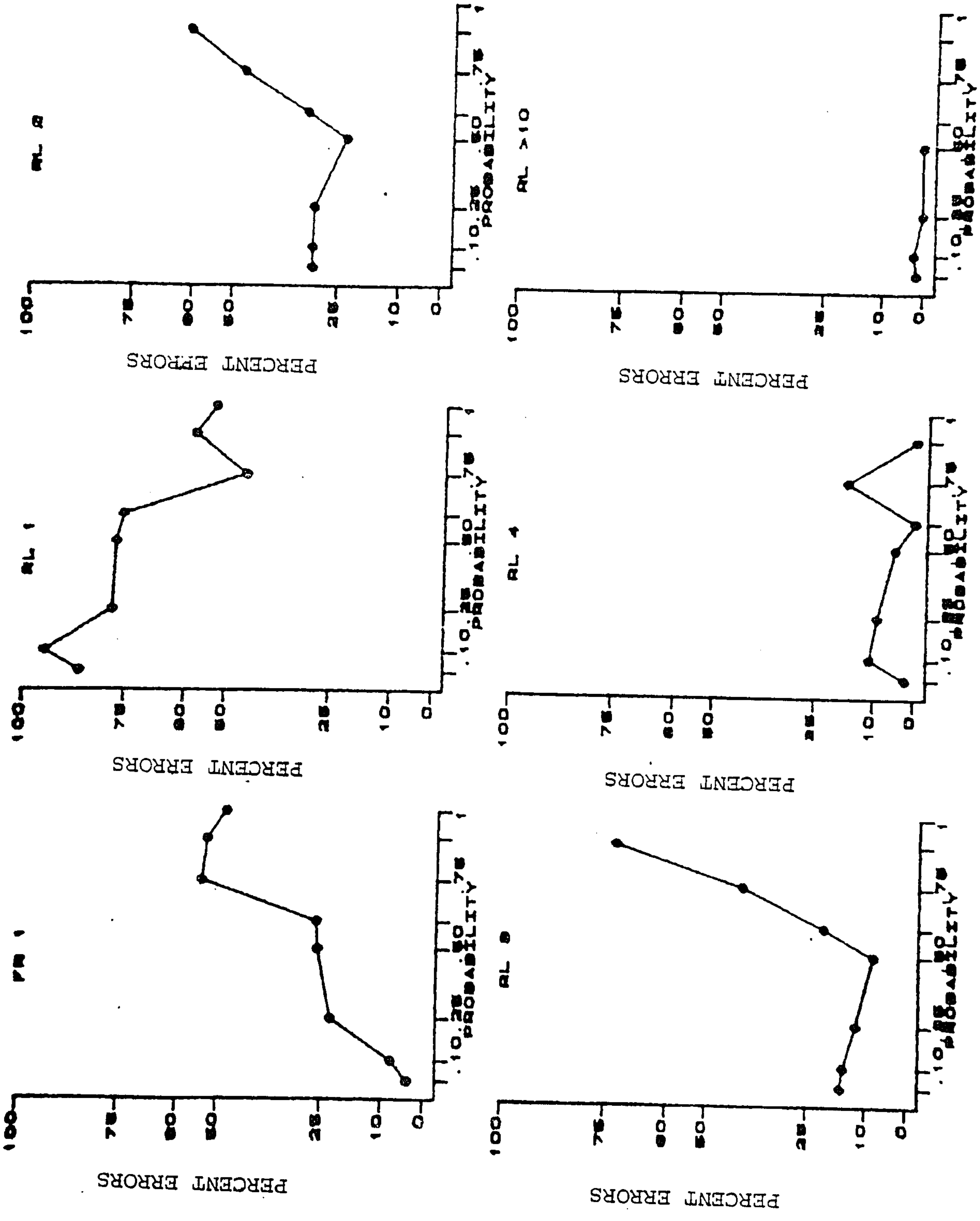

FR 1
RL 1
RL 2
RL 3
RL 4
RL >10
PERCENT ERRORS
PROBABILITY
0
10
25
50
60
75
100
.10
.25
.50
.75
1

Figure 23

Figure 24. Mean percent errors made by bird B146 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

