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RESPONSE BIAS AND SENSITIVITY OF PIGEONS DURING AUDITORY DISCRIMINATION AND GENERALIZATION

by

RICHARD PAUL FOX

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.

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Abstract

RESPONSE BIAS AND SENSITIVITY OF PIGEONS DURING AUDITORY DISCRIMINATION AND GENERALIZATION

by

Richard Paul Fox

Advisor: Eric G. Heinemann

The purpose of this study was to investigate the effects of various combinations of presentation proportions of stimuli and payoff values associated with response choice upon response bias and sensitivity during auditory discrimination and subsequent generalization. Performance during the presolution period of discrimination learning was compared with performance during probability learning to determine the extent to which behaviors in these two situations resemble each other.

Five groups of pigeons were trained to discriminate between two intensities of white noise (S1 and S2) by pecking one key for S1 and another for S2. The intensity difference between the stimuli was 8 dB. A sixth group was trained with probability learning. A rerun procedure was used, where trials were repeated following incorrect choices.

Discrimination groups received different proportions of stimuli or different proportions of reinforcement for correct responses. The proportion of reinforced trials relative to initial presentations of S1 and S2 per session were 24/40 and 24/40, 15/25 and 33/55, 15/15 and 33/65, 15/40 and 33/40, and 9/15 and 39/65, respectively. After 100 days of discrimination training, the intensity difference between the stimuli was changed over a period of 3 days to 2 dB. Deginning with Day 122 all groups were given 10 days of generalization testing to intensities over a range of 23 dB.

Analyses were made of proportion of errors and of measurements derived from the theory of signal detection. The results from the presolution period of the discrimination task indicated that (a) performance was similar to probability learning, and (b) the proportions of responses made matched the proportion of reinforcements given for each response. Matching was also found with probability learning. Results from the large sound differences phase indicated that (a) sensitivity was unaffected by the independent variables, and (b) bias varied as a function of stimulus presentation proportion, regardless of response payoff. Results from the small sound difference phase indicated that (a) sensitivity differed unsystematically between groups, and (b) bias varied as a function of the product of stimulus presentation and payoff. Results from generalization indicated that (a) sensitivity was unaffected by the independent variables, (b) bias was a function of the product of the independent variables, (c) the level of attention to sound intensity varied as a function of relative payoff, (d) the level of attention during generalization and the length of the presolution period were controlled by the same variable, and (e) sound intensity had no control over responding in subjects trained with the probability task.

The results were discussed in terms of theories of learning and signal detection.

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The author is especially grateful to his advisor, Professor Eric G. Heinemann, and to Professor Solomon Weinstock for their support and guidance during the course of this research. He also wishes to thank Professor Donald Mintz and Professor Ralph Miller for their helpful comments.

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INTRODUCTION

In the typical signal recognition task a subject is presented with a series of discrete trials. A stimulus is presented on each trial, and the subject must indicate which stimulus occurred by choosing between two responses. If a correct choice is made, the subject may be rewarded.

In the typical probability learning task a subject is also presented with a series of discrete trials. On each trial the subject must choose between one of two responses. If he chooses correctly, reinforcement is provided. On a given trial no new information is provided for the subject to determine which response will be rewarded. The only available information comes from the past pattern of reinforcing events.

It can be seen that the probability learning task and the signal recognition task are similar. The only difference between the two is that in the signal recognition task varying amounts of information from external stimuli are available for the subject to choose the correct response, whereas such information is not provided in probability learning tasks.

It is possible to view the two tasks in terms of discriminability. If the subject can discriminate the stimuli perfectly on every trial, he can always choose the correct response. If the subject cannot discriminate between the stimuli, the situation becomes identical to a probability learning task. The two extremes are perfect discriminability and no discriminability. Between these extremes a subject will respond differentially to the stimuli, but he will also make incorrect responses on some trials.

A factor which enters into response choice, in addition to how well a subject discriminates the stimuli, is response preference, or response bias. Response bias may be established by means of extraneous variables or by experimental manipulation. The experimenter may control response bias by varying the reward a subject is given for making a particular response. This can be accomplished by manipulating the presentation rate of the stimuli or by manipulating the costs and values of making the various correct and incorrect responses.

Probability Learning

Studies of probability learning have found in some instances that the proportion of trials on which a subject makes a given response tends to match the proportion of reinforcements given for having made that response. This phenomenon is known as probability matching. In other instances the subject learns to make one response on all trials. This phenomenon is referred to as absorption. Absorption to the most frequently reinforced choice is often referred to as maximizing. There are a number of probability learning studies where results are categorized in terms of matching or absorption. Reviews of these studies may be found in Estes (1963), Jones (1971), and Sutherland and Mackintosh (1971, chap. 11-12).

The differences between the outcomes reported seem to reflect phyletic differences in subjects and procedural differences in experiments. Specifically, different results have been obtained using correction, noncorrection, and rerun procedures. These terms are not used uniformly by all authors. To avoid confusion they are defined here, and these definitions apply in the following discussion. In a typical correction procedure an incorrect response is followed by the presentation of the correct choice alone. This is often referred to as guidance. For example, a pigeon in a Skinner box may be presented with only the correct response key illuminated; a rat in a _T_ maze may be allowed to retrace the incorrect arm and enter the correct arm. In a noncorrection procedure either an incorrect or a correct response terminates a trial. All trials are independent of the previous response. In a rerun procedure an incorrect response is followed by repetition of the trial until a correct choice is made.

All animals appear to show absorption when trained under a noncorrection procedure (Bitterman, Wodinsky, & Candland, 1958; North & McDonald, 1959; Graf, Bullock, & Bitterman, 1964; Weinstock, North, Brody, & LoGuidice, 1965). In the study by Weinstock et al. some subjects made the less frequently reinforced response on every trial. Matching by rats trained under a rerun procedure has been reported by Weinstock, Robbins, and Chen (in press). When a correction procedure is used, the results depend upon what animals are used as subjects. Bitterman (1965) has summarized some of the phyletic differences obtained from probability learning experiments. He has concluded that rats and monkeys trained with correction procedures tend to maximize, whereas fish tend to match. Robbins (1969) has also obtained absorption with rats trained under correction. Several subjects in this study absorbed on the alternative with the lower probability of reinforcement. Estes (1957), Hickson (1961), and Weitzman (1967) have reported matching with correction. However, Bitterman et al. (1958) have noted that data for individual subjects in Estes' study do not show matching. A similar finding has been reported by Sutherland and Mackintosh (1971, p. 407) for the data in

Weitzman's study. Graf, Bullock, and Bitterman (1964) have noted that the rats in Hickson's study displayed a tendency to choose on each trial the correct alternative of the last trial.

Bullock and Bitterman (1962) found matching by pigeons with a visual probability learning task using a correction procedure. The visual task involved a choice of responses to keys of two different colors presented simultaneously, which varied randomly in position from trial to trial. The proportion of responses to a given color was found to vary directly with the proportion of reinforcements provided.

A more thorough investigation of probability learning by pigeons was conducted by Graf et al. (1964). Several training conditions were presented. Maximizing was found under noncorrection conditions; matching appeared under rerun conditions in visual tasks. When a correction procedure was used, the results differed depending on whether subjects were required to peck a center key before the choice conditions were made available. Matching was found when the center key was not used; maximizing was found when the center key was used. The authors maintained that the pigeons maximized in a spatial task where response choice was based upon position, and where rerun was used. However, the data indicate that of six subjects, two matched, two tended toward maximizing, and two responded midway between maximizing and matching. Therefore, the conclusion that the birds maximized is misleading. Finally, matching was found in a successive problem where the probability of reinforcement on each key was conditional upon the color presented on both keys. A rerun procedure was used in this study.

Further developments in the research on probability learning in pigeons may be found in experiments reported by Shimp (1966, 1973).

In one experiment (Shimp, 1966, Experiment I) pigeons were trained by a rerun method for 20,000 trials on a successive visual task. The birds approximated matching on the first 1400 trials. This corresponded to the number of trials presented by Graf et al. (1964). However, by the end of training, the response which was reinforced on 75% of the trials was chosen on 86% of the trials. Shimp concluded that the birds tended to "overshoot" matching in the direction of maximizing. In another experiment (Shimp, 1966, Experiment II) matching was observed in a spatial task where reinforcement was not available on every trial on a choice key and there was no intertrial interval. A modified rerun procedure was used, where trials following incorrect responses were signaled by changes in the key colors.

Shimp analyzed these results by sequential statistics. He concluded that all the results could be accounted for in terms of the principle of "momentary maximizing". This principle states that on a given trial a subject chooses the response which momentarily has the greater probability of reinforcement. In a more recent experiment (Shimp, 1973, Experiment I) the response reinforced on 90% of the trials in a visual task under rerun conditions was chosen on an average of 98.2% of all trials. Shimp concluded that the birds tended to deviate from matching in the direction of maximizing.

In a study by Mackintosh, Lord, and Little (1971) pigeons were found to overshoot a 70% matching value in both spatial and visual probability learning tasks under correction procedures. The subjects made the majority response on 93.4% of the trials under spatial conditions and 88.40% of the trials under visual conditions.

Fischer (1972) found that chicks were able to reach a criterion of 90% responding for a response which was rewarded on 70% of all trials. These results were obtained from visual as well as spatial probability learning tasks. In the spatial tasks correction and noncorrection procedures were used. When correction was used, the animals took longer to reach the 90% criterion.

It is clear from all of these experiments that the results obtained depend on the details of the experimental procedure employed. Any general assertion that a particular species always shows matching or absorption is incorrect.

It has been noted that the essential difference between the behavior of a subject in a recognition task and a probability learning task is that in the former the subject's response is based upon information provided by discriminative stimuli, whereas in the latter his response is not based upon such information. A subject may fail to utilize information provided by stimuli because of physiological factors involving limitations of the sensory system or because of the presence of background noise. It is also possible for a situation to exist where the subject is able to resolve stimuli physiologically, but he does not utilize the available information. This may be what happens in the early stages of a recognition task prior to discrimination learning. If the discriminative stimuli do not control responding during the presolution period of a recognition task, then the situation may resemble a probability learning task. It is conceivable that under these conditions a subject would respond as if he were in such task. One purpose of the present study was to investigate this hypothesis. Behavior during the presolution period of a recognition task was compared with behavior in a probability learning task where experimental conditions were identical except for the absence of discriminative stimuli. A rerun procedure was used for all subjects. The data were examined to determine whether there was matching in the probability learning task and during the presolution periods of several discrimination tasks which differed in reinforcement probability. Similar behavior in the two conditions could suggest that prior to learning a discrimination task, subjects treat the task as if it were a probability learning task. Differences between the two conditions would suggest that the stimuli affected behavior even though the data did not show evidence of discrimination.

Signal Recognition

There are several theories and models of signal recognition (or signal detection, which differs from signal recognition in that the subject must distinguish the presence of a signal from its absence). An assumption which is common to several of these theories is that discriminability and response bias are independent of each other (Swets, 1964; Atkinson, Bower & Crothers, 1965, Chapter 5; Green & Swets, 1966).

The theory of signal detection and recognition developed by Swets, Tanner, and Birdsall (1961), and Green and Swets (1966) has been used as a basis for descriptive models of animal discrimination experiments by Boneau and Cole (1967) and by Heinemann and co-workers (Heinemann, Avin, Sullivan & Chase, 1969; Heinemann & Chase, 1970a; Heinemann & Chase, 1970b; Chase & Heinemann, 1972; Heinemann & Avin, 1973).

The theory assumes that the neural effects produced by a given stimulus vary from trial to trial along a continuum. A further assumption is that the underlying distributions of these neural effects are normal and of equal variance. In a typical recognition task with two stimuli, a subject determines whether the observed neural event on a given trial was due to one stimulus or the other and responds accordingly. A response criterion is established along the axis of neural effects. If the observation on a given trial exceeds the response criterion, the subject makes one response. If the observation does not exceed the response criterion, the subject makes the other response.

The criterion is specified in terms of the ratio of the likelihood that an observation was due to one stimulus relative to the other stimulus. This ratio is referred to as the likelihood ratio. According to the theory, the criterion value of likelihood ratio is dependent upon the presentation probabilities of the stimuli and the costs and values associated with the various responses. The criterion value, referred to as β , may be used as an index of response bias. The placement of the criterion is independent of the ability of the subject to discriminate the stimuli.

Discriminability is a function of the physical parameters of the stimuli and is represented as the distance between the means of the underlying distributions of neural effects divided by their common standard deviation. This discriminability index is referred to as $\underline{d}'$.

As the criterion is varied, the proportion of correct responses in the presence of a given stimulus varies monotonically with the proportion of the same responses in the presence of the other stimulus. The values of $\underline{d}'$ and β may be extracted from the data in a recognition task to provide independent measures of sensitivity and response bias.

There have been a number of studies conducted with human subjects where decision criteria were varied. Several of these studies are reported in Green and Swets (1966). Studies with animal subjects using detection theory have been relatively few in number. Several types of animal subjects have been studied, including rats (Hack, 1963; Nevin, 1964; Terman & Terman, 1972), pigeons (Hobson, 1970) and monkeys (Clopton, 1972; Elsmore, 1972). The stimuli presented have included auditory (Hack, 1963; Irwin & Terman, 1970; Terman, 1970), visual (Nevin, 1964), and gustatory stimuli (Suboski & Spevack, 1968). There have also been studies of nonexteroceptive continua, such as schedules of reinforcement (Hobson, 1970) and time duration (Stubbs, 1968; Elsmore, 1972). The general findings of these studies are that animals will adjust their response as a function of payoff and stimulus presentation proportions. Changes in response bias appear to be independent of stimulus discriminability, as predicted by signal detection theory.

In studies of response bias reported thus far, either the stimulus presentation proportions or the response payoffs were manipulated. Hack (1963), for example, varied the presentation proportions of a tone in a detection task with rats and obtained the predicted monotonic relationship between the probability of responding in the presence of the tone and the probability of responding in its absence.

In a study of the detection of increments in noise by monkeys, Clopton (1972) varied the proportion of trials when the increment was presented. Changes in response bias were found to be related to changes in the presentation proportions and independent of sensitivity.

Terman and Terman (1970) trained rats to discriminate between a standard auditory intensity and a comparison intensity whose value was varied during the experiment. The probability of the standard intensity was varied from .1 to .9 between sessions. The results found that changes in bias varied monotonically with presentation proportions, while $\underline{d}'$ remained constant. Changes in the intensity difference of the stimuli resulted in changes in d', while bias appeared to remain constant.

The payoff value associated with a response may be manipulated by varying the amount of reinforcement or the relative frequency of reinforcement. Stubbs (1968) varied reinforcement contingencies in a discrete choice discrimination of stimulus duration using pigeons. In one instance, one of the incorrect responses resulted in resetting the number of correct responses necessary for reinforcement. Another manipulation involved reinforcing only one of the correct responses. The results indicated that manipulating reinforcement contingencies resulted in changes in the proportions of a given response in the presence of the stimuli. However, it was also noted that severe shifts in bias were correlated with a decrease in sensitivity.

In a study of the discrimination of schedules of reinforcement in pigeons, Hobson (1970) found that differentially varying either the amount of food or the proportion of trials on which reinforcement was present for correct responses resulted in changes in bias in the expected direction.

Mandell (1973) varied the reinforcement proportions for making correct responses in an auditory intensity study with pigeons. Bias differences were obtained, but they were reported to be transient.

In an unpublished study of auditory intensity discrimination in pigeons, Fox found that likelihood ratio criteria varied monotonically with variations in a visual cue correlated with reinforcement probability.

Since variations in presentation proportions and payoff result in changes in response bias, it is of interest to determine to what extent the two parameters affect bias when they vary simultaneously. According to signal detection theory, it should be possible for different combinations of presentation proportions and payoff to produce the same degree of response bias if the product of presentation proportion and payoff are constant.

In the present study three groups of pigeons received different combinations of stimulus presentation proportions and of payoffs in the form of reinforcement proportions. For these three groups the product of the values of the two variables are constant. More specifically, the groups received different proportions of loud and soft auditory stimuli. The proportion of each response which was rewarded when correct also varied. However, the number of reinforcements provided for each response was the same. Two other groups were presented with stimuli in the same proportions as two of the equal product groups, but the proportion of each response which was rewarded when correct was the same as the third equal product group. The effect of these variations upon response bias and discriminability was measured.

Generalization

Since the value of neural effects is a function of the stimulus parameters, it is possible to express the position of the criterion in terms of a stimulus value. This can be accomplished by obtaining a psychometric function and finding the stimulus value where the two responses are made equally.

Recent studies by Pierrel and Sherman (1960), Heinemann and coworkers (Heinemann, Avin, Sullivan, & Chase, 1969; Heinemann & Chase, 1970a; Heinemann & Chase, 1970b; Chase & Heinemann, 1972), Stubbs (1968), Mandell (1973), and Weinstock, Robbins, and Chen (in press) have found that generalization curves obtained after training to discriminate between two intensities have the typical sigmoidal form of psychometric functions. This is in contrast to the peaked generalization gradients which are generally obtained following discrimination training with metathetic stimuli (e.g. Hanson, 1959; Heinemann, Chase, & Mandell, 1968; Blough, 1969).

In the studies by Stubbs and Mandell, reinforcement contingencies were manipulated and differences in generalization curves were obtained. Both studies found that the position of the generalization curves along the stimulus axis varied as a function of experimental contingencies. The stimulus value at which each response was made on 50% of the trials was also a function of experimental contingencies.

In the study by Weinstock et al., stimulus presentation ratios were varied in a brightness discrimination task with rats as subjects. The position of the obtained generalization curves was a function of the presentation ratio. In addition, a control group was given training with a probability learning task. The obtained generalization curves for this group were flat, indicating no control by light intensity.

Attention

The analyses of the stimulus generalization curves obtained in Heinemann's experiments were based upon signal recognition theory together with a concept of attention. The term attention is used in an empirical sense. A subject is said to attend to a stimulus dimension if behavior changes as the value of the stimulus changes. In a discrete trial recognition task, subjects do not necessarily attend to the relevant stimuli on each trial. When a subject attends to the relevant stimuli, he responds in accordance with the signal recognition model. However, when a subject does not attend to the relevant stimuli, his behavior is independent of the value of the stimulus. On these trials responding is under control of some other stimulus.

Heinemann and co-workers have derived a means to measure the degree of attention to the relevant stimulus dimension. In addition they have provided a correction to remove the effects of inattention from the generalization gradients and thereby to obtain functions based upon those trials when subjects attended to the relevant stimuli. From these curves it was possible to obtain a criterion value expressed in stimulus terms.

It should be noted that Heinemann's use of the term attention differs somewhat from its use in recent models of selective attention such as those of Zeaman and House (1963), Lovejoy (1965, 1966, 1968), and Sutherland and Mackintosh (1971). According to these theories, discrimination learning involves two processes: learning to attend to the relevant stimulus dimension and learning to attach the correct responses to stimuli along this dimension. Learning to attend involves learning to switch in the relevant analyzer, a process which must be conditioned. Attention is thus considered as a response, whereas Heinemann considers it as a controlling relation between discriminative stimuli and responding.

Another difference between the two concepts of attention is that according to selective models it is possible for the strength of an analyzer to be determined by the value of a stimulus. Heinemann's concept of attention assumes that attention is independent of the stimulus value.

In the present study generalization gradients were obtained for all subjects following training. The level of attention and the value of the stimulus criterion were derived for each subject using Heinemann's model.

The purpose of the present experiment was to examine the effects of different combinations of presentation proportions of stimuli and payoff in the form of partial reinforcement upon responding in a discrete trial choice discrimination of sound intensity and in a subsequent generalization. Responding during the presolution period was compared with the performance of a group trained with a probability learning task.

METHOD

Subjects

The subjects were 30 white Carneaux pigeons, 8 male and 22 female, obtained from the Palmetto Pigeon Farm in Sumter, South Carolina. All birds were experimentally naive at the start of the experiment and were approximately one year old.

The birds were housed in individual cages, where they were given grain, water, and grit. In order to determine the average free-feeding weights, the birds were given free access to grain for 15 days. Beginning with Day 11, they were weighed at the same time every day for 5 consecutive days. The means of the five-day weights were calculated, and the birds were then reduced in weight until they reached 80% of their free-feeding weights. To reduce the weight of the birds, they were fed 5-10 grams of grain daily. The weight reduction took approximately 2 weeks. The birds were maintained at these weights for the duration of the experiment. This was accomplished by weighing them following each daily session and feeding them the appropriate amount of grain. Grit and water were always available in the home cages.

Apparatus

The pigeon chamber was a standard Lehigh Valley model. Its inside dimensions were 20 inches x 13.8 inches x 13.8 inches. A three key response panel divided the box into two sections. One section contained the electrical equipment needed for the panel, and the other section housed the subjects during the experiment. The dimensions of the section within which the subjects were housed were 12.2 inches x 13.8 inches x

13.8 inches.

The three translucent keys were one inch in diameter. They were each located 9.375 inches above the floor of the chamber. One key was centered on the vertical midline. The other two keys were located at a distance of 2.25 inches on either side of this midline. White lights were located behind the keys. They projected approximately equal brightnesses on the keys when illuminated. An opening 2.25 inches x 2 inches located 3.5 inches directly below the center key provided access to grain when the food magazine was operated. A light inside the opening was illuminated when the food magazine was raised. A house light was situated 1.75 inches directly above the center key. This light was turned on at the start of each daily session. It remained on throughout the session, and was turned off at the end of each session.

A speaker 3 inches in diameter was located behind the panel 3.5 inches to the left of the feeder. To prevent any extraneous noises from reaching the animals during the experiment, the entire pigeon chamber was kept in a large wooden box lined with sound absorbing material.

The white noise delivered through the speakers was produced by a Grayson-Stadler noise generator, Model 901B. A series of attenuators was used to produce the various intensities ranging from 60 to 83 dB re 0.0002 dyne $/\mathrm{cm}^2$ which were used during the course of the experiment. The sound intensities were measured with a General Electric sound level meter Type 1565A (C network), which was placed in the box at the approximate position of a pigeon's head.

A series of relays, timers, and counters were used in conjunction with two tape readers to control experimental contingencies. One tape reader was used throughout the experiment. It was programmed to determine which of two sound intensities was presented on a given trial, and whether reinforcement was to be given for a correct response.

For each group of subjects, 24 different sequences were programmed for the first tape reader. The order of these sequences was randomly determined but constrained by the proportions of sound stimuli and reinforced trials scheduled for each group. The order of presentation of sequences was randomized within blocks of 24 days. Consequently, a subject was presented with all 24 sequences every 24 days.

The second tape reader was used only during generalization testing. This tape reader was used in conjunction with the first tape reader to determine whether a trial would be a generalization trial or a training trial. If the trial were a generalization trial, the tape reader determined which of six generalization intensities would be presented to the subjects. If the trial were a training trial, control was shifted to the first tape reader. There were six different generalization sequences for all groups. Each sequence was randomly determined. The data for each daily session was recorded on impulse counters.

Procedure

The 30 subjects were randomly assigned to one of six groups. Five groups were given choice discrimination training, which differed between groups with respect to the proportions of loud and soft sounds presented and the proportions of responses reinforced in the presence of each sound. The sixth group was trained in a choice situation with only one sound stimulus. This group was also differentially reinforced for responses on each key.

There were three replications of the study with ten birds in each replication. Within each replication four groups contained two birds and two groups contained one bird. The groups which contained one bird differed for each replication. Each replication lasted 132 consecutive days.

All subjects were given one day of preliminary training after they had reached their 80% weight level. The pretraining was identical for all birds. Each subject was placed inside the pigeon chamber with the food magazine raised. A small amount of grain was put on the floor of the chamber near the raised magazine. The birds were then trained to approach the illuminated magazine and eat from it.

After the birds had eaten regularly from the food magazine, they were trained to peck the illuminated center key by the method of successive approximations. A peck to the center key darkened it and caused the food magazine to be raised for 2.25 seconds. After a bird had made the desired response, an intertrial interval (ITI) was introduced between the lowering of the food magazine and the next illumination of the center key. The duration of this ITI was gradually increased over several trials from 2 seconds to 10 seconds. During the ITI the keys were not illuminated, no sound was present, and no access to food was possible.

As soon as the birds had responded ten times to the center key, they were trained to peck the two side keys. On a given trial one of the three keys was randomly selected to be lighted. A peck to the lighted key darkened it and caused the food magazine to be raised; a peck to a dark key had no effect. The animals were presented with each lighted key 15 times in a random order, making a total of 45 trials. The duration of the ITI was always 10 seconds.

Discrimination training. On the day after preliminary training, discrimination training was begun for five groups. Each trial was started by illuminating the center key and simultaneously presenting one of two intensities of white noise: 70 or 78 dB re .0002 dyne/cm^2 (S1 and S2). The decision to use these particular intensities in the study was based upon previous unpublished research conducted in the same pigeon chamber. In that study, intensity differences of 8 dB were clearly discriminable, but they were not perfectly discriminable.

A peck to the center key darkened it and simultaneously caused the two side keys to be illuminated. For each sound a peck to one of the side keys was defined as a correct response, and a peck to the other side key was defined as incorrect. The correct responses in the presence of the soft and loud sound stimuli are referred to as R1 and R2, respectively. It follows that the incorrect responses in the presence of the soft and loud stimuli are R2 and R1, respectively. For even-numbered birds, R2 represents a response to the left key, while for odd-numbered birds it represents a response to the right key.

Reinforcement was scheduled on some trials and not on others. When a reinforcement was scheduled, a correct response removed the sound, turned off the side key lights, and caused the food magazine to be raised for 2.25 seconds. An ITI of 10 seconds followed the lowering of the food magazine. During this interval the keys were dark and inoperative. The only light present was the house light, which remained on until the session was terminated. An incorrect response removed the sounds, turned off the side keys and produced a 10 second ITI, but it did not cause the magazine to be raised. On trials when nonreinforcement was scheduled, either a correct or an incorrect response removed the sound, darkened the side keys, and produced a 10 second ITI.

If a response was correct, the stimulus and reinforcement contingencies on the next trial were randomly determined by the punched tape. If a response was incorrect, the stimulus and reinforcement contingencies were repeated on the following trial until the correct response was made. This procedure forced the birds to make the same number of correct responses daily, and therefore to receive equal amounts of reinforcement. All trials were terminated by a response. Experiments using similar procedures with the same apparatus have found that subjects generally respond to the keys within .9 seconds. A daily session was terminated after a bird had made 80 correct responses.

The names assigned to each group reflect the number of reinforcements provided for R2 and the number of initial presentations of the loud stimulus (S2) per session. Since the total number of daily reinforcements for all groups was 48, and the total number of initial trials was 80, the corresponding values for the soft stimulus (S1) can be easily derived.

Groups 33/55, 24/40, and 39/65 differed in the proportion of soft and loud stimuli presented. For these groups, reinforcement for a correct response occurred on 60% of the trials with each stimulus. Group 24/40 received equal proportions of each stimulus. There were 40 soft stimuli and 40 loud stimuli presented daily. Twenty-four correct responses were reinforced in the presence of each stimulus. Group 33/55 was presented with 25 soft stimuli and 55 loud stimuli daily. A correct response was reinforced on 15 trials with the soft stimulus and 33 trials with the loud stimulus. Group 39/65 was presented with 15 soft stimuli and 65 loud stimuli daily. A correct response was reinforced on 9 trials with the soft stimulus and 39 trials with the loud stimulus.

Groups 33/65 and 33/40 were presented with the same number of soft and loud stimuli as Groups 39/65 and 24/40, respectively, but they were reinforced in different proportions. Each of these groups was reinforced for 15 correct responses in the presence of the soft stimulus and 33 correct responses in the presence of the loud stimulus. Thus, the number of reinforcements in the presence of each sound was the same for Groups 33/40, 33/55, and 33/65. Group 33/40 was presented with each stimulus 40 times daily. A correct response was reinforced on 15/40 or 37.5% of the trials with the soft stimulus and on 33/40 or 82.5% of the trials with the loud stimulus.

Table 1 presents a summary of the conditions for the five groups. The first two rows show the number of times the soft and loud stimuli were scheduled to be presented each session. These values refer to the initial presentation of a stimulus, and do not include repeated presentations following incorrect responses. The third and fourth rows give the probability of the occurrence of the soft and loud stimuli on a given trial. These proportions were obtained by dividing the values in the previous rows by 80 trials. The fifth and sixth rows show the number of correct responses in the presence of each stimulus which were reinforced each session. The following two rows present the proportion of correct responses reinforced in the presence of each stimulus. These values were obtained by dividing the number of correct responses which were reinforced by the number of times the stimulus was initially presented. The next two rows present the quotient of the probability of a correct response being reinforced and the proportion of all responses which were reinforced. Finally, the last two rows present the proportion of reinforcements which were given for making a correct response in the presence of each stimulus. These values equal the product of the presentation

TABLE 1

Summary of Conditions for Each Group

	Group				
	33/55	24/40	33/65	33/40	39/65
Number of soft sounds (S1) presented	25	40	15	40	15
Number of loud sounds (S2) presented	55	40	65	40	65
p(S1)	.3125	.5	0.1875	.5	.1875
p(S2)	.6875	.5	0.8125	.5	.8125
Number of correct R1 responses reinforced	15	24	15	15	9
Number of correct R2 responses reinforced	33	24	33	33	39
p(correct R1 reinforced)	.6	.6	1.0000	.375	.6
p(correct R2 reinforced)	.6	.6	0.5077	.825	.6
p(correct R1 reinforced)/ *p*(reinforcement)	1	1	1.6667	.625	1
p(correct R2 reinforced)/ *p*(reinforcement)	1	1	0.8462	1.375	1
Proportion of reinforcements which were given for R1	.3125	.5	0.3125	0.3125	.1875
Proportion of reinforcements which were given for R2	.6875	.5	0.6875	0.6875	.8125

proportions from rows three and four and the payoff quotients from rows nine and ten.

Discrimination training with the 8 dB sound difference was continued for 100 successive days. By that time all birds had learned to discriminate between the sounds, and the learning curves, based upon the daily data, appeared asymptotic. Beginning with Day 101, the intensity difference was reduced to 2 dB over a period of 3 days. On Day 101 the two stimuli were changed to 71.5 and 76.5 dB re 0.0002 dyne/cm^2. On Day 102 the stimuli were changed to 72.5 and 75.5 dB re 0.0002 dyne/cm^2. Finally, on Day 103 the sound intensity difference was reduced to 2 dB. The soft sound was increased to 73 dB re 0.0002 dyne/cm^2, and the loud sound was decreased to 75 dB re 0.0002 dyne/cm^2. This intensity difference was maintained for the next 20 days.

Probability training. The subjects in the sixth group, Group P, received the same preliminary training as the other five groups. They were presented with a choice task, but this task differed from the one previously described in that there were no discriminative stimuli. The procedure was the same as for the other groups, except that the same intensity level of white noise was presented on every trial, 74 dB re 0.0002 dyne/cm^2.

On 25 trials a response to one key was designated correct, and on 55 trials a response to the other key was so designated. R1 refers to the less frequently correct response, and R2 refers to the more frequently correct response. No cues were available to determine which response would be correct on a given trial. The rerun procedure was used. If an incorrect response was made, the trial was repeated until the correct response was made. Reinforcement occurred 15 times after a correct

R1 and 33 times after a correct R2. For Birds 242 and 296, R2 represents a peck to the left key; for Birds 243, 256, and 297, R2 represents a response to the right key. A daily session was terminated after a bird had made 80 correct responses.

The training sessions for Group P were identical to those for Group 33/55, except that the latter received two discriminative stimuli, whereas the former did not. The only procedural difference was that a switch was thrown, allowing one sound (74 dB re 0.0002 dyne/cm^2) to be presented to Group P. The same punched tape was used for both groups, since response-reinforcement contingencies were the same. Subjects in Group P received training for 122 days under these conditions.

Generalization test. Beginning with Day 113, all subjects were given generalization tests for 10 consecutive days. During a generalization test, subjects were presented with eight different intensities of white noise. These intensities were 60 dB, 65 dB, 70 dB, 73 dB, 74 dB, 75 dB, 78, dB and 83 dB re 0.0002 dyne/cm^2. Each group was given 80 training trials daily with the stimuli last used in training (73 dB and 75 dB for the groups which received discrimination training, and 74 dB for Group P). On training trials reinforcement was available according to the schedule used for the particular group during training. The rerun procedure was maintained for training trials.

The remaining intensities were randomly interspersed on trials between the training trials. Each of these test intensities was presented 13 times daily, making a total of 158 daily trials for the groups which received discrimination training and 171 daily trials for Group P. Test trials differed from training trials in two respects: (a) reinforcement was never available on a test trial; (b) there was no repetition of test trials.

RESULTS

A description of the results of discrimination training will be presented first in this section. Statistical analyses of these results will be discussed later. After that the results of the generalization tests will be presented.

A uniform terminology is used to describe the various experimental conditions. The soft and loud sounds presented to the discrimination groups during training are referred to as S1 and S2, respectively. These terms also refer to the soft and loud sounds presented during the reduced sound difference phase. The animals could respond in two different ways, R1 and R2. The proportions of R1 and R2 which were made in the presence of S1 are referred to as $\underline{p}$(R1/S1) and $\underline{p}$(R2/S1), respectively. These are the conditional proportions of making the two responses given the presence of S1. Similarly, the proportions of R1 and R2 made in the presence of S2 are referred to as $\underline{p}$(R1/S2) and $\underline{p}$(R2/S2), respectively. $\underline{p}$(R1/S1) and $\underline{p}$(R2/S2) represent the proportions of correct responses, while $\underline{p}$(R1/S2) and $\underline{p}$(R2/S1) represent the proportions of incorrect responses. These terms refer to the first responses of each "trial" and exclude responses following incorrect choices.

The stimulus presentation proportions for the various groups are specified in terms of the proportion of initial trials on which the loud sound was presented. The relative proportions of reinforcements which were given for making each response are specified in terms of the proportion of reinforcements given for R2, and written $\underline{p}$(E2).

The proportions of R2 made on the first response of each "trial" in the presence of each stimulus were plotted in five day blocks for each bird. Figure 1 presents the plots of $\underline{p}(R2)$ for the five probability learning birds (Group P). Since these birds were presented with only one sound, each point represents the proportion of R2 made on 400 trials from 5 days. The lines drawn at $\underline{p}(R2) = .6875$ indicate the value at which $\underline{p}$ (R2) matches $\underline{p}(E2)$.

The figure shows general similarities between the individual response patterns of these birds. Each bird shows a clear preference in favor of responding R2. For Birds 242, 243, 256, and 297 the values of $\underline{p}(R2)$ were generally higher than .6875. The values of $\underline{p}(R2)$ for Bird 296 tended to be lower than .6875. However, the deviations from matching are not large. The individual curves appear to be flat, which indicates that the birds maintained similar levels of $\underline{p}(R2)$ throughout the experiment.

Figures 2 through 6 present the proportions of R2 made in the presence of each sound in five day blocks for each bird in Groups 33/55, 24/40, 33/65, 33/40, and 39/65, respectively. In all figures the points along the lower curves represent the values of $\underline{p}(R2/S1)$. The points along the upper curves represent $\underline{p}(R2/S2)$. The number of trials represented by each point varies according to the stimulus presentation ratio of S1 to S2. For Group 33/55 each point for $\underline{p}(R2/S1)$ represents 125 trials, and each point for $\underline{p}(R2/S2)$ represents 225 trials. For Groups 24/40 and 33/40, each point represents 400 trials. For Groups 33/65 and 39/65, each point for $\underline{p}(R2/S1)$ represents 75 trials, and each point for $\underline{p}(R2/S2)$ represents 325 trials.

The separation between each pair of curves indicates that the sounds were discriminated by all birds. The period before the sound

Figure 1. Proportion of R2 in blocks of 5 days for individual subjects in Group P. Horizontal line represents the matching value of p (E2)

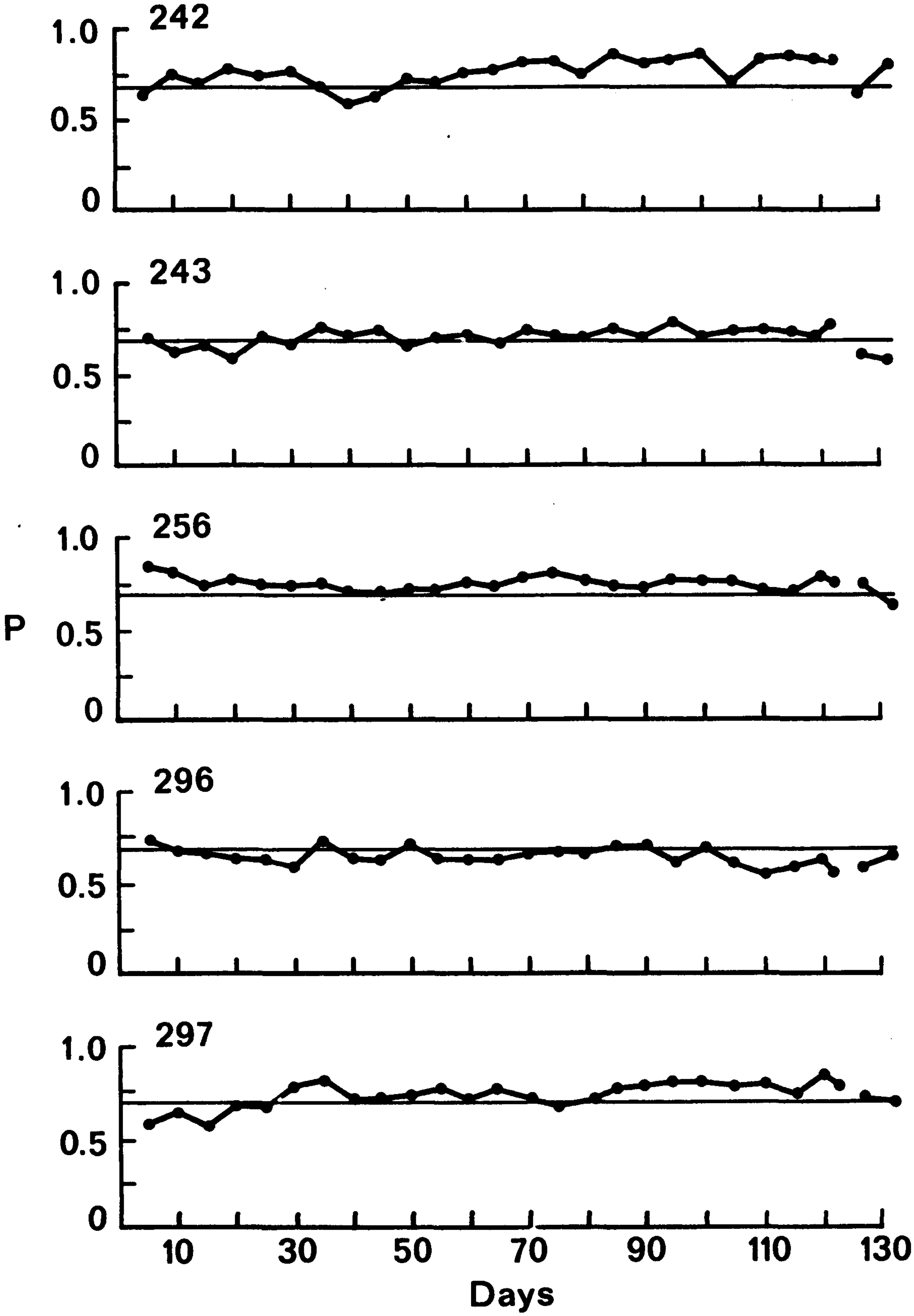

242
243
256
296
297
1.0
0.5
0
P
10
30
50
70
90
110
130
Days

Figure 2. *p*(R2/S1) and *p*(R2/S2) in blocks of 5 days for individual subjects in Group 33/55.