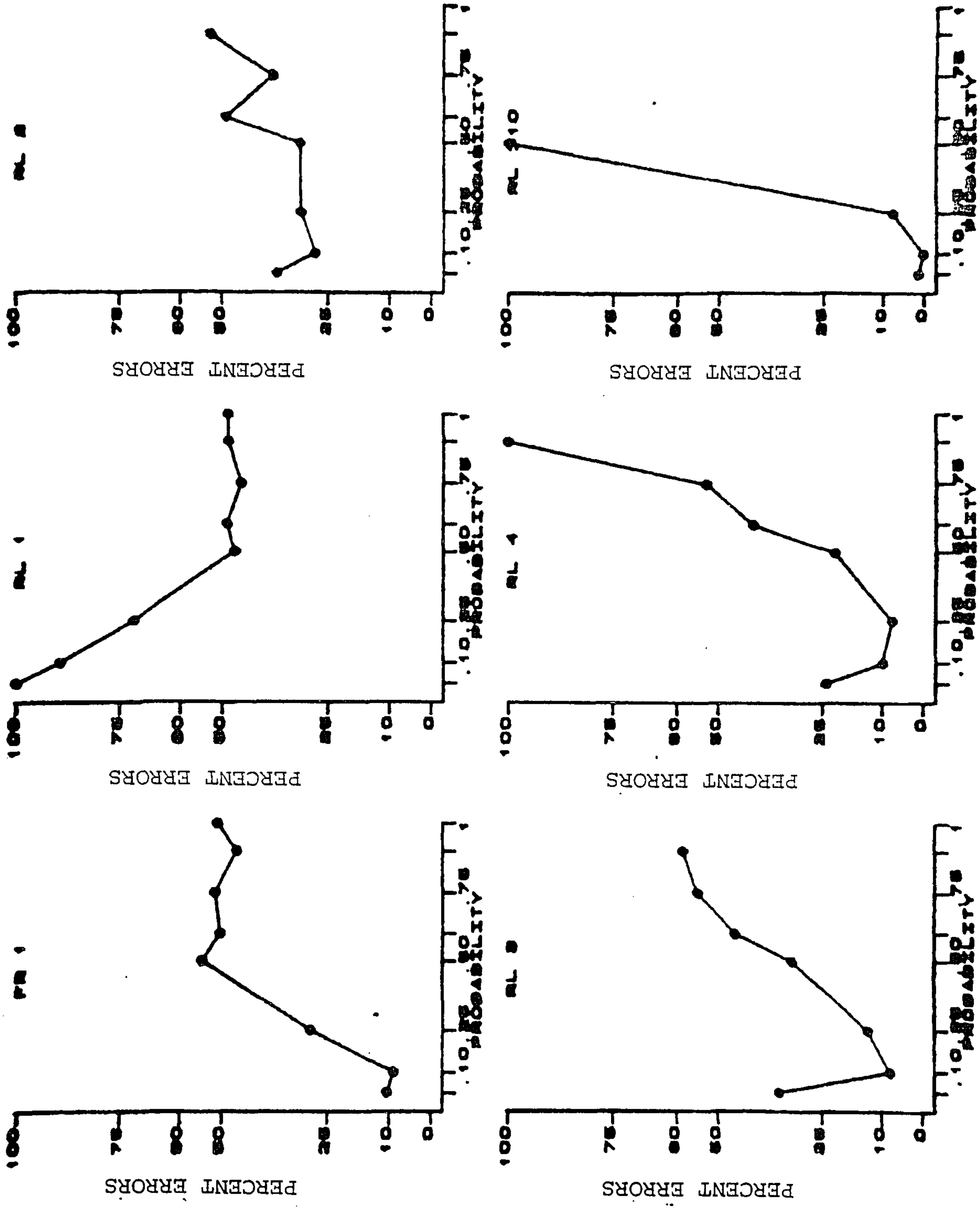

RL 2
RL 210
RL 1
RL 4
FR 1
RL 3
PERCENT ERRORS
0
10
25
50
60
75
100
PROBABILITY
.10
.25
.50
.75

Figure 24

Figure 25. Mean percent errors made by bird B145 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

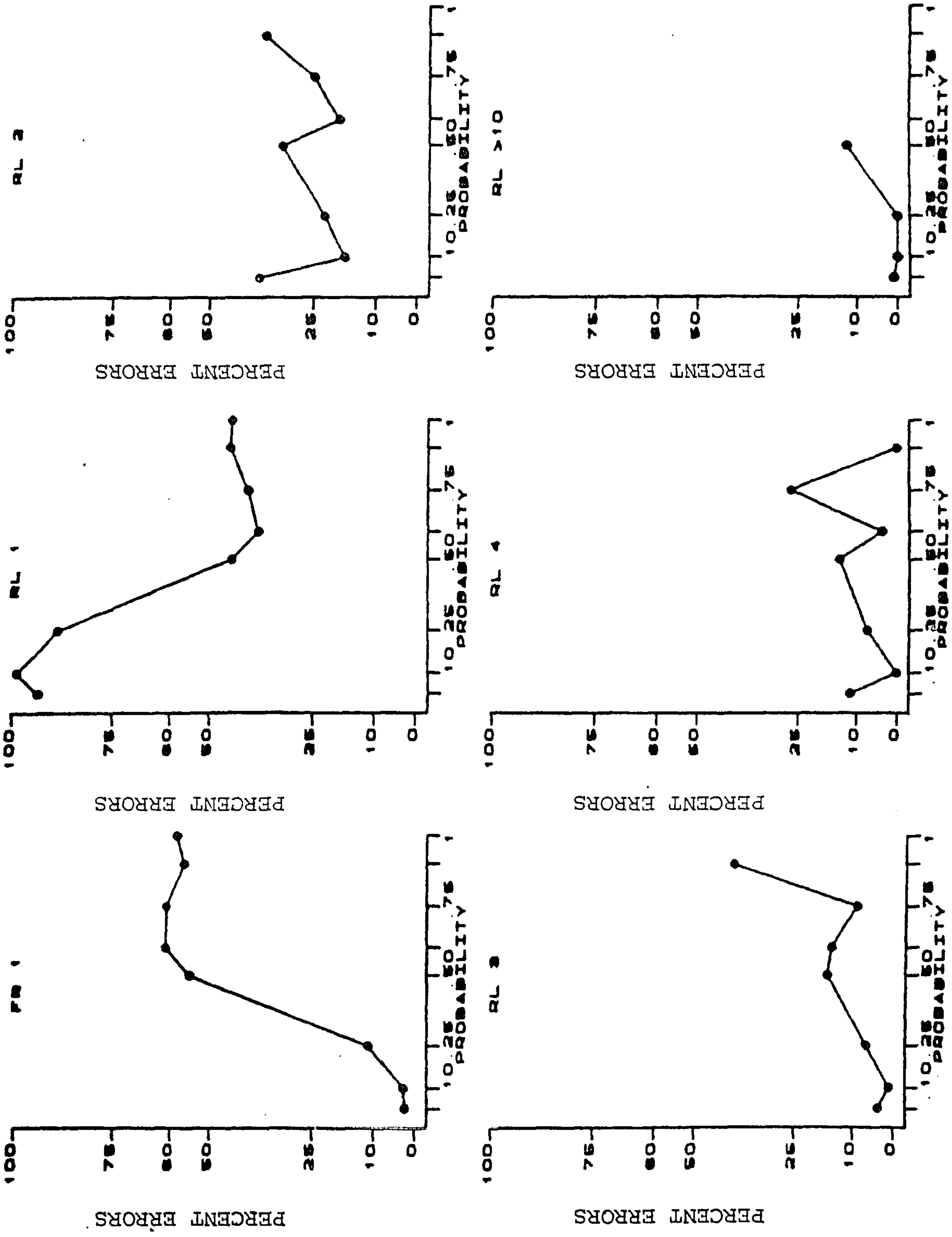

FR 1
RL 1
RL 2
RL 3
RL 4
RL >10
PERCENT ERRORS
0
10
25
50
60
75
100
PROBABILITY
.10
.25
.50
.75

Figure 25

Figure 26. Mean percent errors made by bird B127 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

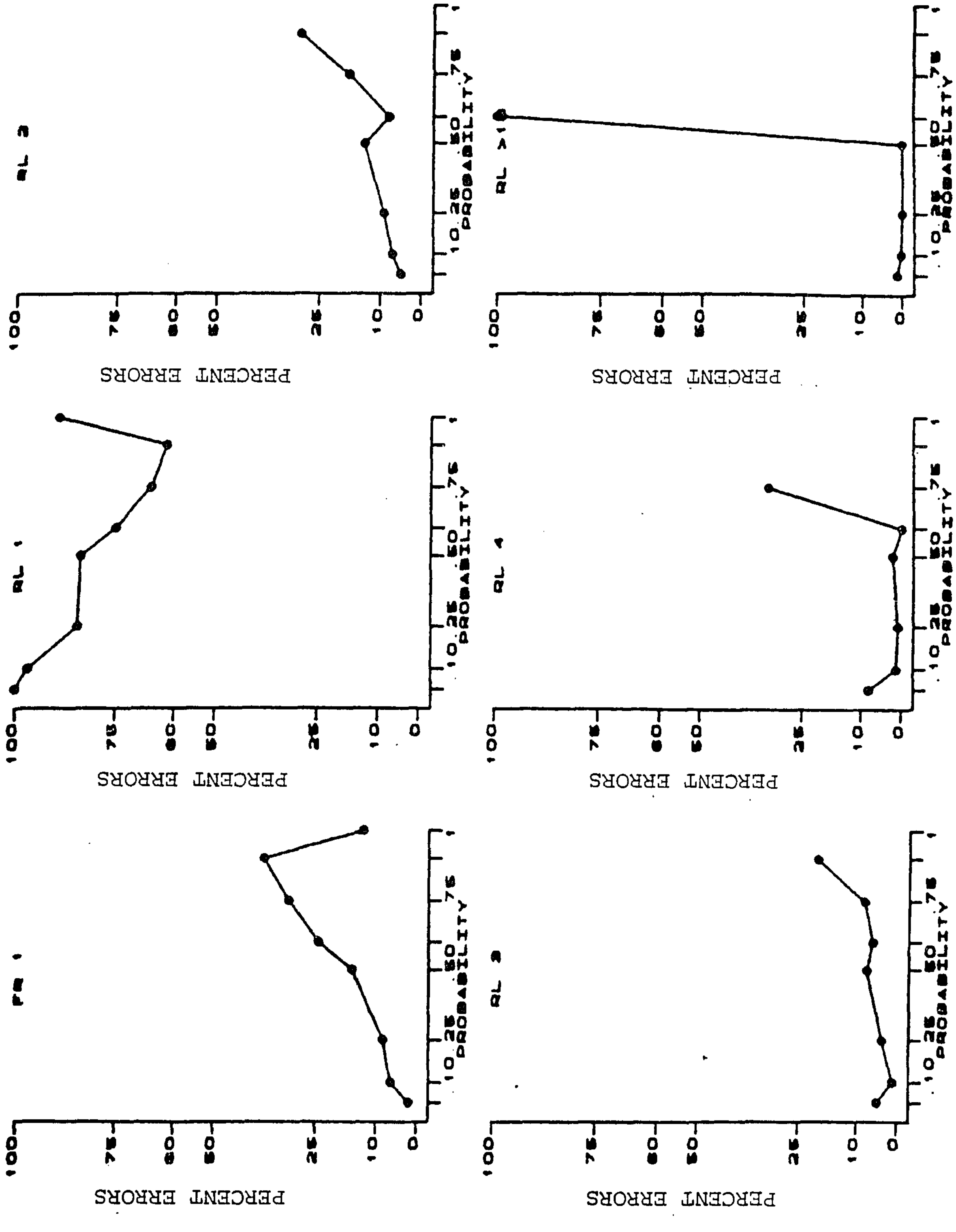

RL 2
RL >1
RL 1
RL 4
FR 1
RL 3
PERCENT ERRORS
0
10
25
50
60
75
100
PROBABILITY
.10
.25
.50
.75

Figure 26

Figure 27. Mean percent errors made by bird B147 on each of the representative run length (RL) values, RL 1 through RL 4 of the p component, as a function of p value. The error function labeled RL> 10, represents the mean percent errors on all trials containing a RL> 10, at the different p values. The corresponding error function for FR 1 trials is also shown. Each point in these functions is the mean of the last 10 sessions at a p value.