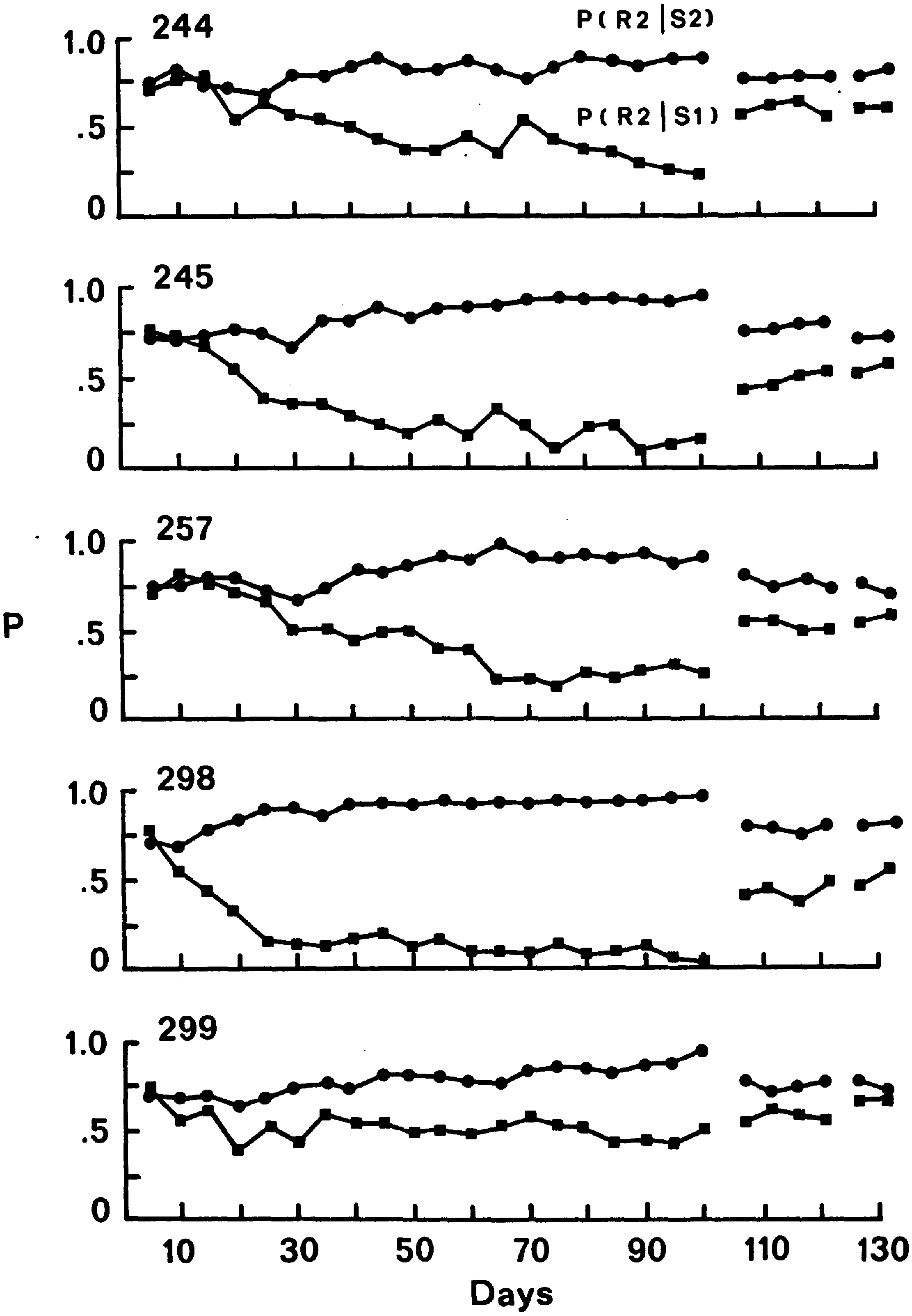

244
245
257
298
299
P(R2|S2)
P(R2|S1)
P
1.0
.5
0
10
30
50
70
90
110
130
Days

Figure 3. p(R2/S1) and p(R2/S2) in blocks of 5 days for individual subjects in Group 24/40.

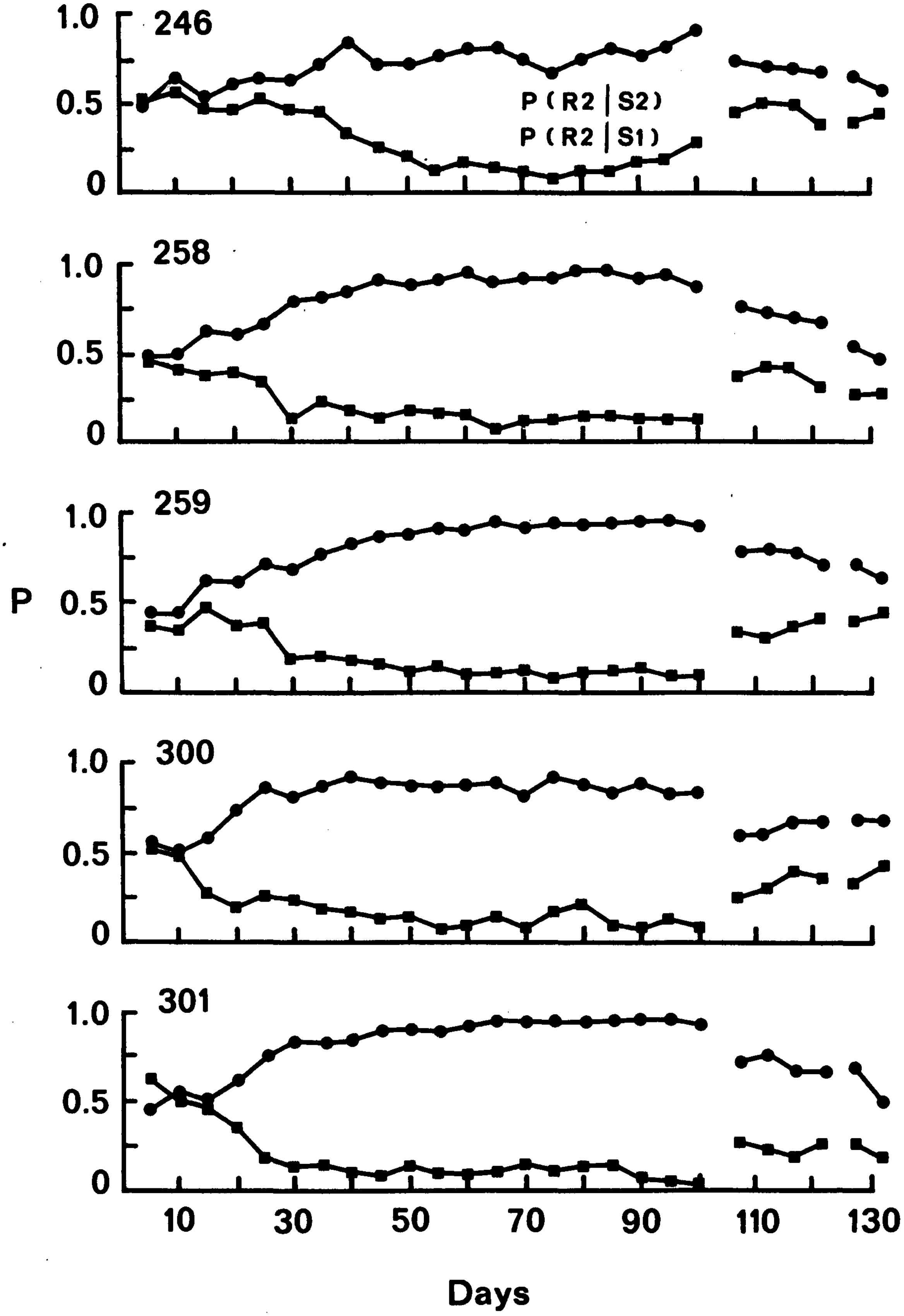

246
258
259
300
301
P (R2 | S2)
P (R2 | S1)
1.0
0.5
0
P
10
30
50
70
90
110
130
Days

Figure 4. p(R2/S1) and p(R2/S2) in blocks of 5 days for individual subjects in Group 33/65.

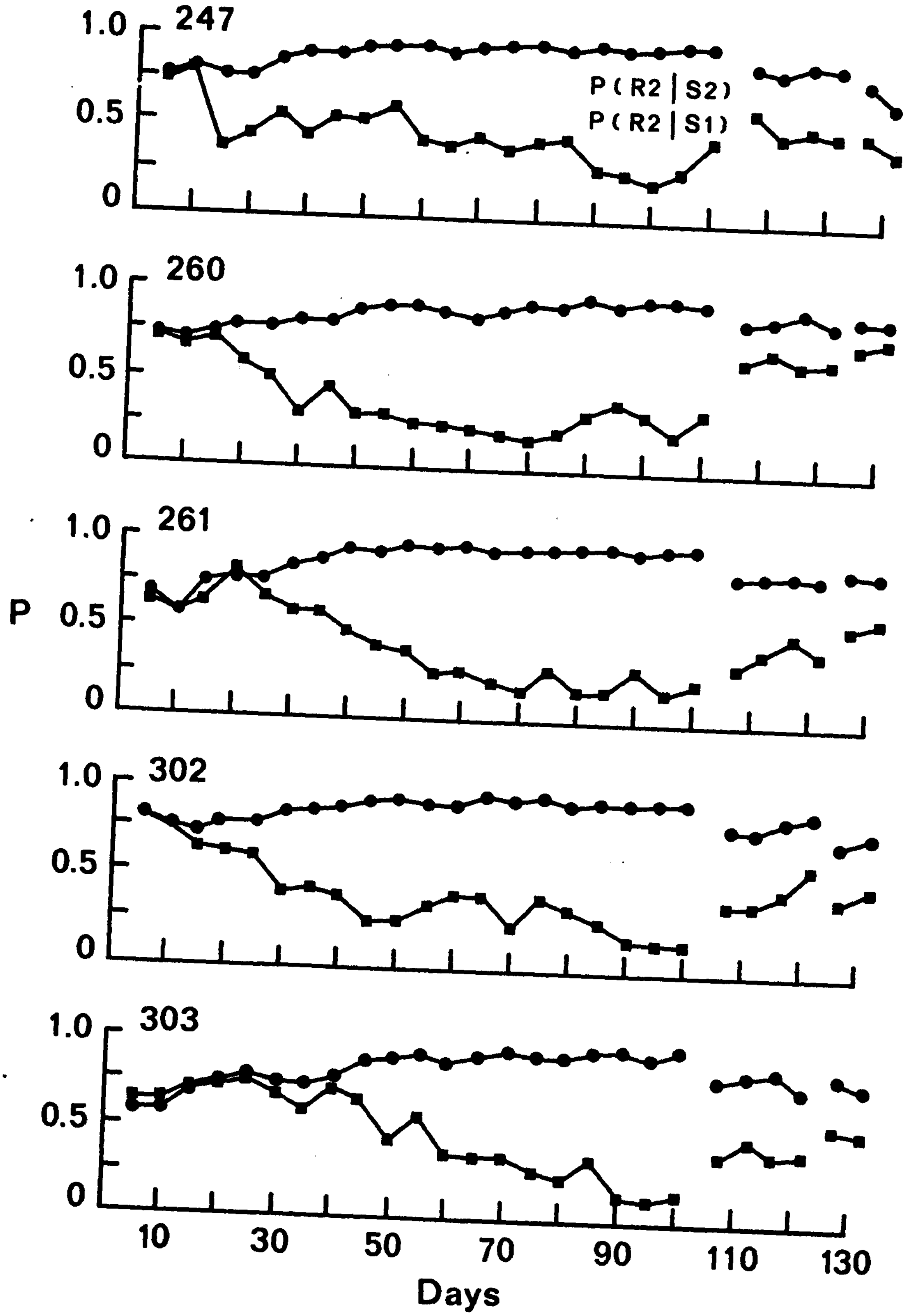

247
260
261
302
303
1.0
0.5
0
P
P (R2 | S2)
P (R2 | S1)
10
30
50
70
90
110
130
Days

Figure 5. p(R2/S1) and p(R2/S2) in blocks of 5 days for individual subjects in Group 33/40.

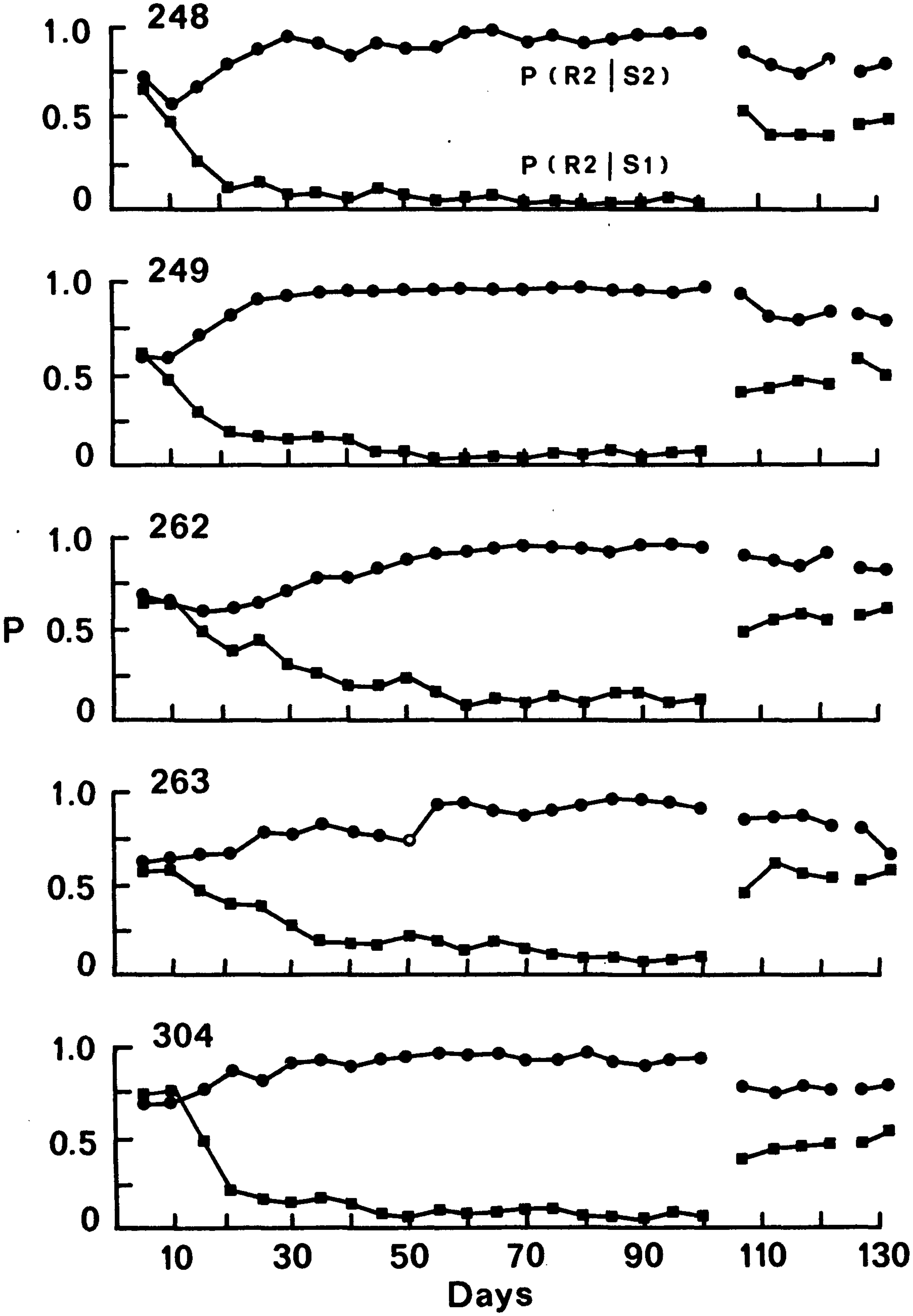
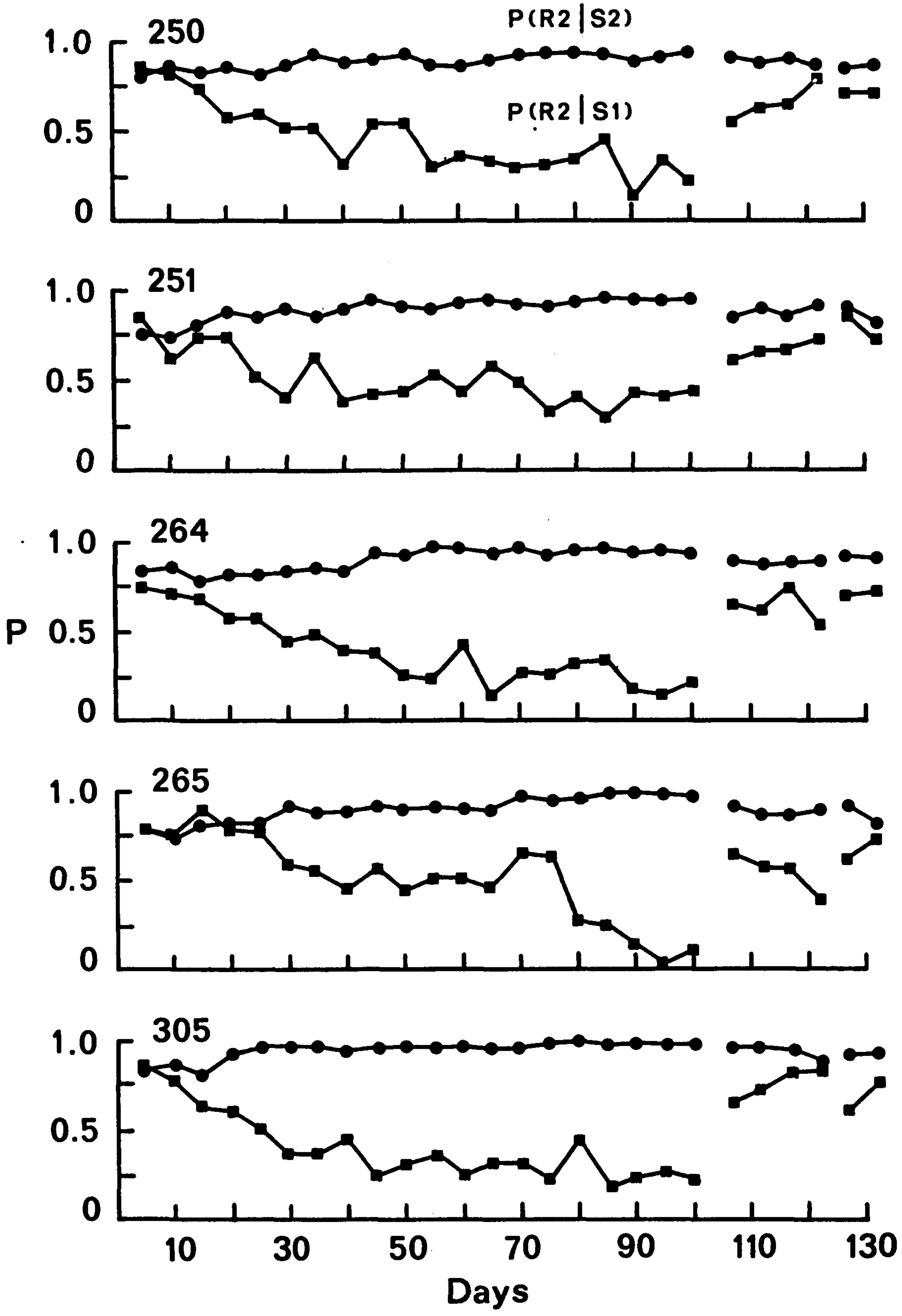

248
249
262
263
304
P (R2 | S2)
P (R2 | S1)
1.0
0.5
0
P
10
30
50
70
90
110
130
Days

Figure 6. p(R2/S1) and p(R2/S2) in blocks of 5 days for individual subjects in Group 39/65.