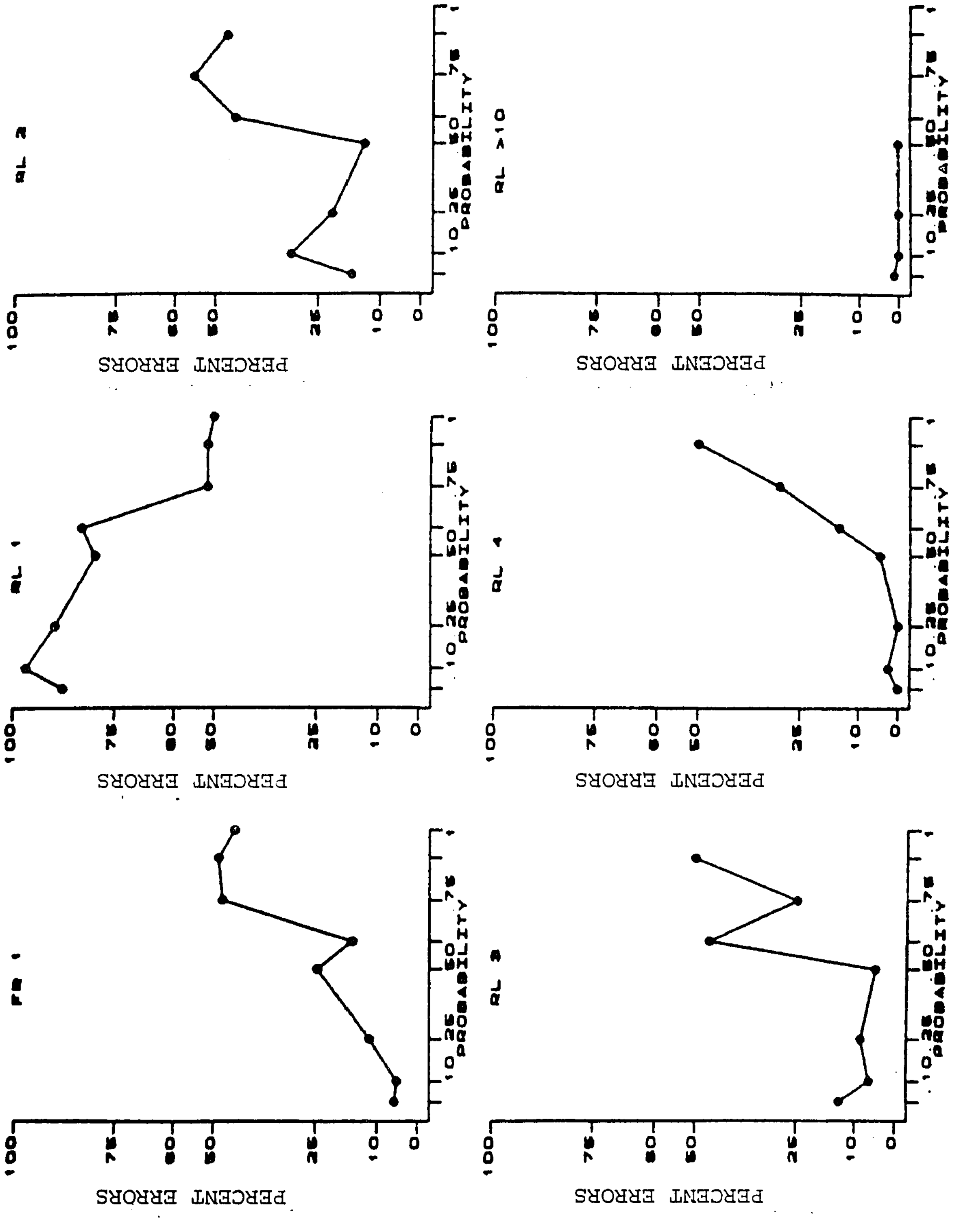

FR 1
RL 1
RL 2
RL 3
RL 4
RL >10
PERCENT ERRORS
100
75
60
50
25
10
0
PROBABILITY
.10
.25
.50
.75

Figure 27

errors at all RL values, with the exception of RL 1, for all animals. However, there appears to be a different likelihood of errors associated to the RL value. That is, the slope of the error functions for short RLs appear generally steeper than for longer RLs, suggesting that at a given p value, the shorter the RL the greater the frequency of errors obtained. This seems to be the case in spite of a few reversals, such as that at p=.75 for B127 and B145, which made more errors on RL 4 than on RL 3 trials. The high frequency of errors made by B127 on RL> 10 at p=.60, for instance, does not seem significant in view of the trend of this animal's functions at this, and larger p values. The reliability of this high score is also questionable, because at p=.60 a score for RL> 10 is based on very rare occurrences. To better appreciate the effects on RL discriminability, errors at various RL's, at each p value, were plotted as a function of RL value. These data are shown in Figures 28 through 30.

In general, choice errors on the side keys decreased as the value of the antecedent RL increased. The trend for all animals was to exhibit differential responding to RL value, across several p values, rather than to partition the RL distribution into two categories of single and multiple peck. Improvements in discrimination (fewer errors) continued as RL increased, although the rate of improvement decreased and appeared to asymptote at RL> 10.

These data are consistent with those from studies on the discriminative properties of behavior along the number of responses dimension. When pairs of FR requirements are investigated, for instance, choice errors are shown to increase as the difference between the FR values is decreased (Hobson, 1975; Pliskoff & Goldiamond, 1966; Rilling & McDiarmid, 1965). In the present study, a single peck (FR 1) value was contrasted with a distribution of RL values. The functions in Figures 28 through 30 indicate that errors increased the closer a RL value was to a single peck.

Another characteristic of the functions in Figures 28 through 30, is the relatively large difference in errors made on RL 1 compared to those on RL 2 trials. No comparable difference was obtained between any two other adjacent RL values. This indicates that, in addition to differential responding to RL value, the RL> 1 category was indeed highly discriminable from a single peck, for all animals. The difference in performance associated to these two RL values is very likely accounted for by the differences in the contingencies of reinforcement associated with them. The RL 1 value was associated with non-differential reinforcement via its indiscriminability from the contrasting FR 1 value. Multiple pecks, on the other hand, had no similar history of non-differential

Figure 28. Mean percent errors in the p component, made by birds B127, and B128, as a function of run length (RL) value, at each p value. The mean percent errors for representative RL values, RL 1 through RL 4, are shown, in addition to the mean for all RL> 10 values. Each point in the functions is the mean for the last 10 sessions at a p value.

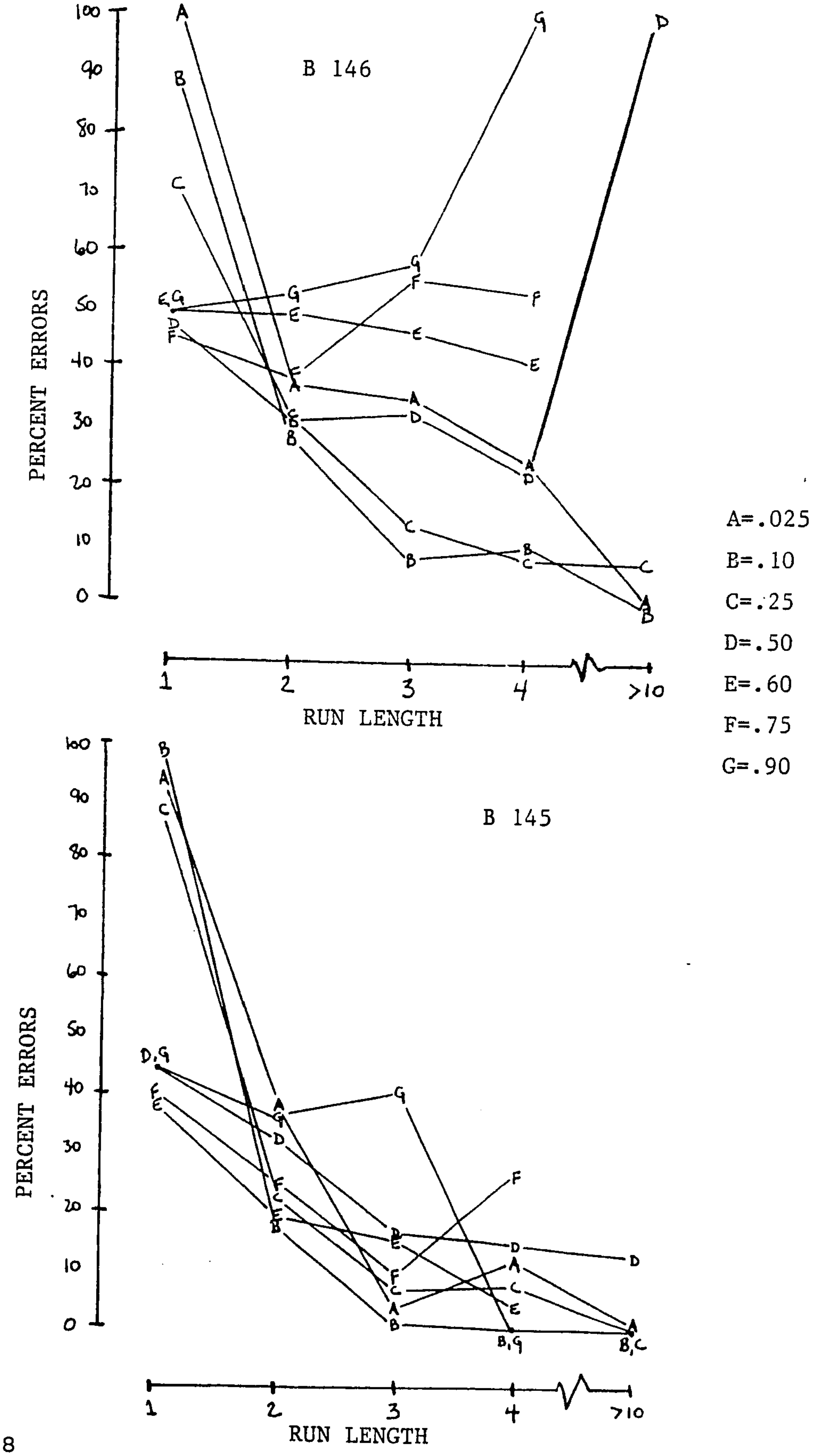

B 146
PERCENT ERRORS
100
90
80
70
60
50
40
30
20
10
0
RUN LENGTH
1
2
3
4
>10
A=.025
B=.10
C=.25
D=.50
E=.60
F=.75
G=.90
B 145
PERCENT ERRORS
100
90
80
70
60
50
40
30
20
10
0
RUN LENGTH
1
2
3
4
>10

Figure 28

Figure 29. Mean percent errors in the p component, made by birds B145, and B146, as a function of run length (RL) value, at each p value. The mean percent errors for representative RL values, RL 1 through RL 4, are shown, in addition to the mean for all RL> 10 values. Each point in the functions is the mean for the last 10 sessions at a p value.

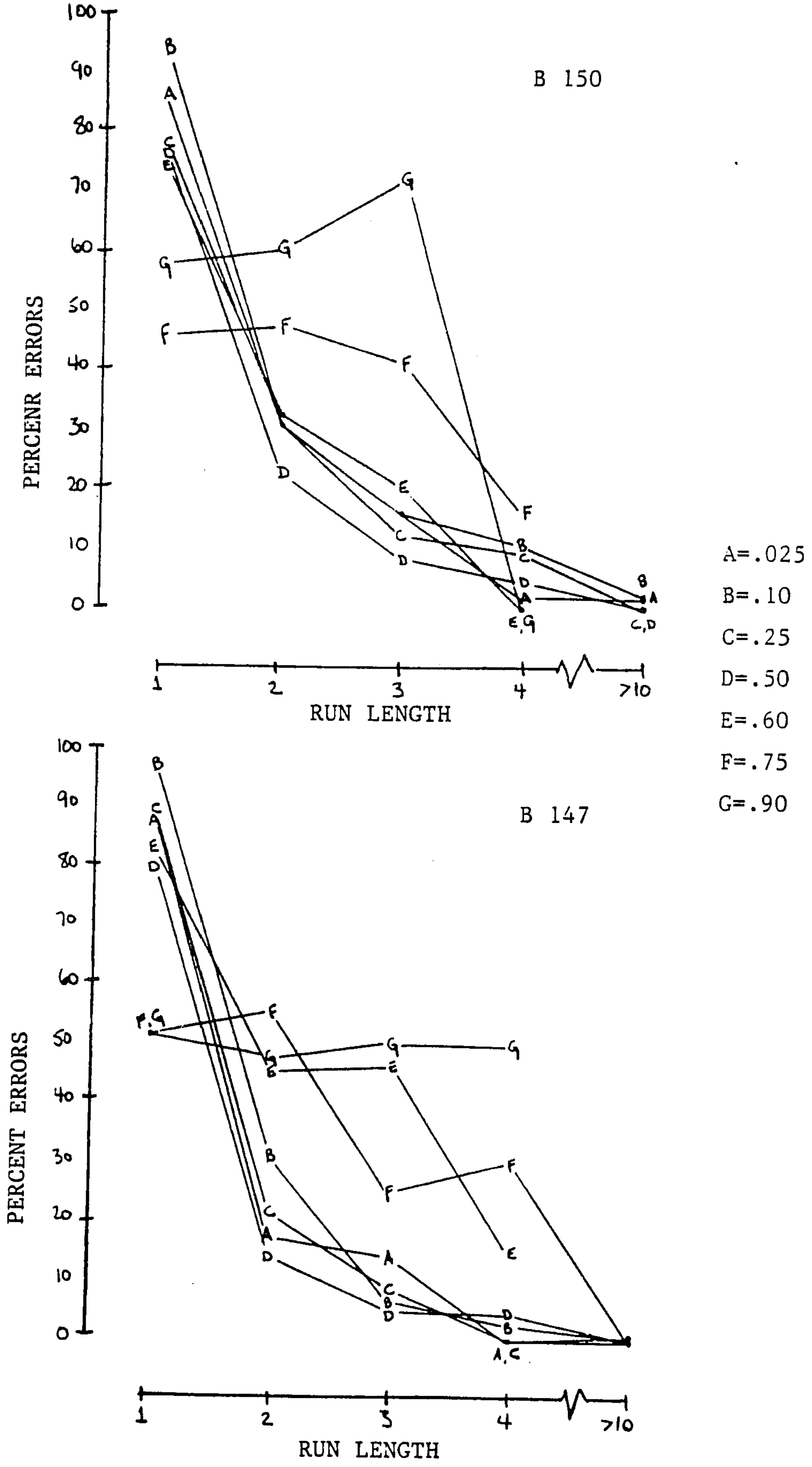

B 150
PERCENR ERRORS
0
10
20
30
40
50
60
70
80
90
100
RUN LENGTH
1
2
3
4
>10
A=.025
B=.10
C=.25
D=.50
E=.60
F=.75
G=.90
B 147
PERCENT ERRORS
RUN LENGTH

Figure 29

Figure 30. Mean percent errors in the p component, made by birds B147, and B150, as a function of run length (RL) value, at each p value. The mean percent errors for representative RL values, RL 1 through RL 4, are shown, in addition to the mean for all RL> 10 values. Each point in the functions is the mean for the last 10 sessions at a p value.