250
P(R2|S2)
P(R2|S1)
251
264
265
305
1.0
0.5
0
P
10
30
50
70
90
110
130
Days

stimuli appear to control behavior is defined as the presolution period. Inspection of the curves reveals considerable differences in the length of the presolution period. However, there appear to be no obvious systematic differences between groups.

An examination of the levels of p(R2/S1) and p(R2/S2) during the presolution period provides evidence that the birds tended to match p(E2) prior to discrimination learning. For the birds in Groups 33/40, 33/55, and 33/65, p(E2) was .6875. The curves of Group 33/55 show that the presolution proportions of R2 lie roughly between .65 and .80. The corresponding proportions of the subjects in Group 33/65 lie between .60 and .85, while the proportions of the birds in Group 33/40 lie between .60 and .75. These values are generally close to the value of p(E2). In contrast, p(E2) for Group 24/40 was .50. A glance at the curves for this group shows that the presolution proportions lie between .40 and .60. A comparison of the figures reveals that the presolution proportions of Group 24/40 had the lowest values.

For Group 39/65 p(E2) was .8125. Visual inspection shows that the presolution proportions for this group lie between .80 and .85. These levels of p(R2) are higher than the levels of p(R2) for the other groups. The presolution data thus suggest that prior to discrimination p(R2) tended to match p(E2).

The curves for each bird reach asymptotic levels by the end of 100 days of training with the large sound difference. The distance between each pair of asymptotes is a reflection of the accuracy of discrimination. It is apparent that accuracy varied greatly within groups. For instance, the curves for Birds 298 and 299 in Group 33/55 reveal a large difference in accuracy. All of the curves from Group 33/40 show a wide separation between asymptotes. However, there is too much overall variability to draw conclusions regarding between group differences in accuracy.

The relative asymmetry of the asymptotes around .50 is a reflection of key preference, or bias. The figures reveal systematic differences in bias between groups during the first phase of training. The symmetry of the curves of Group 24/40 (Figure 3) indicates the absence of bias favoring either key. This is not surprising, since the values of p(S2) and p(E2) for this group were .50. The curves for Group 33/40 (Figure 5) are also symmetrical. Since p(S2) for Group 33/40 was .50 and p(E2) was .6875, the apparent absence of bias toward either response suggests that key preference was controlled by p(S2) rather than p(E2).

The curves of Groups 33/55, 33/65, and 39/65 are generally asymmetrical in the same direction. The lower asymptotes are closer to .50 than the upper asymptotes. This means that the bias was toward R2. The curves of Groups 33/65 and 39/65 appear to be the most asymmetrical, while the curves of Group 33/55 appear less asymmetrical. The values of p(S2) for Groups 33/55, 33/65, and 39/65 were .6875, .8125, and .8125, respectively. The values of p(E2) for these groups were .6875, .6875, and .8125, respectively. The data thus suggest that bias during this phase of training was a function of p(S2) rather than p(E2).

The decrease in the distance between the curves at Day 103 reflects the decrease in discriminability which occurred when the sound difference was reduced. The proportions from Days 101 and 102 were not plotted, since the 3 dB and 5 dB sound differences were maintained only one day. The curves for this phase of the experiment continue to show individual differences in the accuracy of discrimination. All the birds were affected by the decrease in sound difference.

The figures reveal that biases in favor of one response, as judged by the degree of asymmetry, were present during this phase. Figure 3 shows that the birds in Group 24/40 held relatively slight biases, Bird 300 had a slight bias in favor of R1, and Birds 246, 258, and 259 had slight biases in favor of R2. No bias can be observed for Bird 301. The curves of the birds from Group 33/55 continue to show moderate biases in favor of R2. The curves of the birds from Groups 33/65 and 39/65 continue to show large biases in favor of R2.

Of particular interest is the asymmetry seen in Figure 5 for Group 33/40. The birds who appear to have no response preference during the training with the large sound difference all show biases during the decreased sound difference phase. The lower asymptotes show a sharp rise during this phase, while the upper asymptotes fall slightly. These data indicate control by $\underline{p}$(E2) over responding.

The last two points on each curve represent proportions of R2 made in the presence of the training stimuli during generalization testing. The data indicate a slight loss in discrimination accuracy. The degree of bias, however, appears to be maintained from training.

The results obtained during the training phase may be summarized as follows: During the presolution period, the proportions of R2 made by the discrimination groups appear to reflect the proportion of E2. This matching behavior is also seen in the data of the probability birds. There is considerable variability seen in the individual abilities to discriminate the sounds as indicated by the final levels of separation between the curves of $\underline{p}$(R2/S1) and $\underline{p}$(R2/S2). However, there are indications that Group 33/40 achieved the greatest accuracy in the discrimination and that Group 39/65 achieved the least accuracy. Bias was measured by the relative asymmetry of the curves around .50. Groups 33/55, 24/40, and 39/65 show a bias favoring the R2 response during the large sound difference phase of the experiment. The degree of bias appears greater for Groups 33/65 and 39/65 than for Group 33/55. Groups 24/40 and 33/40 show little evidence of bias toward either response.

During the reduced sound difference phase, Group 33/40 shows a bias favoring R2. The other groups appear to have maintained their previous biases. Finally, the data from generalization indicate that while accuracy of discrimination tended to decrease, the degree of bias was maintained by all birds.

Statistical Analysis of Discrimination Data

Statistical analyses were performed upon data from the following four phases of the experiment: the presolution period, the period during which the subjects discriminated between the two noise levels (8 dB difference), the period during which the difference in noise level was shifted to 2 dB, and the generalization period. The results are presented in accordance with these analyses.

For each bird the data selected were based upon the same days from each period. This insures that the same number of trials are represented during a given part of the experiment for every bird. Furthermore, it means that each bird's performance has been measured at exactly the same point in the experiment.

The analyses of the results were concerned with two questions. To what extent did the various conditions affect the discriminability of the stimuli, and to what extent did they affect bias, or preferences for one of the two response keys.

Two types of statistical analyses were performed. The first type was an attempt to translate the effects noted by visual inspection into quantitative terms. To perform statistical analyses on proportions it was desirable to apply a transformation that equalized their variances. For this purpose an angular transform was used in which the arc sine of the square root of each proportion was found (Fisher and Yates, 1948). The obtained values, expressed in degrees, were subjected to statistical analyses. All statistical analyses employed the arc sine transformation.

The second type of analysis examined the data from the point of view of signal detection theory (Green & Swets, 1966). The measurements used here were based upon assumptions from this theory regarding the underlying sensory effects of stimuli, specifically, that the distribution of underlying sensory events are normal and that they are of equal variance. If these assumptions are correct, the theory provides indices of sensitivity and bias which are independent of each other.

The index of discriminability, $\underline{d}'$, is the distance between the means of the underlying sensory distributions expressed in normal scores. The bias index, β , represents the decision point established by a subject along the axis of neural events. This decision criterion is expressed as the ratio of the likelihood that a given event was due to S2 relative to S1. These indices can be empirically derived from the proportions of a response made in the presence of each stimulus by using a table of the normal probability integral. In the present experiment $\underline{p}$(R2/S1) and $\underline{p}$(R2/S2) were used to derive these values.

The format for presenting the data is similar for each analysis. After presenting graphs of the grouped data, the results of a simple analysis of variance are summarized. Next, the results of individual comparisons between groups are discussed. These multiple comparisons were performed using the procedure suggested by Tukey known as the Tukey (b) method (Winer, 1962, page 87).

Presolution period. It will be recalled that the presolution period was defined as the period during which the sound stimuli did not appear to control behavior. The data from this period were analyzed in an attempt to determine (a) whether there were reliable differences between groups in response preference, as measured by the proportion of R2 responses made on the first response of each trial, and (b) to what extent the subjects exhibited matching.

The first task was to determine the length of the presolution period for each bird. The last day of the presolution period was defined as the last day on which $\underline{p}(R2/S1)$ was greater than $\underline{p}(R2/S2)$. The length of the presolution period, thus determined, is presented for each bird in Table 2. The table indicates that the longest presolution period (39 days) occurred for Bird 303, while the shortest presolution period (5 days) occurred for Bird 298. The means for each group show that the subjects in Group 33/65 tended to have relatively long presolution periods, while the subjects in Group 33/40 tended to have relatively short presolution periods. However, there is considerable variability within groups.

A one-way analysis of variance performed on the lengths of the presolution period revealed no significant differences between groups, $\underline{F}(4,20) = 1.25$. The results of the analysis of variance are summarized in Table A (appendix). It will be seen later that the length of the presolution period had a significantly negative correlation with the degree of attention to the sound intensity continuum during generalization.

TABLE 2

Summary of Presolution Data

Group	Bird	Days to Learn	*p*(R2)-Days 2-5
P	242	-	.634
	243	-	.669
	256	-	.838
	296	-	.728
	297	-	.538
	Mean		.686
33/55	244	24	.781
	245	12	.741
	257	23	.706
	298	5	.747
	299	12	.700
	Mean	15.2	.736
24/40	246	29	.509
	258	10	.478
	259	14	.400
	300	9	.572
	301	15	.559
	Mean	15.4	.504
33/65	247	7	.763
	260	21	.769
	261	22	.691
	302	13	.856
	303	39	.600
	Mean	20.4	.740
33/40	248	9	.713
	249	7	.613
	262	13	.691
	263	7	.550
	264	9	.722
	Mean	9.2	.659
39/65	250	23	.831
	251	16	.800
	264	8	.831
	265	25	.806
	305	11	.844
	Mean	16.6	.828

In order to equate the number of responses in the presolution period for all birds, the data used in the statistical analysis that follows were based upon the length of the shortest presolution period. Also, data from the first day of training were not used, to eliminate early probability learning. The analysis of $p(R2)$ was thus based upon 320 trials from Days 2 through 5. The data for the probability birds (Group P) were included in this analysis. The values of $p(R2)$ for all 30 birds are presented in column 3 of Table 2. The table also contains a "mean proportion" for each group, obtained by calculating the means of the transformed proportions in degrees and then transforming these means back into proportions. These retransformed proportions are thus estimates of the population means of each group.

Examination of Table 2 shows a clear relationship between $p(R2)$ and $p(E2)$. Group 24/40 had the lowest mean value of $p(R2)$, followed by Groups 33/40, P, 33/55, 33/65 and 39/65. An analysis of variance of the transformed proportions revealed statistical significance between groups, $F(5,24) = 10.38$, $p < .001$. Multiple comparisons of the means revealed that $p(R2)$ made by Group 24/40 was significantly lower than $p(R2)$ made by the other groups. $p(R2)$ for Group 39/65 was found to be significantly higher than for Groups 33/40 and P. Table B (appendix) presents a summary of the analysis of variance of $p(R2)$ for Days 2 through 5. The results of the multiple comparisons are summarized by the underscoring at the bottom of tables where significance was found. Any two means underscored by the same line do not differ significantly. Any two means not underscored by the same line do differ significantly. These results confirm the hypothesis that $p(R2)$ varied with $p(E2)$.

Next, the data were analyzed for matching. Examination of Table 2 indicates that all the groups came reasonably close to matching $\underline{p}(E2)$, especially Groups 24/40, P, and 39/65. The means for Groups 33/55 and 33/65 tend to overshoot the matching proportion, while the mean for Group 33/40 tends to undershoot the matching proportion.

A series of $\underline{t}$ tests were performed on the differences between the transformed values of $\underline{p}(R2)$ and $\underline{p}(E2)$ for each group. The value of the standard error of the mean was obtained from the within-groups variance (Table B, appendix). No significant differences were found. The values of $\underline{t}$ were as follows: for Group P $\underline{t}(4) = .04$; for Group 24/40 $\underline{t}(4) = .10$; for Group 33/55 $\underline{t}(4) = 1.45$; for Group 33/40 $\underline{t}(4) = .83$; for Group 33/65 $\underline{t}(4) = 1.60$; for Group 39/65 $\underline{t}(4) = .54$. The indications are that the proportions of R2 made on the first response of each trial tended to match $\underline{p}(E2)$ during the presolution period.

Visual inspection of the curves of $\underline{p}(R2)$ for the probability group (Figure 1) indicated that there were no substantial shifts in responding throughout the 122 days of training. A $\underline{t}$ test was performed on the difference between the transformed values of $\underline{p}(R2)$ on Days 2 through 11 and on Days 113 through 122. The results showed no significant differences between $\underline{p}(R2)$, $\underline{t}(4) = 1.02$. There were no statistical differences between responding in the probability learning task at the beginning and end of training.

Large sound difference discrimination. Visual inspection of the training curves shows responding to be asymptotic for all birds by Day 90. The analysis of discrimination behavior with the 8 dB sound difference is based on 800 first trial responses from Days 91 through 100.

Table 3 presents the values of $\underline{p}(R2/S1)$ and $\underline{p}(R2/S2)$ for each bird for Days 91 through 100. Again, the means which are presented are

TABLE 3

Summary of Data - Days 91-100

Group	Bird	*p*(R2/S1)	*p*(R2/S2)	*d*'	Likelihood Ratio	Ln Likelihood Ratio
33/55	244	.243	.884	1.8917	0.6238	-0.4720
	245	.164	.949	2.6137	0.4235	-0.8592
	257	.272	.895	1.8602	0.5477	-0.6020
	298	.052	.962	3.4009	0.7766	-0.2528
	299	.458	.902	1.3984	0.4358	-0.8307
	Mean	.222	.921	2.2329		-0.6033
24/40	246	.228	.868	1.8623	0.7073	-0.3462
	258	.120	.910	2.5161	0.8117	-0.2087
	259	.083	.938	2.9239	0.7995	-0.2238
	300	.100	.833	2.2478	1.4259	+0.3548
	301	.035	.950	3.4575	1.3349	+0.2889
	Mean	.105	.904	2.6014		-0.0270
33/65	247	.387	.995	2.8630	0.0377	-3.2774
	260	.287	.955	2.2576	0.2780	-1.2800
	261	.200	.988	3.0990	0.1114	-2.1943
	302	.173	.955	2.6381	0.3701	-0.9939
	303	.147	.945	2.6479	0.4833	-0.7270
	Mean	.234	.972	2.7010		-1.6945
33/40	248	.058	.988	3.8297	0.2691	-1.3125
	249	.073	.968	3.3067	0.5174	-0.6589
	262	.108	.960	2.9885	0.4641	-0.7676
	263	.100	.928	2.7431	0.7817	-0.2463
	304	.075	.935	2.9542	0.8957	-0.1102
	Mean	.082	.959	3.1643		-0.6191
39/65	250	.287	.938	2.1003	0.3585	-1.0257
	251	.427	.962	1.9584	0.2105	-1.5580
	264	.185	.958	2.6284	0.3356	-1.0918
	265	.073	.980	3.5083	0.3490	-1.0527
	305	.240	.978	2.7206	0.1687	-1.7799
	Mean	.231	.965	2.5824		-1.3016

retransformed proportions corresponding to the mean of the arc sine transformation values for the birds in each group.

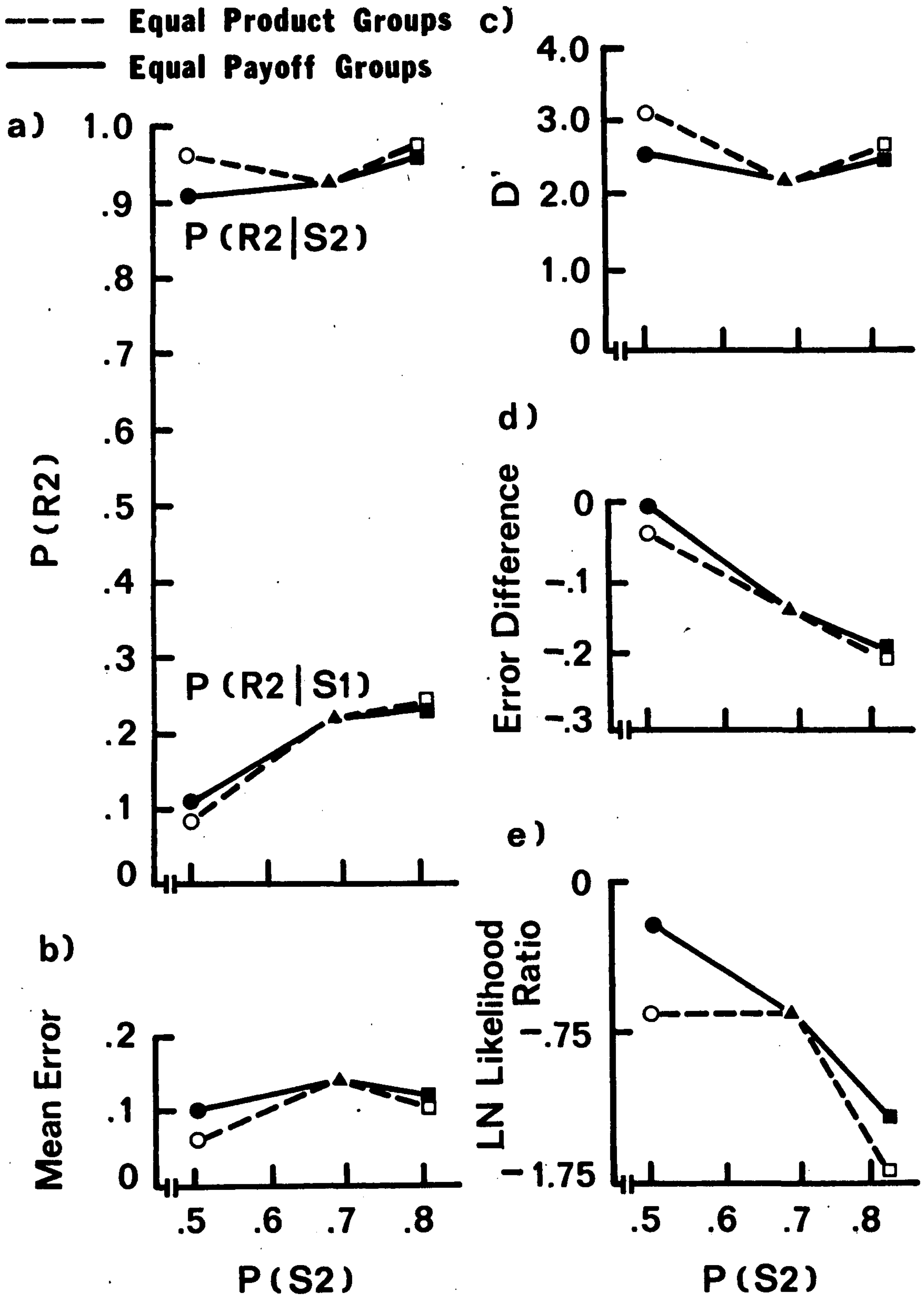
The first analysis was undertaken to determine whether there were any differences in the asymptotic levels of the five groups. The values of p(R2/S1) and p(R2/S2) were analysed independently. Subsequent analyses attempted to determine the extent to which asymptotic differences reflect differences in bias and sensitivity.