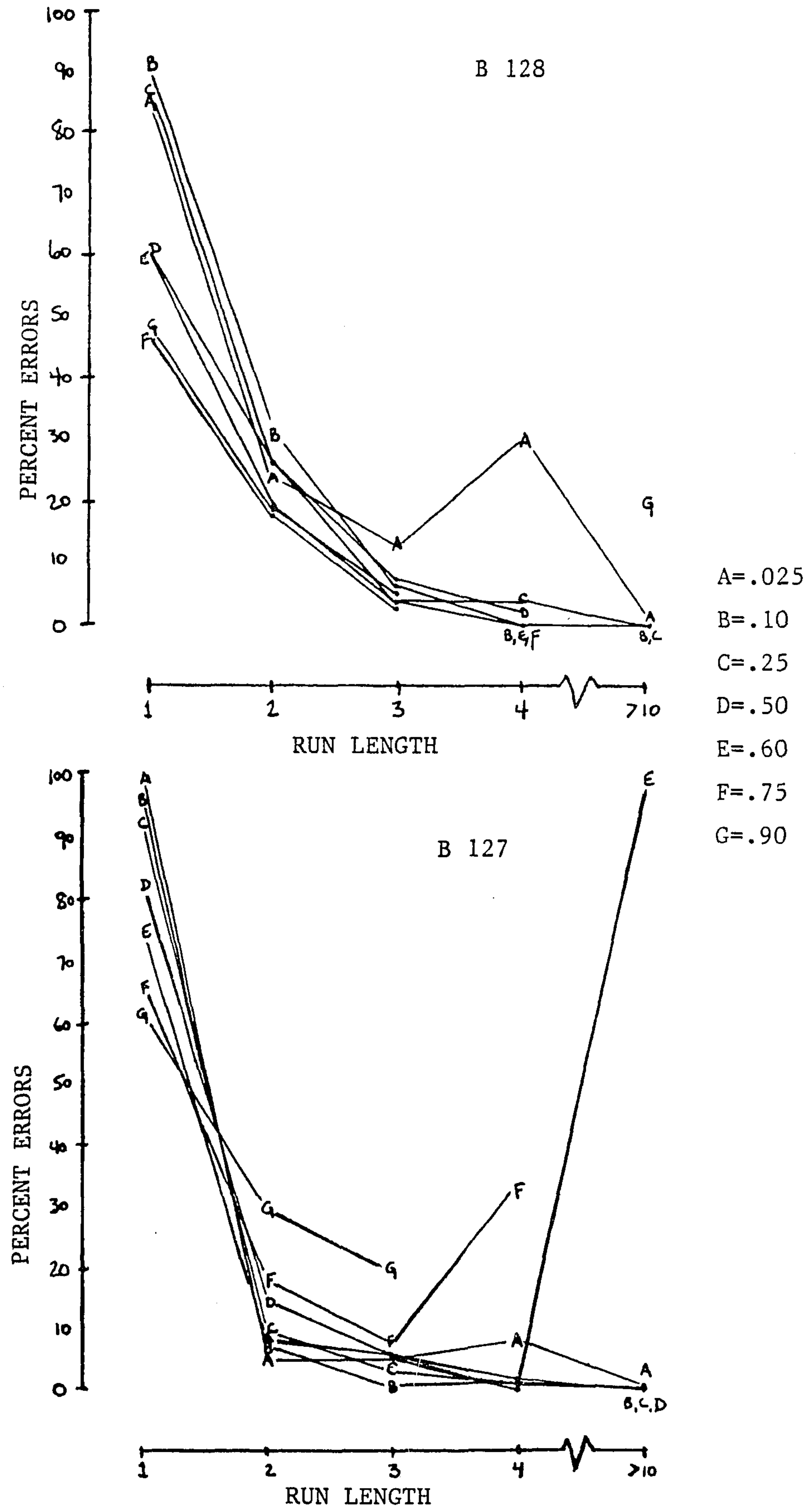

B 128
PERCENT ERRORS
100
90
80
70
60
50
40
30
20
10
0
RUN LENGTH
1
2
3
4
>10
B 127
PERCENT ERRORS
100
90
80
70
60
50
40
30
20
10
0
RUN LENGTH
1
2
3
4
>10
A=.025
B=.10
C=.25
D=.50
E=.60
F=.75
G=.90

Figure 30

reinforcement; only green choices were reinforced after RL> 1 values.

In Figures 28 through 30 errors represent red choices. The fact that the percentage of errors made on RL 1 decreased as p increased was the result of an increase in green choices on those trials (Figure 20), and reflects the fact that, as p increased, the animals' tendency to distribute their choices equally among the red and the green stimulus also increased.

A third characteristic of the error functions for the various RL values which can also be seen in Figures 22 through 27, is that the percentage of errors an animal made after a given RL value increased with increases in *p* value. Although the magnitude of the effect differed among animals, the error functions in Figures 28 through 30 are generally displaced upward with increases in p. Therefore, discriminative performance in relation to a RL depended not only on the RL value but also on the *p* value. It is also clear that errors on RL> 1 trials increased even though the reinforcement of choice on those trials was always differential with respect to single peck trials.

### Changes in the RL distribution

One factor which may have contributed to the accuracy decreases for the RL values plotted in Figures 28 through 30 is related to the increased frequency of occurrence of these values against a decrease in the frequency of longer

RL values. From examples given in Table 1, it will be remembered that the probability of occurrence of large RL values, i.e., RL 200, shows a sharp drop as the selected p values increased. Table 1 also shows that with increases in probability value, the relative frequency of short values, (e.g., RL 3), also increases up to the middle range of p values, where their frequency begins to decrease in favor of the ever increasing RL 1 value. It is possible then, that the RL error functions show the effects of these changes; that is they show what could be labeled a "context" effect. The term is used here to refer to the proportion of the RL distribution that is occupied by the different RL values relative to each other. Thus, for any given RL value, the relative frequency of all other RL values in the distribution constitute the context of that RL value. Furthermore, when an individual RL value is considered across several p values, given that the distribution of RL values changes with the value of p, we find the given RL embedded in a different context at each p value. Thus, on a RL 2 trial at a p=.025, for instance, an animal was asked to discriminate a RL 2 from a single peck against a background of large RL values; at a p=.75, on the other hand, the average RL value is less than 2 and a RL 1 value is expected to occur on 75 out of 100 trials. Under the latter conditions, the context for a RL 2 is one of frequently occurring short RL values. Perhaps the discriminability of short RLs was affected by such context effects. If so, discriminability of short RLs was decreased by decreases in the relative frequency of large RL values. This effect resembles the decrease in FR discriminability with decreases in the 'background' FR value (Hobson, 1975). In her study, animals were asked to discriminate various FR values against a constant, 'background' FR value. Hobson (1975) reports improvement in discriminability as the size of the constant FR was increased.

### Changes in differential and non-differential reinforcement.

Another factor that may have contributed to the error increase in RL> 1 trials is represented by the decrease in the frequency of occurrence of these trials with increases in p value, as shown in Figure 2, where RL> 1 trials are identified as Type III trials.

One major consequence of decreasing the RL> 1 portion of the probability distribution was that, as p increased fewer trials of the p component represented an opportunity for differential responding (RL> 1 requirement), and, therefore, represented a decrease in the frequency of differential reinforcement in the p component. These changes in differential reinforcement opportunities may have contributed to the increase in errors on RL> 1 trials.

On the other hand, it was shown earlier that simultaneous to the decreased opportunity for reinforcement of the RL> 1 - green relation, there was a systematic increase in the animals' tendency to choose the red and the green stimulus equally frequently on single peck trials; that is, it will be remembered that as the frequency of green choices increased, it approached the frequency of red choices (Figure 20). Because equal likelihood of reinforcement for both red and green choices is approached by increasing responding to one side key,it can be said that the data in Figure 20 also indicate that a position preference on single peck trials was increasingly reinforced with increases in $p$. This trend was further facilitated under the $p=1.0$ condition, where all trials in the FR 1 and the $p$ component were single peck trials. In effect, most animals adopted total position preference at this final $p=1.0$ value.

Perhaps the error increase in RL> 1 trials of the $p$ component was the result of stimulus generalization of position based responding after RL values greater than a single peck. It was shown earlier, when discussing the data plotted in Figures 14 and 15 that, in effect, position preference increased in both components with increases in $p$ value. The error function for RL> 1 in Figure 21 also indicated an increase in position preference, i.e., increases in non-differential responding to color on those trials. This generalization effect could have, in turn, been facilitated by the concurrent decrease in the opportunity for reinforcement of the RL> 1 - green relation, with increases in p value. However, because the increase in non-differential reinforcement on single peck trials was simultaneous with the decrease in the opportunities for differential reinforcement, it is not possible to determine their relative contribution to the error increase in RL> 1 trials. Nevertheless, the fact that increases in position preference were observed on both the FR 1 and the p components, points to the effects of non-differential reinforcement on single peck trials as a strong contributor.

A similar generalization effect or reduced discriminative control of responding by a stimulus dimension due to exposure to non-differential reinforcement with respect to one stimulus value along that dimension, was reported by Blough (1969). His was a study of conditions that render a stimulus dimension irrelevant, and although procedural differences do not allow for a direct comparison with the present study, some analogies can be drawn. In Blough's (1969) study, pigeons responding was reinforced in relation to a combination of a visual stimulus and an auditory stimulus. Reinforcement always occurred at the same combination of light and tone value; any other combination of light and tone values went unreinforced. Under these conditions, the animals were sensitive to changes in stimulus value along both the wavelength and tone dimensions. On the constant stimulus phase, Blough presented the animals with reinforcement in the presence of the same stimulus combination as before, but for a block of sessions the visual stimulus remained at its reinforced value, as a member of all stimulus combinations, and only the tone values were allowed to vary; in another block of sessions, it was the auditory stimulus which remained constant at its reinforced value across all light-tone combinations. In the constant stimulus phase, then, the animals had no opportunity to respond to other values along the constant stimulus dimension. This is similar to the reduction in opportunities for differential responding at RL> 1 values in the present study. At the same time, in Blough's constant stimulus phase the constant stimulus was not a predictor of reinforcement; an analogy could also be drawn here with the fact that the FR 1-RL 1 value had no perfect correlation with reinforcement of one side key choice. In Blough's study, the effects of the constant stimulus condition were determined by returning to the base line condition where all values along the two stimulus dimensions were again introduced. It was found that, after each constant procedure the constant stimulus had lost control of the animal's responding, as indicated by an increase in generalization of responding to all values along the constant stimulus dimension, whereas differential responding to the variable stimulus was maintained. Blough suggested that the differential reinforcement contingencies that were interpolated between base line sessions, were responsible for the decrease in discriminative performance. In addition, Blough (1969) interpreted the decrease as indicating that the animal no longer "attended" to the constant stimulus dimension. The relevant aspect with respect to this experiment is that discriminative control by one stimulus dimension was reduced by alternating exposure to non-differential reinforcement with respect to one stimulus value within that dimension. The latter can be analogous to the introduction of non-differential reinforcement with respect to one value along the RL dimension (single peck), which may have accounted for the relative loss of discriminative control by other RL values (RL> 1 values). Unlike Blough's study, however, the present study introduced controlled proportions of such non-differential reinforcement via changes in $\underline{p}$ value, and is therefore, possible to show different degrees of loss of discriminative control as a function of the $\underline{p}$ value.

Given the observed changes of performance on RL> 1 trials, it can be suggested that, RL discriminability was not eliminated, but rather that the error increases in RL> 1 trials with increases in $\underline{p}$ value represent a decrease in the likelihood of occurrence of the controlling stimulus-response relation. This interpretation appears to be supported by a related study on conditions leading to changes in stimulus control (Stoddard & Sidman, 1971). In their study, Rhesus monkeys were exposed to a block of non-differential reinforcement interpolated between a base line condition of differential reinforcement. As a result of abolishment trials in the non-differential condition during which no discrimination was possible, the animals' visual discrimination was replaced by position preferences. In addition, responding during differential trials immediately following exposure to non-differential reinforcement was either disrupted or almost completely eliminated, depending on the level of difficulty of the visual discrimination. Also, position preferences were carried over to the differential condition. These results appear related to those in the present study in that, disruption of performance on the differential RL> 1 trials, e.g., decreases in accuracy and increases in position preference, were more evident as the difficulty of the discrimination increased, i.e., as the p value increased.

In the Stoddard and Sidman (1971) study, it was also found that the reinstatement of differential reinforcement resulted in a faster acquisition than on first exposure. The authors interpreted these results to indicate that the controlling stimulus-response relation represented by the visual discrimination had not been eliminated but that, instead, its probability of occurrence had been decreased.

A similar result was obtained in the present study when an informal recovery condition was run for all animals. After exposure to the p=1.0 condition within the ascending sequence, five out of six animals were returned to a p=.10 condition. For all animals, the re-acquisition function started at a much higher level on the first session -at, or above 60% accuracy- than on the original acquisition at p=.025 where all animals were at chance level on the first session. Moreover, all five animals stabilized at the same average accuracy level they had exhibited on first exposure to p=.10. However, most animals' accuracy functions trailed below the first p=.10 function for several sessions. When the number of sessions needed to reach, and stabilize, at the average accuracy level on second exposure to p=.10 was compared to the respective number of sessions needed on original acquisition at p=.025, it was found that, on the average, the animals took five more sessions on re-acquisition at p=.10 than on acquisition at p=.025. Nevertheless, birds who show greater disruption of differential responding to RL value in Figures 28 through 30, generally took a greater number of sessions. Bird B146, for instance, needed 10 more sessions on re-acquisition. On the other hand, birds who show minimal disruption, needed fewer sessions. Thus, B127 needed only 4 more sessions on re-acquisition, whereas B128 showed practically no difference in number of sessions to stability.