The mean values of p(R2/S1) and p(R2/S2) are plotted as a function of p(S2) in part (a) of Figure 7. A dashed line connects the means of Groups 33/40, 33/55, and 33/65, the three groups for which p(E2) was .6875. Since p(E2) is the product of stimulus presentation probability and reinforcement probability, these groups are referred to as the equal product groups. A solid line connects the means of Groups 24/40, 33/55, and 39/65, the groups for which the probability of reinforcement for being correct was constant at .60. These groups are referred to as the equal payoff groups. Since Group 33/55 is included in both sets, the point representing this group lies on both curves.

Furthermore, the means of p(R2/S1) increased monotonically with presentation rate for all groups. Group 33/40 had the smallest value of p(R2/S1), followed in order by Groups 24/40, 33/55, 39/65, and 33/65. The values of p(R2/S2) increased monotonically with p(S2) when payoff was equal. No such relationship is seen for the equal product groups. Group 24/40 had the lowest value of p(R2/S2), followed in order by Groups 33/55, 33/40, 39/65, and 33/65.

Separate analyses of variance of the transformed asymptotic values for p(R2/S1) and for p(R2/S2) indicated significant differences, $F(4,20) = 3.09$, $p < .05$, and $F(4,20) = 4.42$, $p < .05$ respectively. These results

Figure 7. Group data from Days 91-100 (large sound difference). Solid lines represent equal payoff groups (Groups 24/40, 33/55 and 39/65. Dashed lines represent equal product groups (Groups 33/40, 33/55, and 33/65). The triangle represents Group 33/55; the open and filled circles represent Groups 33/40 and 24/40, respectively; the open and filled squares represent Groups 33/65 and 39/65, respectively. Figure 7(a) presents the group means of $\underline{p}(R2/S1)$ and $\underline{p}(R2/S2)$ as a function of $\underline{p}(S2)$. Figure 7(b) presents the group means of the mean error discriminability index as a function of $\underline{p}(S2)$. Figure 7(c) presents the group means of $\underline{d}'$ as a function of $\underline{p}(S2)$. Figure 7(d) presents the group means of error difference as a function of $\underline{p}(S2)$. Figure 7(e) presents the group means of ln likelihood ratio criterion as a function of $\underline{p}(S2)$.


---- Equal Product Groups
—— Equal Payoff Groups
a)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
P (R2)
P (R2|S2)
P (R2|S1)
b)
Mean Error
.2
.1
0
.5
.6
.7
.8
P (S2)
c)
D'
4.0
3.0
2.0
1.0
0
d)
Error Difference
0
-.1
-.2
-.3
e)
LN Likelihood Ratio
0
-.75
-1.75
.5
.6
.7
.8
P (S2)

are presented in Table C (appendix). Multiple comparisons using the Tukey (b) procedure failed to detect differences between the values of p(R2/S1). Comparisons between the values of p(R2/S2) indicated that the mean of Group 24/40 was significantly lower than the means of Groups 33/65 and 39/65. No other significant differences were found.

The finding that Groups 33/65 and 39/65 did not differ significantly from each other in p(R2/S1), but did differ from Group 24/40 suggests that the differences were due to differences in presentation proportions, since Groups 33/65 and 39/65 each had the most extreme value of p(S2), while Group 24/40 had the least extreme value of p(S2). One limitation in interpreting these results is that the sounds were easily discriminated. The lowest value of p(R2/S2) was .833 for Bird 300.

The next analysis was an attempt to determine whether the observed asymptotic differences reflect differences in sensitivity or bias. To this end, a discriminability index was computed by averaging the asymptotic error rates to S1 and S2. Part (b) of Figure 7 shows the mean of this discriminability index as a function of p(S2). There appear to be no systematic differences between groups.

An analysis of variance of the transformed error proportions is presented in Table D (appendix). The results show that the groups did not differ significantly from each other, $F(4,20) = 1.92$. Multiple comparisons also found no significant differences.

The values of d' obtained for each bird for Days 91 through 100 are presented in column 5 of Table 3. Part (c) of Figure 7 shows how d' varied as a function of p(S2). An analysis of variance of the d' values shown, summarized in Table E (appendix), revealed no significant differences between groups, $F(4,20) = 1.70$. This finding is in agreement with the results of the error index analysis. Neither index provides evidence of differences between groups in the ability to discriminate the 8 dB sound difference.

It will be recalled that the visual determination of bias was based upon the degree of asymmetry of the training curves. This asymmetry was translated into quantitative terms by obtaining the difference between the proportion of errors made in the presence of each stimulus. If these proportions were equal, the curves would be symmetrical. If a greater proportion of errors were made in the presence of S1, the curves would be asymmetrical in the direction above .50, and the bias index would be negative. If a greater proportion of errors were made in the presence of S2, the curves would be asymmetrical in the direction below .50, and the bias would be positive.

Part (d) of Figure 7 shows the means of the bias index as a function of $\underline{p}$(S2). Error difference appears to increase with presentation rate for all groups. The smallest error difference was found for Group 24/40. This was followed in order by Groups 33/40, 33/55, 39/65, and 33/65.

An analysis of variance of the differences between the transformed error scores found significant differences between groups, $\underline{F}(4,20) = 6.08$, $\underline{p} < .01$. The results are presented in Table F (appendix). Multiple comparisons indicated that Groups 24/40 and 33/40 differed significantly from Groups 33/65 and 39/65. Other differences were not found to be significant.

All significant differences among groups can be accounted for in terms of differences in the values of $\underline{p}$(S2), regardless of the $\underline{p}$(E2) value. These results suggest that bias, as measured by error difference, was controlled by the stimulus presentation proportions during the large sound difference phase of the experiment, and thus support the conclusions drawn from visual inspection of the training curves.

In order to perform statistical analyses based on likelihood ratios, it is necessary first to normalize them. This was accomplished by taking the natural logarithm of the likelihood ratio.(Tanner & Birdsall, 1964, p. 149), i.e. ln likelihood ratio. Specifically, the density values corresponding to p(R2/S2) and p(R2/S1) were obtained from a table of the normal distribution. The ln of the ratio of the first to the second density was computed.

The values of the criterion ln likelihood ratio for all birds are presented in column 7 of Table 3. Negative values indicate a preference for response R2. Positive values indicate a preference for response R1. Part (e) of Figure 7 presents the means of the ln likelihood ratios for each group as a function of p(S2). The figure shows a tendency for the likelihood ratio criterion to decrease with p(S2). Group 24/40 had the ln likelihood ratio criterion closest to zero, followed in order by Groups 33/55, 33/40, 39/65, and 33/65. The one exception to monotonicity is seen in the value of Group 33/40, which is approximately the same as that of Group 33/55.

The analysis of variance of ln likelihood ratios, summarized in Table G (appendix), yielded significant differences between groups $F(4,20) = 6.72$, $p < .01$. Three differences between individual groups were found to be significant using the Tukey (b) procedure: Group 24/40 was found to be significantly less biased in favor of R2 than Groups 39/65 and 33/65, and Group 33/55 was found to be significantly less biased than Group 33/65.

These results differ slightly from the results of the error difference analysis. In that analysis Group 33/55 was not found to differ from Group 33/65, while Group 33/40 differed from both Groups 39/65 and 33/65. The ordinal relation of the groups is similar for both measurements except for Groups 33/40 and 33/55. The extreme position of Group 33/65 for both measurements is of interest, since it suggests that responding was under control of p(S2) and that payoff was not a factor. However, this should be tempered by the observation that very small changes in p(R2/S2) will yield very large changes in the likelihood ratio.

Small sound difference discrimination. The analysis of discrimination behavior with the decreased stimulus difference is based upon 800 first trials from Days 113 through 122 of training. These were the last ten days of training under these conditions.

Table 4 presents the values of p(R2/S1) and p(R2/S2) for each bird for Days 113 through 122. The means for each group which are presented are again the retransformed proportions corresponding to the mean of the arc sine transformation values.

Part (a) of Figure 8 shows the means of p(R2/S1) and p(R2/S2) as a function of p(S2) for each group. The solid and dashed lines represent the equal payoff and equal product groups, respectively. The equal payoff groups exhibit a clear monotonic relationship between presentation probability and the levels of p(R2) in the presence of each stimulus. The slope of the function appears to be much steeper than that of the corresponding function for Days 91 through 100. The curves for the equal product groups are relatively flat and non-monotonic.

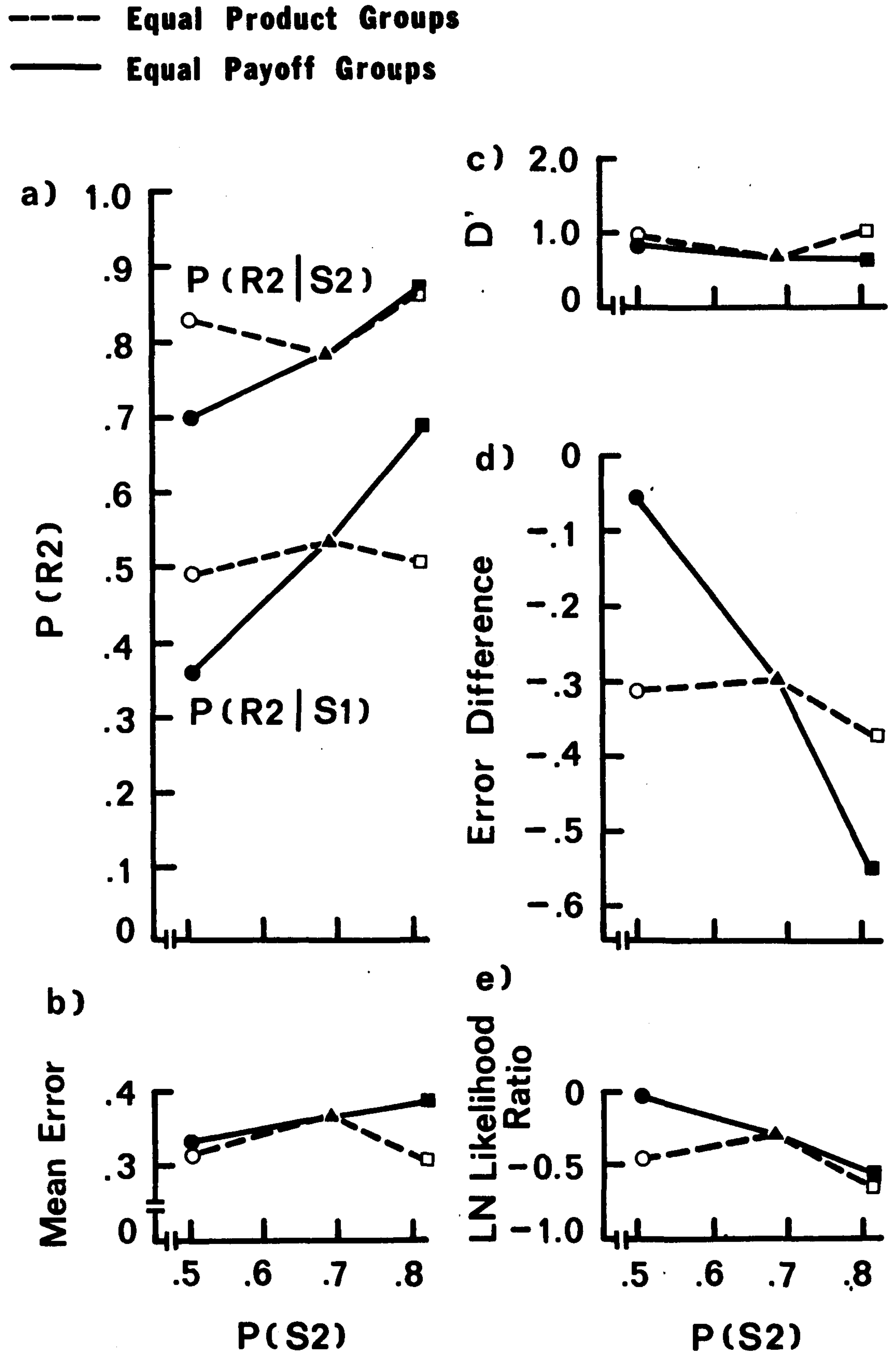
Analyses of variance, summarized in Table H (appendix), indicated that there were significant differences among groups in values of

TABLE 4

Summary of Data - Days 113-122

Group	Bird	p(R2/S1)	p(R2/S2)	d'	Likelihood Ratio	Ln Likelihood Ratio
33/55	244	.616	.776	0.4640	0.7833	-0.2443
	245	.536	.815	0.8062	0.6719	-0.3977
	257	.500	.767	0.7287	0.7668	-0.2655
	298	.440	.780	0.9226	0.9226	-0.2866
	299	.560	.764	0.5683	0.5683	-0.2471
	Mean	.531	.781	0.6979		-0.2882
24/40	246	.430	.683	0.6517	0.9070	-0.0977
	258	.355	.688	0.8612	0.9503	-0.0510
	259	.385	.745	0.9505	0.8401	-0.1742
	300	.383	.683	0.7729	0.9333	-0.0690
	301	.230	.675	1.1919	1.1853	+0.1700
	Mean	.355	.697	0.8855		-0.0443
33/65	247	.533	.900	1.1991	0.4413	-0.8180
	260	.633	.888	0.8767	0.5057	-0.6819
	261	.447	.832	1.0950	0.6351	-0.4539
	302	.547	.897	1.1470	0.4525	-0.7929
	303	.400	.822	1.1759	0.6744	-0.3939
	Mean	.502	.870	1.0986		-0.6281
33/40	248	.415	.798	1.0486	0.7225	-0.3251
	249	.464	.825	1.0247	0.6488	-0.4326
	262	.563	.885	1.0422	0.4926	-0.7081
	263	.535	.848	0.9403	0.5919	-0.5244
	304	.448	.773	0.8790	0.7621	-0.2716
	Mean	.485	.828	0.9869		-0.4523
39/65	250	.733	.891	0.6104	0.5679	-0.5657
	251	.715	.901	0.7198	0.5129	-0.6676
	264	.642	.735	0.2643	0.8772	-0.1310
	265	.473	.880	1.2427	0.5025	-0.6881
	305	.813	.921	0.5232	0.5478	-0.6020
	Mean	.680	.871	0.6720		-0.5308

Figure 8. Group data from Days 113-122 (small sound difference). Solid lines represent equal payoff groups (Groups 24/40, 33/55, and 39/65). Dashed lines represent equal product groups (Groups 33/40, 33/55, and 33/65). The triangle represents Group 33/55; the open and filled circles represent Groups 33/40 and 24/40, respectively; the open and filled squares represent Groups 33/65 and 39/65, respectively. Figure 8(a) presents the group means of $\underline{p}$(R2/S1) and $\underline{p}$(R2/S2) as a function of $\underline{p}$(S2). Figure 8(b) presents the group means of the mean error discriminability index as a function of $\underline{p}$(S2). Figure 8(c) presents the group means of $\underline{d}'$ as a function of $\underline{p}$(S2). Figure 8(d) presents the group means of error difference as a function of $\underline{p}$(S2). Figure 8(e) presents the group means of ln likelihood ratio criterion as a function of $\underline{p}$(S2).


---- Equal Product Groups
—— Equal Payoff Groups
a)
P (R2)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
P (R2 | S2)
P (R2 | S1)
b)
Mean Error
.4
.3
0
.5
.6
.7
.8
P(S2)
c)
D'
2.0
1.0
0
d)
Error Difference
0
-.1
-.2
-.3
-.4
-.5
-.6
e)
LN Likelihood Ratio
0
-0.5
-1.0
.5
.6
.7
.8
P(S2)

$\underline{p}$(R2/S1), $\underline{F}(4,20)$ - 8.33, $\underline{p} < .001$, and $\underline{p}$(R2/S2), $\underline{F}(4,20) = 11.52$, $\underline{p} < .001$, respectively.

The lowest mean value of $\underline{p}$(R2/S1) was found for Group 24/40, followed by Groups 33/40, 33/65, 33/55, and 39/65. Multiple comparisons revealed that Groups 33/40, 33/65, and 33/55 did not differ significantly from each other. Groups 24/40, 33/55, and 39/65 were all found to be significantly different from each other. Of the groups which received the same values of $\underline{p}$(S2), Group 33/65 was found to be significantly lower than Group 39/65, while Group 24/40 and Group 33/40 were found not to be significantly different from each other. An additional significant difference was found between Groups 33/40 and 39/65.

The lowest mean of $\underline{p}$(R2/S2) was again found for Group 24/40, followed in order by Groups 33/55, 33/40, 33/65, and 39/65. Multiple comparisons indicated that Groups 24/40, 33/55, and 39/65 differed significantly from each other with the size of the mean varying according to $\underline{p}$(S2). Among the equal product groups, Group 33/55 and 33/65 were found to differ significantly. Group 33/40 did not differ from either of these groups. While significant differences were found among the equal product groups, the relationship between $\underline{p}$(R2/S2) and $\underline{p}$(S2) was not monotonic. Of the two pairs of groups which received the same values of $\underline{p}$(S2), Group 24/40 was found to have a significantly lower value of $\underline{p}$(R2/S2) than Group 33/40. Of the remaining comparisons, Group 24/40 had a lower value than Group 33/65. These results indicate that the proportions of responses made in the presence of each stimulus varied with $\underline{p}$(E2).

Again an index of discriminability was computed by averaging the asymptotic error rates to S1 and S2 for each bird for Days 113 through 122. The group means for this index was shown in part (b) of Figure 8 as a function of p(S2). With the major exception of Group 33/65 the figure reveals a slight tendency for the proportion of errors to increase as a function of p(S2).

An analysis of variance, summarized in Table I (appendix), revealed significant differences between groups, $F(4,20) = 3.57$, $p < .05$. This is in contrast to the findings of no significant differences for the large sound difference discrimination. Group 33/65 had the lowest mean proportion of errors, followed by Groups 33/40, 24/40, 33/55, and 39/65. Multiple comparisons indicated that Group 33/65 had a significantly lower mean discriminability index than Groups 33/55 and 39/65, and that Group 33/40 had a significantly lower mean than Group 39/65. It is possible to account for each difference between a pair of groups in terms of a significant difference in either p(R2/S1) or p(R2/S2). The difference between Groups 33/65 and 39/65 can be accounted for by lower proportions of p(R2/S1) for Group 33/65. The difference between Groups 33/40 and 39/65 can be similarly accounted for in terms of p(R2/S1). The proportions of errors made in the presence of S2 did not differ significantly between Groups 33/40 and 39/65. The difference between Groups 33/55 and 33/65 can be accounted for by differences between p(R2/S2). Group 33/55 had a lower value of p(R2/S2), indicating a greater proportion of errors.

The values of d' derived for the 2 dB sound difference discrimination are presented in column 5 of Table 4. Part (a) of Figure 8 shows the mean values of d' as a function of p(S2). The ordering of these values is the same as that of the discriminability index. Group 39/65 had the smallest mean value of d', followed by Groups 33/55, 24/40, 33/40, and 33/65. The figure shows a slight tendency of d' to decrease with an increase in p(S2), except for Group 33/65, which had the highest mean value of d'. In general while some monotonicity is seen in the figure, the individual values of d' appear somewhat closer to each other for this sound difference condition than for the easy discrimination.