It appears then, that the data from this experimental design makes contact with various other studies on stimulus control, especially those interested in the stimulus functions of behavior. However, it differs from them in the complexity represented by the simultaneous changes that take place when the probability variable is manipulated. Whereas it is not possible to isolate the effects of any one of such changes, the reliability of the control over discriminative performance that resulted from merely 'dialing' the p, makes the present design a most economic procedure to control choice behavior.

Similarly, the present design can provide a methodological contribution to those studies concerned with the stimulus function of behavior. For instance, those interested in the dicriminability of a behavioral stimulus relative to an exteroceptive stimulus, have typically utilized only one pair of behavior values representing only one level of behavior discriminability (Cohen et al. 1980; Urcuioli Honig, 1980). The data presented in Figure 9, for instance, clearly indicate that the present procedure can reliably generate different base line levels of behavior discriminability against which to asses, parametrically, the relative control exerted by various exteroceptive stimuli.

# Summary

This study investigated the stimulus function of the animal's own behavior in the control of subsequent behavior, when the behavior acting as the discriminative stimulus is manipulated along the number of responses dimension. On a conditional discrimination paradigm, two alternating behavior requirements varied in the number of responses required on the center key. When the two choice stimuli were presented on the side keys, the reinforcement of the animal's choice of side key stimulus was conditional on which of the two antecedent behavior requirements it had completed on the center key. The animal's accuracy of choice indexed the extent to which the antecedent behavior on the center key exerted discriminative control over subsequent choice behavior. In other words, accuracy of choice indicated the extent to which the animal discriminated its preceding behavior.

One of the two center key behavior requirements was a fixed ratio of one response (FR 1). The FR 1 requirement was a constant component in all pairs of behavior requirements. The alternating component was a probability requirement p whose value was changed after a criterion number of sessions.

Under the FR 1 requirement, the probability that a center key peck would produce the side key stimuli was p=1.0, i.e., a single peck always produced the stimulus change. Under the p requirement, the probability that a center key peck would produce the side key stimuli was manipulated as the independent variable of this study. The probability value that was assigned to behavior on the p component applied to each and every center key response the animal made under the p component. Under these conditions, a random distribution of ratios of responses to stimulus change was generated in this component. The values of such ratios or runs of responses were identified as run length (RL) values. The statistical properties of the RL distribution are known and specifiable in advance, although not the sequence in which the RL values will be generated, i.e., it is a random distribution of RL values.

With this procedure, a gradient of overall accuracy level was obtained as a function of p value. The orderliness of the relation between p value and accuracy level was shown for individual data (Figure 16), as well as for group data (Figure 9); the p values investigated effectively sampled various degrees of discriminability of behavior differences. Control of accuracy level by p value was such that the accuracy obtained within the first two sessions, at a given p value, was a predictor of the mean accuracy level to be achieved at that value.

The systematic decrease in the animals' overall accuracy of choice with increases in p value, was accounted for in terms of an increase in the frequency of abolishment trials (Keller & Schoenfeld, 1950). The procedure leading to this accuracy decrease can also be described as the weakening of the reinforcement contingencies (Nevin, et al. 1982); this resulted from increasing the frequency of reinforcement of errors with respect to one of the two discriminative stimulus-response relations supporting the base line discriminative performance, i.e., performance established at $p$=.025.

The effects that this procedure had on discriminative performance were shown in terms of various measures. Discriminative performance, as measured by overall accuracy, showed a gradual decline, eventually to chance, with increases in p value. However, when discriminability of individual RL values was considered, it was found that whereas accuracy of choice as a function of RL value exhibited a decrease with increases in p value, the effect was small for some animals, and for others, differential responding to RL value was not eliminated even at the higher p values. Because the extent of RL discriminability cannot be reflected by the overall accuracy measure, it is concluded that accuracy in individual trials, i.e., accuracy by RL, is a more analytical measure of the animals' performance. With respect to performance in conditional discrimination paradigms, it has already been suggested that the analysis of behavior by trials is needed, beyond the overall accuracy measure (Sidman, 1980), and by others as well.

The changes in discriminability exhibited by the various RL values were discussed in terms of the following factors. One is the fact that the reinforcement of errors sets an upper limit to the animal's accuracy in both, the FR 1 and the p component. This is because, the increased reinforcement of the RL 1 - green relation not only abolished discriminative performance in the FR 1 component, but it was also associated to a decrease in the frequency of occurrence of discriminable RL> 1 trials in the p component. The fact that, when presented, any RL> 1 requirement was associated with differential reinforcement must have accounted for the maintenance of differential responding to RL value across p values (Figures 28 through 30). However, the proportion of the RL distribution that was occupied by the discriminable RL> 1 values decreased, and was eventually eliminated at $p$=1.0. With no differential behavior requirement on p trials, discriminative performance was also eliminated in the p component.

On the other hand, the error increases on the various RL values were viewed in terms of possible context effects, stemming from the changes that the RL distribution undergoes with changes in the p value.

In relation to the animals' discriminative performance as a function of the different RL values, the following considerations were made. First, the simultaneous changes in differential and non-differential reinforcement that take place with increases in p value, were discussed as responsible for the reinforcement of a position preference on single peck trials; and that such reinforcement possibly accounted for a generalization effect to RL> 1 values, where RL values closer to a single peck were the most affected by the position based responding that was increasingly reinforced on single peck trials.

Second, the relation of the present procedure to other studies which investigate the conditions leading to the abolishment of discriminative performance, or to the loss of stimulus control (Blough, 1969; Sidman & Stoddard, 1971), was discussed.

The results obtained indicate that the use of a probability manipulation as a response requirement is a feasible method with clearly replicable results, for investigating the discriminative control of behavior by the animal's own behavior.

One advantage of the use of probability in this procedure is that a single p value of this variable generates all possible RL values, and thus allows for the determination of discriminability of behavior within a wide range of points along the number of responses continuum. This provides an economy of procedure to investigate a greater range of values that has been previously investigated.

Finally, it was suggested that the present design could be used to generate different base line levels of behavior discriminability, against which to assess the relative control of various exteroceptive stimuli.

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