An analysis of variance revealed significant differences among groups, $F(4,20) = 3.71$, $p < .05$. The results are summarized in Table J (appendix). Two significant differences were found between groups: Group 33/65 was found to have significantly higher values of d' than Group 39/65 and Group 33/55. These results are in general agreement with the results of the discriminability index analysis. Although significant differences in d' were found between groups, there were no monotonic relationships between d' and the independent variables.

It is obvious that discriminability was reduced in all subjects as a result of the reduction in the difference between sound intensities. An analysis of variance was performed on the differences between d' during Days 91-100 and Days 113-122 to determine whether there were any differences between groups in the amount of reduction of d'. The results, summarized in Table K (appendix), found no significant differences in d' reduction among groups, $F(4,20) = 1.64$.

Next, the results were analyzed to determine whether there was a correlation between the value of d' for Days 91-100 and Days 113-122. The results found a significant correlation, $r(23) = .64$, $t(23) = 3.99$, $p < .001$. This means that the relative ability to discriminate was maintained between birds when the sound difference was reduced.

Turning to the analysis of bias for the reduced sound discrimination, the mean values of error differences for each group are shown in part (d) of Figure 8 as a function of $p(S2)$. The figure shows clearly that this index of bias varied for Groups 24/40, 33/55, and 39/65 as a function of p(S2), but did not vary for Groups 33/40, 33/55, and 33/65. Group 24/40 had the mean error difference closest to zero, followed by Groups 33/55, 33/40, 33/65, and 39/65. The results can be accounted for in terms of differences among the groups in p(E2).

Analysis of variance of error difference for Days 113 through 122 is presented in Table L (appendix). Differences between groups were found to be significant, $F(4,20) = 11.40$, $p < .001$. Multiple comparisons using the Tukey (b) test found significant differences among Groups 24/40, 33/55, and 39/65. No significant differences were found among Groups 33/40, 33/55, and 33/65. Of the groups receiving the same value of p(S2), Group 24/40 was significantly closer to zero than Group 33/40. Of the remaining comparisons, Group 24/40 was significantly closer to zero than Group 33/65, and Group 33/40 was significantly closer to zero than Group 39/65. The results of the bias analysis suggest that the relative difference in errors varied as a function of p(E2).

Of the five pairs of groups which differed significantly in error difference, only one pair (Groups 33/40 and 39/65) also differed significantly in sensitivity. All three comparisons between the equal payoff groups showed significance. These groups differed from each other in p(R2/S1) as well as in p(R2/S2). The differences in error difference therefore reflect differences in the proportions of R2 made in the presence of both sound stimuli. The observed difference in error difference between Groups 24/40 and 33/40 reflects lower values of p(R2/S2)for the former group. The observed differences between Groups 24/40 and 33/65 can also be accounted for by differences between p(R2/S2).

A comparison of the results from the two sound difference conditions indicates that behavior was under greater control of p(E2)during the 2 dB difference condition. During the 8 dB sound difference condition, behavior appears to have been a function of p(S2).

The individual values of ln likelihood ratio criteria are presented in column 7 of Table 4. Part (e) of Figure 8 shows the mean values as a function of p(S2). Group 24/40 had the least extreme likelihood ratio criteria, followed in order by Groups 33/55, 33/40, 39/65, and 33/65. This order is similar to the order found with error differences.

An analysis of variance, summarized in Table M (appendix), revealed significant differences, $F(4,20) = 9.35$, $p < .001$. Multiple comparisons yielded results that differ from those of the error difference analysis. Among the equal payoff groups, only Groups 24/40 amd 39/65 differed from each other. The error difference measure differed significantly between all three equal payoff groups. Further difference in criterion likelihood ratios was found between two equal product groups, Groups 33/55 and 33/65, whereas the index of error differences did not differ significantly for these groups.

The results of the likelihood ratio analysis were in general agreement with the findings of the error difference analysis (namely, that Group 24/40 showed significantly less bias than Groups 33/40 or 33/65) except that no significance was found between Groups 33/40 and 39/65. The results of the bias analysis appear to indicate that bias varied with p(E2).

Next, the relationship between likelihood ratio criteria during the large sound difference and small sound difference phases was examined. A comparison of the values of ln likelihood ratio in Table 3 and Table 4 shows that nearly every bird adopted a less extreme likelihood ratio during the small sound difference discrimination. The only birds who adopted more extreme criteria were Birds 263 and 304 from Group 33/40. It will be recalled that the curves of *p*(R2/S1) for the subjects in Group 33/40 (Figure 5) showed a sharp increase during this phase.

Despite the shifts towards less extreme criteria, a significant correlation was found between the likelihood ratio criteria adopted during the two phases of the experiment, $r(23) = .68$, $t(23) = 4.46$, $p < .001$. This means that subjects exhibited similar orderings of the criteria during both phases.

The results of the decreased sound difference phase suggest that (a) there were differences in sensitivity between groups, although no monotonic relationships between sensitivity and the independent variables were observed, and that (b) bias varied as a function of *p*(E2).

Generalization

During the ten days of generalization, the discrimination birds were reinforced for making correct responses in the presence of the two stimuli presented during the 2 dB difference discrimination training. The probability learning birds were reinforced in the presence of the training stimulus in the same manner as during training.

Before examining the responses to the generalization stimuli, it is of interest to see whether there were any changes in responding to the training stimuli. The proportions of R2 made in the presence of each stimulus during testing were compared with the corresponding values during the ten days prior to testing.

Differences between the data for the probability learning birds were examined first. A *t* test was performed on the difference between the transformed values of *p*(R2) made in the ten days prior to generalization and in the ten days of generalization. The results barely exceeded significance, $\underline{t}(4) = 2.78$, $\underline{p} < .05$, where $\underline{t}_{.05}(4) = 2.776$. The results suggest that $\underline{p}(R2)$ in the presence of the training stimulus was higher prior to generalization than during generalization. The mean values of $\underline{p}(R2)$ prior to and during generalization were .739 and .634, respectively.

Individual $\underline{t}$ tests were performed to determine whether the values of $\underline{p}(R2)$ differed from the predicted matching proportion of .6875. The arc sine transform was used again. No significant differences were found, $\underline{t}(4) = 1.44$ and $\underline{t}(4) = .81$, for the data prior to and during generalization, respectively.

Next, the data for the discrimination birds were analyzed to determine whether there were any differences between groups in the degree of response change. As before, the measure used was the difference between the transformed proportion of responses for the ten days of generalization and the transformed proportion for the last ten days of acquisition. The results of an analysis of variance, summarized in Table N (appendix), indicated no significant differences between groups, $\underline{F}(4,20) = 1.0$, and $\underline{F}(4,20) = 1.52$ for $\underline{p}(R2/S1)$ and $\underline{p}(R2/S2)$, respectively. Therefore the data for all groups were combined to determine whether there were any overall differences in degree of response change.

The results of $\underline{t}$ tests indicated that the mean value of $\underline{p}(R2/S1)$ was significantly higher during generalization, $\underline{t}(24) = 2.70$, $\underline{p} < .01$. Also, the mean value of $\underline{p}(R2/S2)$ was found to be significantly lower during generalization, $\underline{t}(24) = 2.20$, $\underline{p} < .05$. These results indicate that the discrimination deteriorated during generalization.

Because responding to the training stimuli during generalization differed from responding to these stimuli during training, the proportions obtained during generalization were subjected to the same analyses as the training proportions. Table 5 presents the values of $p(R2/S1)$ and $p(R2/S2)$, respectively, for each bird during generalization. Part (a) of Figure 9 presents the mean values of these proportions as a function of $p(S2)$. The figure shows a monotonic increase in both R2 proportions as a function of $p(S2)$ for the equal payoff groups. No such relationship is seen for the equal product groups.

Group 24/40 had the lowest mean value of $p(R2/S1)$, followed in order by Groups 33/40, 33/65, 33/55, and 39/65. Group 24/40 also had the lowest mean values of $p(R2/S2)$, followed in order by Groups 33/55, 33/40, 33/65, and 39/65. Analyses of variance, summarized in Table O (appendix), revealed significant differences between $p(R2/S1)$ and between $p(R2/S2)$, $F(4,20) = 17.59$, $p < .001$ and $F(4,20) = 20.93$, $p < .001$, respectively. Multiple comparisons found similar results for both proportions. The values of Group 24/40 were significantly lower than the values of the other groups. No significant differences were found between Groups 33/55, 33/40, and 33/65. The values of Group 39/65 were significantly higher than the other groups. All differences can be accounted for in terms of differences in $p(E2)$.

The mean proportions of errors made in the presence of the training stimuli during generalization are shown in part (b) of Figure 9 as a function of $p(S2)$. The figure reveals slight differences in this index of sensitivity between groups. No monotonic relationship is present. An analysis of variance, summarized in Table P (appendix), confirmed that there were no significant differences in error between groups, $F(4,20) = 2.20$.

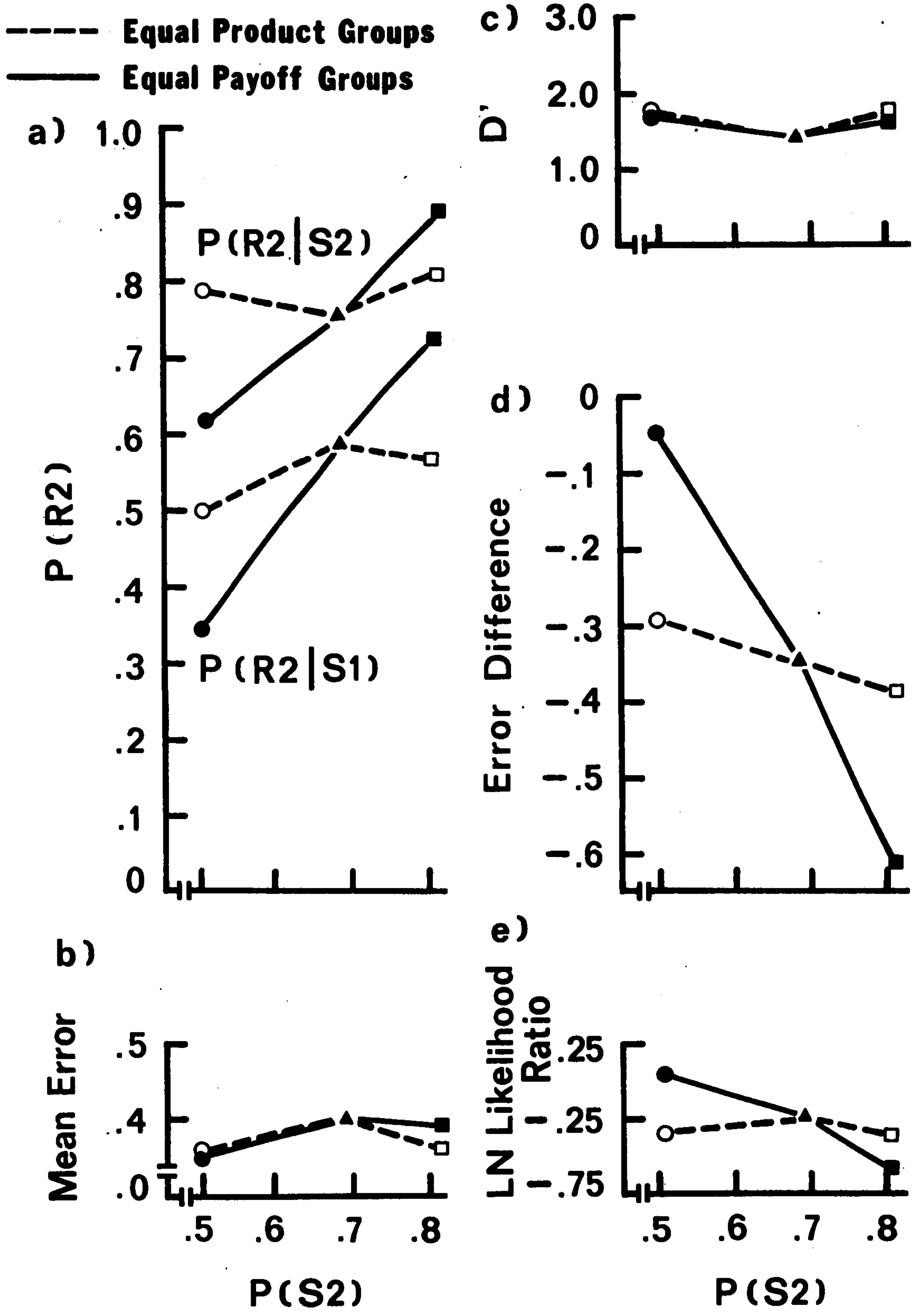
The values of d' obtained from the proportions are presented in column 5 of Table 5. Part (c) of Figure 9 shows the mean values of d'

TABLE 5

Summary of Data from Training Stimuli during Generalization

Group	Bird	*p*(R2/S1)	*p*(R2/S2)	*d*'	Likelihood Ratio	Ln Likelihood Ratio
33/55	244	.625	.791	0.4915	0.7579	-0.2772
	245	.560	.727	0.4528	0.8431	-0.1707
	257	.556	.724	0.4539	0.8464	-0.1668
	298	.552	.808	0.7400	0.6905	-0.3703
	299	.655	.748	0.2695	0.8662	-0.1437
	Mean	.590	.760	0.4815		-0.2256
24/40	246	.408	.610	0.5112	0.9882	-0.0119
	258	.270	.504	0.6225	1.2062	+0.1875
	259	.415	.674	0.6649	0.9245	-0.0785
	300	.378	.679	0.7748	0.9420	-0.0597
	301	.223	.601	1.0174	1.2938	+0.2576
	Mean	.336	.614	0.7182		+0.0589
33/65	247	.487	.752	0.7130	0.7937	-0.2310
	260	.760	.867	0.4064	0.6911	-0.3695
	261	.587	.860	0.8609	0.5715	-0.5596
	302	.467	.783	0.8648	0.7390	-0.3025
	303	.553	.812	0.7522	0.6819	-0.3829
	Mean	.573	.817	0.7174		-0.3690
33/40	248	.500	.790	0.8062	0.7225	-0.3250
	249	.536	.820	0.8251	0.6605	-0.4148
	262	.595	.825	0.6945	0.6651	-0.4078
	263	.541	.740	0.5403	0.8175	-0.2015
	304	.501	.781	0.7729	0.7404	-0.3006
	Mean	.500	.792	0.7278		-0.3298
39/65	250	.728	.874	0.5392	0.6236	-0.4723
	251	.800	.872	0.2945	0.7474	-0.2912
	264	.695	.907	0.8130	0.4748	-0.7449
	265	.680	.845	0.5479	0.6662	-0.4061
	305	.752	.949	0.9551	0.3309	-1.1060
	Mean	.723	.892	0.6299		-0.6040

Figure 9. Group data from training stimuli during generalization. Solid lines represent equal payoff groups (Groups 24/40, 33/55, and 39/65). Dashed lines represent equal product groups (Groups 33/40, 33/55, and 33/65). The triangle represents Group 33/55; the open and filled circles represent Groups 33/40 and 24/40, respectively; the open and filled squares represent Groups 33/65 and 39/65, respectively. Figure 9(a) presents the group means of $\underline{p}$(R2/S1) and $\underline{p}$(R2/S2) as a function of $\underline{p}$(S2). Figure 9(b) presents the group means of the mean error discriminability index as a function of $\underline{p}$(S2). Figure 9(c) presents the group means of $\underline{d}'$ as a function of $\underline{p}$(S2). Figure 9(d) presents the group means of error difference as a function of $\underline{p}$(S2). Figure 9(e) presents the group means of ln likelihood ratio criterion as a function of $\underline{p}$(S2).


---- Equal Product Groups
—— Equal Payoff Groups
a)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
P (R2)
P (R2|S2)
P (R2|S1)
b)
Mean Error
.5
.4
.0
.5
.6
.7
.8
P(S2)
c)
3.0
2.0
1.0
0
D'
d)
Error Difference
0
-.1
-.2
-.3
-.4
-.5
-.6
e)
LN Likelihood Ratio
.25
-.25
-.75
.5
.6
.7
.8
P(S2)

as a function of p(S2). This figure also reveals only slight differences between groups. The analysis of variance done on the values of d' found no significant differences between groups during generalization, F(4,20) = 1.53. The results are summarized in Table Q (appendix).

These findings differ from the findings of significance during the last ten days of training. Differences between mean errors were found between Groups 33/65 and 33/55, 33/65 and 39/65, and 33/40 and 39/65. Differences between d' were found between Groups 33/65 and 33/55, and between Groups 33/65 and 39/65.

Measurements of bias were examined next. Part (d) of Figure 9 presents the mean error differences as a function of p(S2) for all groups during generalization. The figure indicates that the error difference index varied monotonically with p(S2) for equal payoff and equal product groups. However, the eqyal payoff function is much steeper, indicating greater control. Group 24/40 had the bias value closest to zero, followed in order by Groups 33/40, 33/55, 33/65, and 39/65.

The analysis of variance, summarized in Table R (appendix), produced significant differences, F(4,20) = 48.28, $p < .001$. Multiple comparisons found that Group 24/40 had an error difference value significantly closer to zero than the other groups. Groups 33/40, 33/55, and 33/65 were found not to differ significantly from each other. Group 39/65 had an error difference value significantly more extreme than the other groups. These results can be accounted for by differences in p(E2). The differences all reflext the variations in p(R2/S1) and p(R2/S2).

The criterion values of ln likelihood ratio obtained from the proportions of R2 made in the presence of the training stimuli during generalization are presented in column 7 of Table 5. Part (e) of Figure 9 shows how the mean criterion values varied as a function of S2. The figure indicates a monotonic relationship between ln likelihood ratio and $\underline{p}(S2)$ for the equal payoff groups, but not for the equal product groups. Group 24/40 had the least extreme mean criterion value, followed in order by Groups 33/55, 33/40, 33/65, and 39/65.

The subsequent analysis of variance, summarized in Table S (appendix), found significance, $\underline{F}(4,20) = 8.99$. $\underline{p} < .001$. Of the individual comparisons, Group 24/40 was found to differ significantly from Groups 33/40, 33/65, and 39/65, and Group 33/55 was found to differ significantly from Group 39/65. These significances were also found using the error difference index.

The analysis of responses made in the presence of the training stimuli during the generalization test suggests that generalization did have some effects upon responding in the presence of the training stimuli. Larger proportions of errors were made in the presence of each training stimulus during generalization. No differences in sensitivity were found during generalization, whereas differences in sensitivity were found during the last ten days of training. All differences found in error difference during the last ten days of training were found during generalization. One additional difference, between Groups 24/40 and 33/55, was found during generalization. All differences found between ln likelihood ratio criteria during the last ten days of training were found during generalization, except that no difference was found between Groups 24/40 and 33/65 during generalization, where previously a difference was found, and an additional difference was found between Groups 33/55 and 39/65 during generalization, where previously no difference was seen.

Responding in the presence of all eight stimuli is examined next. Figures 10 through 15 show the proportions of R2 responses as a function of stimulus intensity for each bird in each of the six groups. The points represent the actual proportions of R2.

Figure 10 presents the generalization data for the probability learning group. The points for the 74 dB stimulus are based upon 800 trials, while the points for the other intensities are based upon 130 trials each. Inspection of the individual curves reveals no systematic variations in $\underline{p}(R2)$ with stimulus intensity. Horizontal lines are drawn at $\underline{p}(R2)=.6875$, the value of $\underline{p}(E2)$. The curves for Birds 242, 256 and 297 lie above $\underline{p}(E2)$. The curves for Birds 243 and 296 lie below $\underline{p}(E2)$. A comparison with the curves in Figure 1 indicates that Birds 242, 256, and 297 maintained approximately the same level of responding during generalization as during training, while Birds 243 and 296 appear to have made fewer R2 responses.

Figures 11 through 15 represent the generalization data for Groups 33/55, 24/40, 33/65, 33/40, and 39/65, respectively. The smooth curves which are fitted to the data are theoretical curves based upon a model developed by Heinemann and co-workers (1969). The figures reveal control by sound intensity for every bird tested. The shape of the functions is similar for each bird. For stimuli less intense than S1 the values of $\underline{p}(R2)$ tend to be lower than $\underline{p}(R2/S1)$. For stimuli of greater intensity than S2 the values of $\underline{p}(R2)$ tend to be greater than $\underline{p}(R2/S2)$. All functions showed sigmoidal shapes characteristic of psychometric functions. They differ from psychometric functions in the position of their asymptotes, which were not at 0.0 and 1.0.

Three aspects of the curves may be distinguished, the slopes of the middle segments, the position of the curves along the $\underline{x}$ axis, and

Figure 10. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group P. Horizontal lines represent the matching value of p(E2). Points in squares indicate the stimuli used in training.

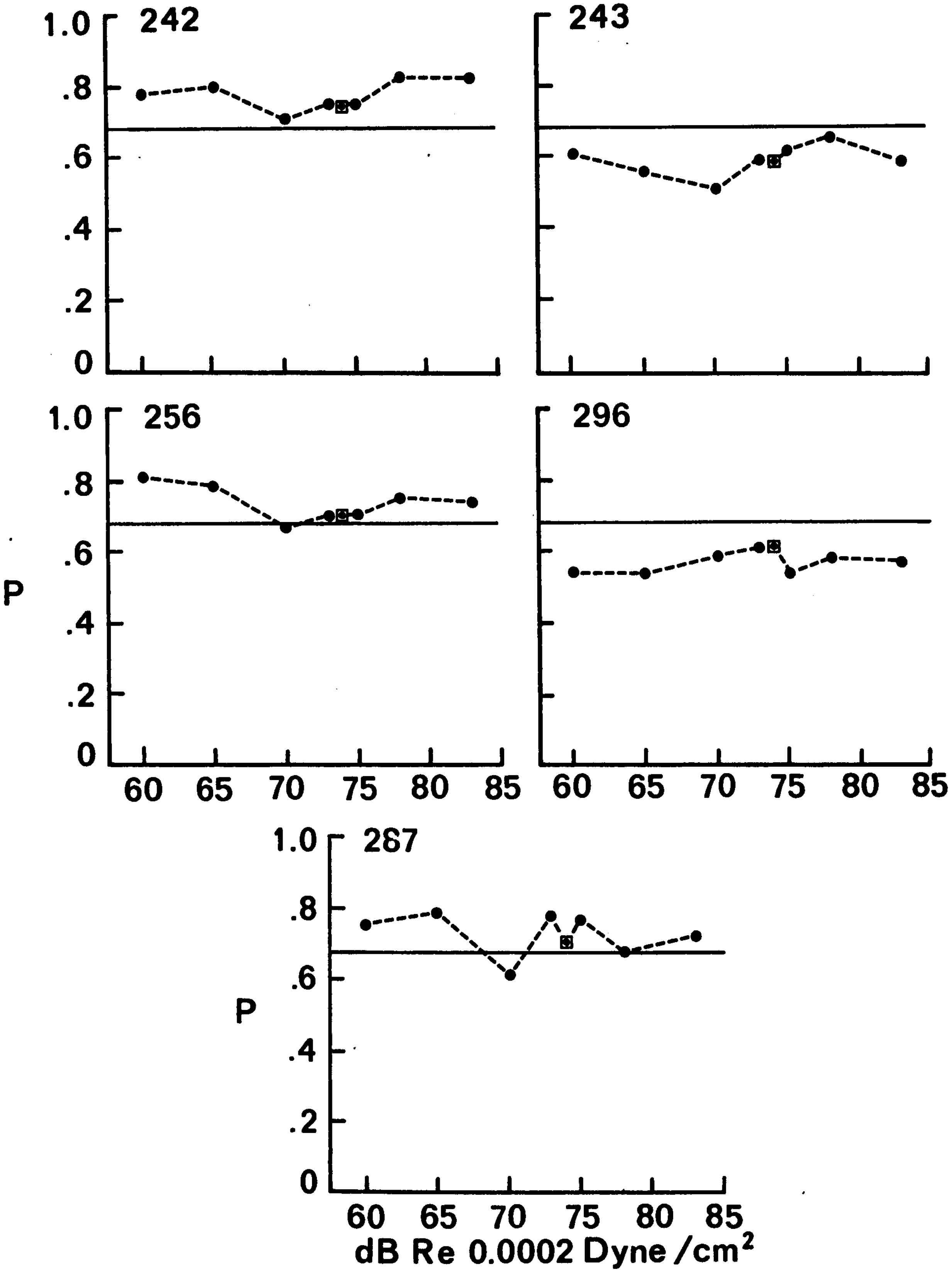
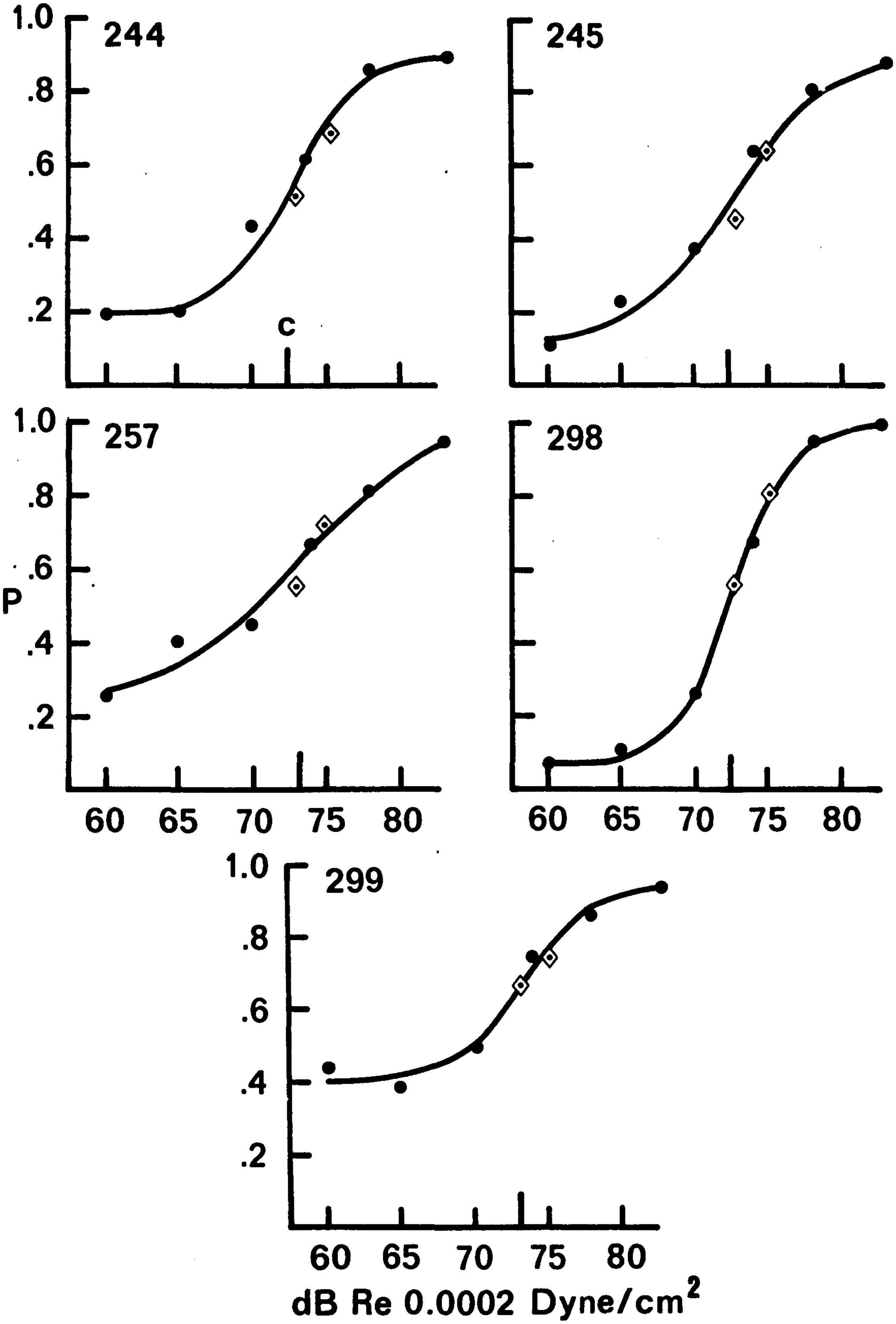

242
243
256
296
287
1.0
.8
.6
.4
.2
0
P
60
65
70
75
80
85
dB Re 0.0002 Dyne /cm²

Figure 11. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group 33/55. Smooth curves are theoretical. Lines labeled C represent criterion intensity derived from theoretical curves. Points in diamond shapes indicate stimuli used in training. See text for further details.



244
245
257
298
299
1.0
.8
.6
.4
.2
P
c
60
65
70
75
80
dB Re 0.0002 Dyne/cm²

Figure 12. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group 24/40. Smooth curves are theoretical. Lines labeled C represent criterion intensity derived from theoretical curves. Points in diamond shapes indicate stimuli used in training. See text for further details.

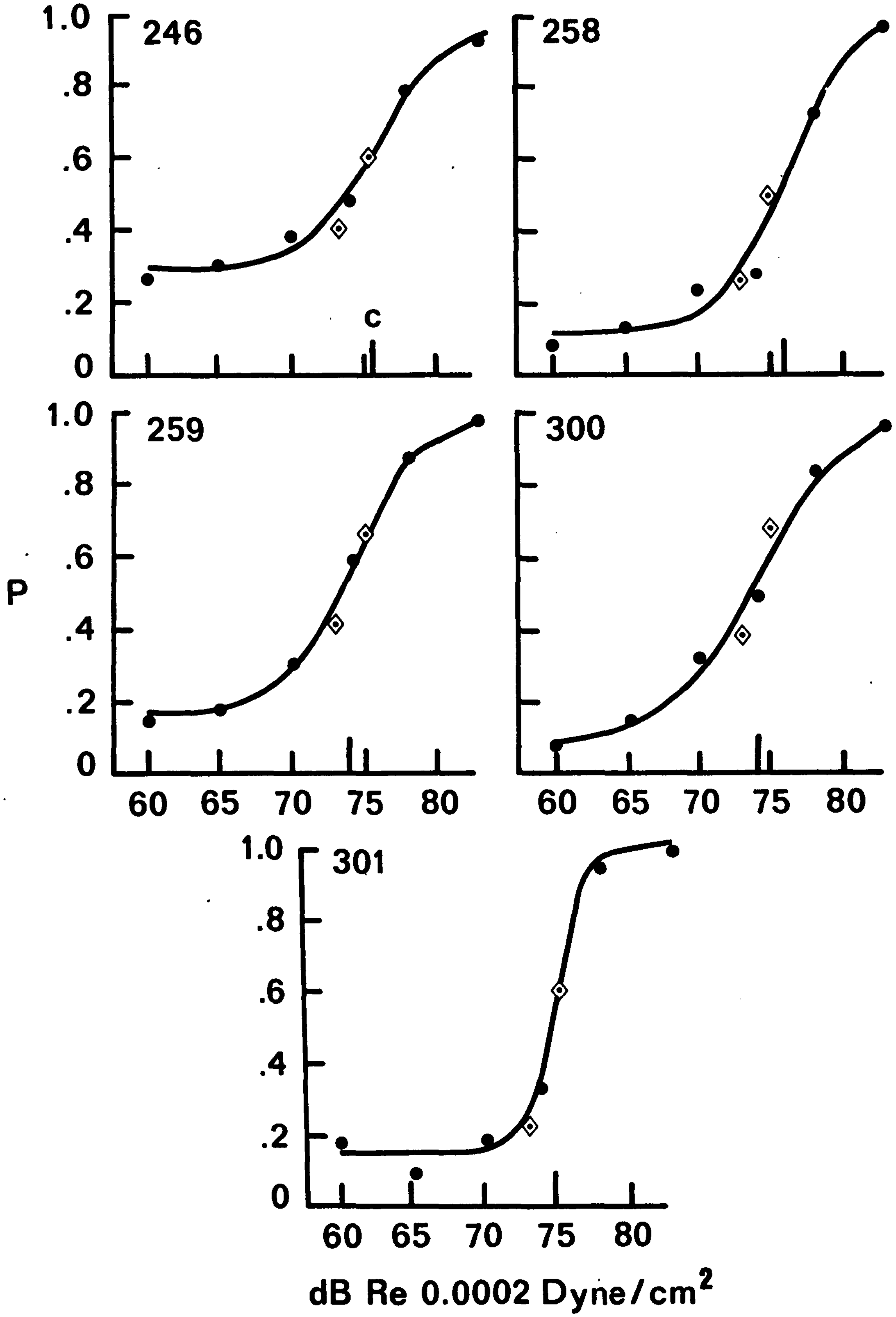

246
258
259
300
301
1.0
.8
.6
.4
.2
0
P
c
60
65
70
75
80
dB Re 0.0002 Dyne/cm^2

Figure 13. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group 33/65. Smooth curves are theoretical. Lines labeled C represent criterion intensity derived from theoretical curves. Points in diamond shapes indicate stimuli used in training. See text for further details.

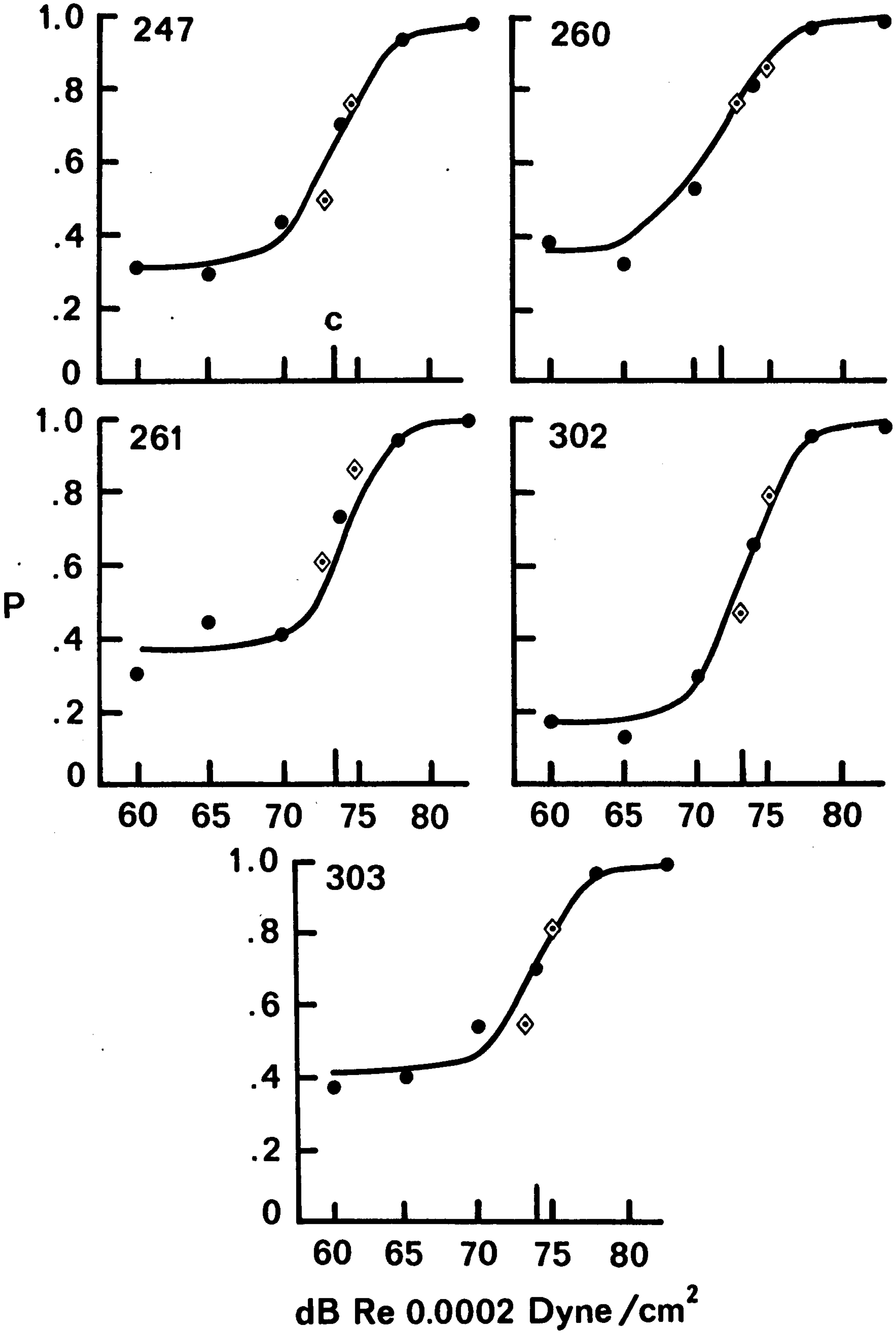

247
260
261
302
303
c
P
1.0
.8
.6
.4
.2
0
60
65
70
75
80
dB Re 0.0002 Dyne/cm^2

Figure 14. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group 33/40. Smooth curves are theoretical. Lines labeled C represent criterion intensity derived from theoretical curves. Points in diamond shapes indicate stimuli used in training. See text for further details.

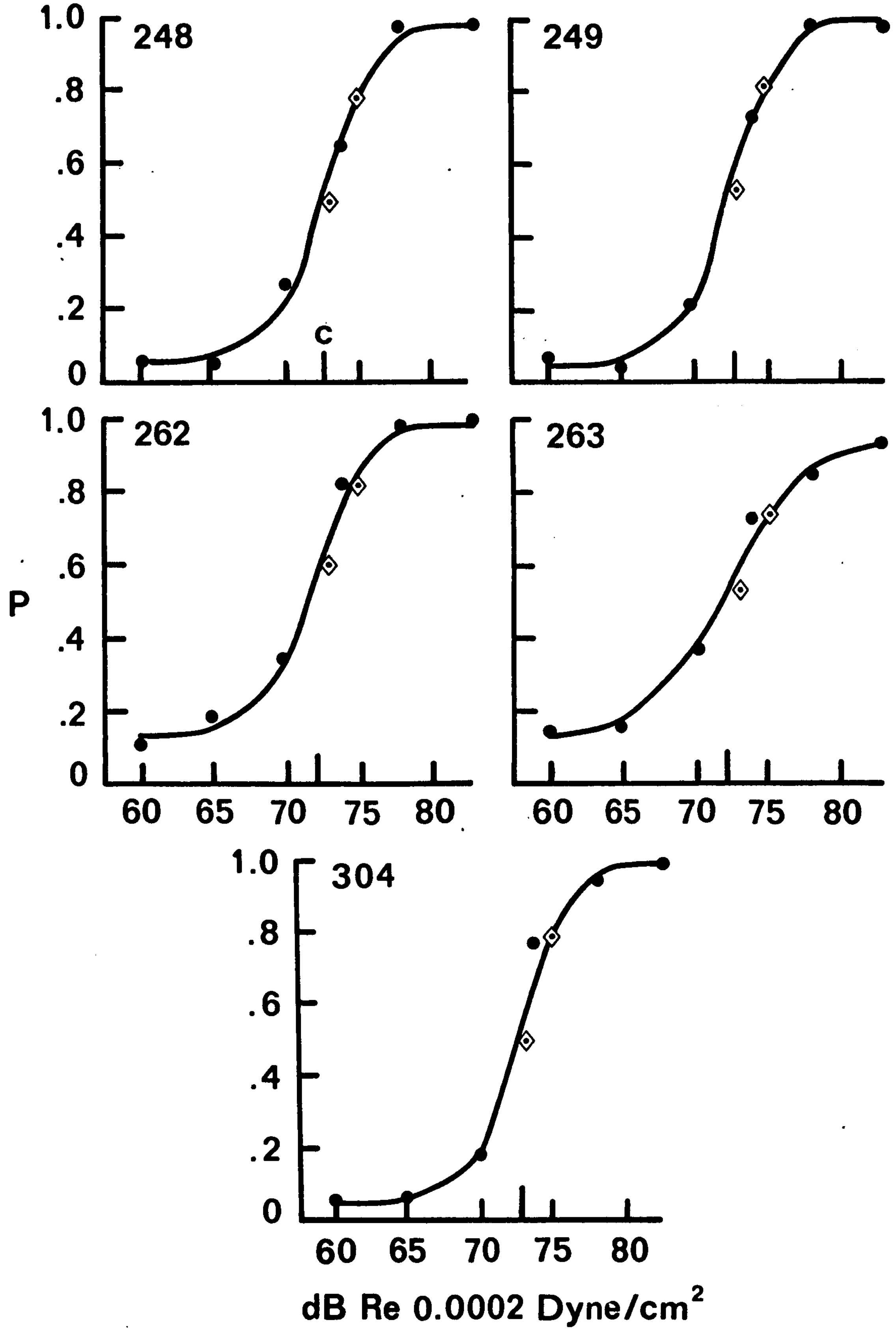
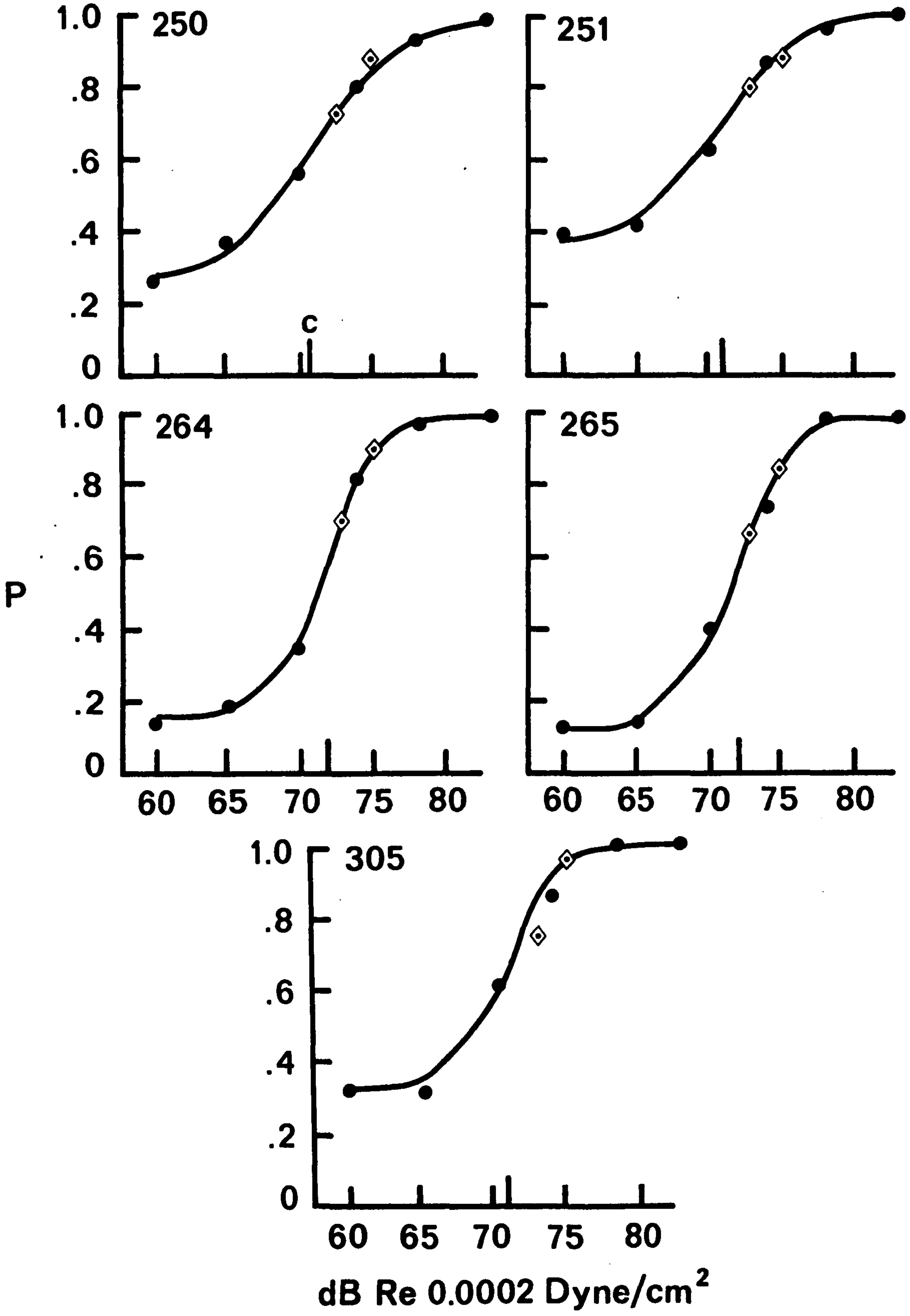

248
249
262
263
304
c
P
1.0
.8
.6
.4
.2
0
60
65
70
75
80
dB Re 0.0002 Dyne/cm²

Figure 15. Proportion of R2 as a function of sound intensity during generalization tests for individual subjects in Group 39/65. Smooth curves are theoretical. Lines labeled C represent criterion intensity derived from theoretical curves. Points in diamond shapes indicate stimuli used in training. See text for further details.


250
251
264
265
305
c
P
1.0
.8
.6
.4
.2
0
60
65
70
75
80
dB Re 0.0002 Dyne/cm²

the range of the curves along the y axis. These features of the curves will be subjected to statistical analyses after a discussion of the theoretical model. For the present they will be discussed in terms of visual inspection.

There are no obvious differences among the groups in the slope of the curves, although there appears to be variability within groups. As a rough estimate of the position of the curves along the x axis, consider the location of the point representing 74 dB, the sound intensity midway between the two training intensities. Examination of the curves reveals that four of the five birds in Group 24/40 responded R2 on fewer than 50% of the trials with this stimulus, all the birds in the other groups responded R2 on more than 60% of the trials with this stimulus, and three of the birds in Group 39/65 responded R2 on more than 80% of the trials with this stimulus. Thus, rough visual inspection indicates differences in the location of the curves along the x axis. The range of the curves along the y axis varies between birds. A rough examination suggests that the curves for Group 33/40 have the widest range.

Heinemann and co-workers have developed a model to describe choice curves obtained under the conditions of the present experiment. The model is based upon the theory of signal recognition and a concept of attention.

The assumptions from signal recognition theory have already been discussed. The underlying distributions of neural effects of each stimulus presented are assumed to be normal and of equal variance. Subjects come to establish a criterion along the axis of neural effects. If the neural effects on a given trial are greater than this criterion intensity, the animal responds R2. If the neural effects are below this intensity, the animal responds R1.

It can be shown that as stimulus intensity increases from low values to high values, the probability of responding R2 varies monotonically to produce a function whose shape is a normal ogive. If the probabilities are converted to z scores a straight line is obtained. The slope of this line equals the z score difference for any two stimuli. This is the same as d'. Thus slope, which has the dimensions d'/dB, may be used as an index of sensitivity.

The stimulus value corresponding to p(R2) = .5 represents the stimulus whose mean is equal to the criterion value. It is thus possible to estimate the criterion on the stimulus axis. This measure may be used as an index of bias.

It follows from these assumptions that stimuli of very high intensity should produce neural effects which almost always exceed the criterion, and that stimuli of very low intensity should produce neural effects which are almost always below the criterion. The proportions of R2 made in the presence of these extreme stimuli should reach 1.0 and 0.0, respectively.

Previous research has shown that the asymptotes of empirical choice curves generally do not lie at 1.0 and 0.0. The present research confirms this observation. To account for these discrepancies the model assumes that on some trials responding is not under control of the relevant stimuli, but is under control of some other, unspecified stimulus. It is assumed that the animals do not attend to the relevant stimulus dimension on these trials. A further assumption is that the probability of attending to the sound dimension is independent of the intensity of the stimulus. It should be emphasized that attention is defined here as control by the relevant stimulus dimension, while inattention is defined as control by some other, unspecified stimuli.

It can be seen that if the effects of inattention were removed, the obtained choice curves would be normal ogives with asymptotes at 1.0 and 0.0. The model presents a way to derive the probability of attention. The derivation may be found in Heinemann et al. (1969). To derive the probability of attention, the obtained value of the lower asymptotes is subtracted from the obtained value of the upper asymptote. Note that this has been referred to previously as the range of the function along the $\underline{y}$ axis.

The model also derives a correction for the effects of inattention using the following formula:

$$\underline{p}(R2/A) = \frac{\underline{p}(R2) - \underline{p}(R_l)}{\underline{p}(R_u) - \underline{p}(R_l)}$$

where $\underline{p}(R2/A)$ represents the conditional probability of making R2 given attention to the auditory stimulus dimension, $\underline{p}(R_l)$ represents the obtained value of the lower asymptote, and $\underline{p}(R_u)$ represents the obtained value of the upper asymptote.

Another parameter which may be obtained from the model is the probability of responding under conditions of inattention. This parameter will be referred to as $\underline{k}$. The formula for $\underline{k}$ is

$$\underline{k} = \frac{\underline{p}(R_l)}{1 - \underline{p}(A)}$$

where $\underline{p}(A)$ is the probability of attention.

The advantage of this model is that it provides a way to separate the effects of sensitivity, bias, and attention. It is possible to determine the sensitivity and bias of a subject under conditions of perfect attention by examining the slope and criterion value of the attention-corrected function.

The smooth curves shown in Figures 11 through 15 represent the functions which best fit the empirical data. The data were fit using an iterative computer program incorporating all the assumptions of the model. The program began by fitting a normal ogive to the attention-corrected points obtained from generalization. Probabilities were converted to z scores so that the ogive could be fit in the form of a straight line. Next, the attention-correction formula was applied in reverse to obtain an ogive which was used as the starting point for the iterative fitting procedure. The points were fit repeatedly using different combinations of values of slope and upper and lower asymptote. The best fitting ogive was considered the one which yielded the least sum of squared deviations of uncorrected proportions about the theoretical curve.

The values of slope, criterion, upper and lower asymptote, level of attention, and k derived from the theoretical fits are presented in Table 6 for each bird.

The values of slope presented in Table 6 represent the slope of the attention-corrected function. Steeper slopes indicate greater sensitivity to the sound intensity continuum. To perform statistical analyses upon slope, it is necessary to normalize the obtained values by finding the inverse tangent. The mean arc tangent for each group was transformed back as an estimate of the mean slope. These values are presented in part (a) of Figure 16 as a function of p(S2). Clearly, slope did not vary monotonically with p(S2).

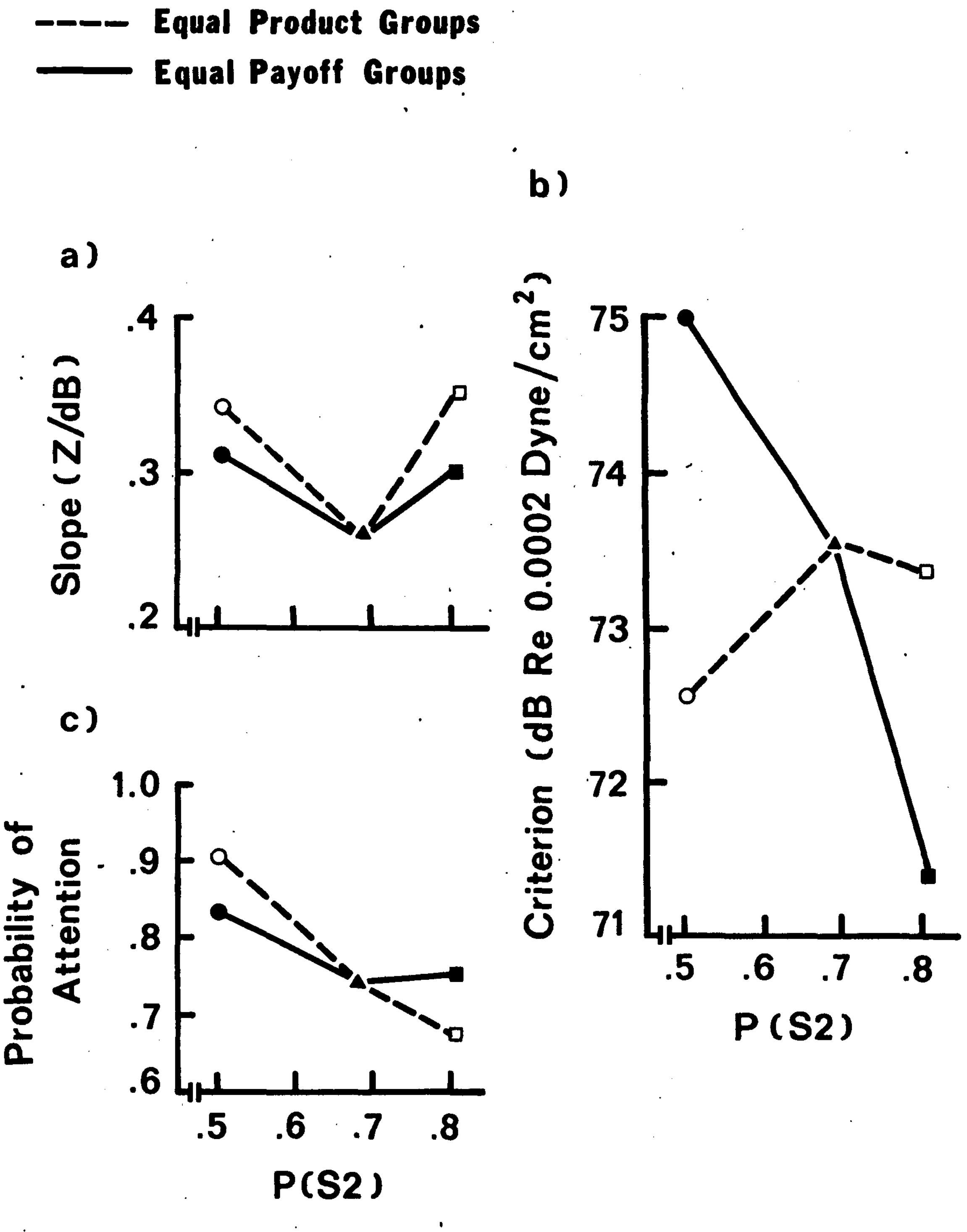
The subsequent analysis of variance of the slopes, summarized in Table T (appendix), found no significant differences, F(4,20) = 1.08. This is in accordance with the measures of discriminability made on

TABLE 6

Data Obtained From Theoretical Fits of Generalization Data

Group	Bird	Slope	Criterion Intensity	Upper Asymptote	Lower Asymptote	Attention Level	k
33/55	244	.270	72.702	1.000	.300	.700	1.000
	245	.201	72.712	1.000	.230	.770	1.000
	247	.260	73.494	1.000	.260	.740	1.000
	298	.322	72.583	0.989	.070	.919	0.864
	299	.265	73.267	0.929	.410	.519	0.852
	Mean	.259	73.552			.741	
24/40	246	.262	75.694	0.959	.290	.669	0.876
	258	.276	76.199	0.989	.120	.869	0.916
	259	.275	74.129	0.999	.170	.829	0.994
	300	.214	73.975	0.989	.090	.899	0.891
	301	.586	75.037	0.989	.130	.859	0.922
	Mean	.315	75.007			.831	
33/65	247	.339	73.794	0.979	.310	.669	0.937
	260	.298	71.911	0.989	.350	.639	0.970
	261	.393	73.830	0.999	.370	.629	0.997
	302	.368	73.372	0.989	.160	.829	0.936
	303	.379	73.923	0.979	.410	.569	0.951
	Mean	.354	73.366			.671	
33/40	248	.362	72.848	1.000	.060	.940	1.000
	249	.375	72.573	1.000	.040	.960	1.000
	262	.368	72.205	1.000	.130	.870	1.000
	263	.246	72.244	0.939	.130	.809	0.681
	304	.398	72.792	0.989	.050	.930	0.820
	Mean	.344	72.532			.910	
39/65	250	.206	70.878	0.989	.250	.739	0.958
	251	.234	70.942	1.000	.370	.630	1.000
	264	.375	71.962	0.999	.160	.839	0.994
	265	.334	71.943	1.000	.130	.870	1.000
	305	.365	71.196	1.000	.320	.680	1.000
	Mean	.306	71.384			.758	

Figure 16. Group data derived from theoretical fits of generalization data (see Figures 11-15). Figure 16(a) presents the group means of the slopes of the theoretical gradients. Figure 16(b) presents the group means of criterion intensity derived from the theoretical gradients. Figure 16(c) presents the group means of the level of attention derived from the theoretical gradients. The solid lines represent equal payoff groups (Groups 24/40, 33/55, and 39/65). The dashed lines represent equal product groups (Groups 33/40, 33/55, and 33/65). The triangle represents Group 33/55; the open and filled circles represent Groups 33/40 and 24/40, respectively; the open and filled squares represent Groups 33/65 and 39/65, respectively. See text for further details.


---- Equal Product Groups
—— Equal Payoff Groups
a)
Slope (Z/dB)
.4
.3
.2
b)
Criterion (dB Re 0.0002 Dyne/cm²)
75
74
73
72
71
.5
.6
.7
.8
P(S2)
c)
Probability of Attention
1.0
.9
.8
.7
.6
.5
.6
.7
.8
P(S2)

responses to the training stimuli. It is possible to conclude that there were no differences between groups in ability to discriminate the stimuli during generalization.

The values of criterion intensity presented in Table 6 are expressed in decibels. They represent the sound intensity corresponding to .5 on the ordinate of the attention-corrected function. The mean criterion intensity for each group is shown in part (b) of Figure 16 as a function of p(S2). The figure reveals noticeable differences in the functions of the equal payoff and equal product groups. There appears to be a clear monotonic relationship of criterion intensity to p(S2) for the equal payoff groups and no such relationship for the equal product groups. Group 39/65 had the lowest criterion intensity, followed in order by Groups 33/40, 33/65, 33/55, and 24/40.

The analysis of variance of criterion intensity levels summarized in Table U (appendix) yielded significance, $F(4,20) = 20.07$, $p < .001$. Multiple comparisons revealed that all differences could be attributed to differences in p(E2). Group 39/65 had a significantly lower criterion intensity than the other groups. The criteria for Groups 33/40, 33/65, and 33/55 did not differ significantly from each other.

These results show quite clearly that criterion intensity, as derived from the attention-corrected curves, was a function of p(E2). The two bias indices derived from p(R2/S1) and p(R2/S2) showed similar trends (Figure 9(d), Figure 9(e)).

The next analysis dealt with attention. The levels of attention presented in Table 6 were determined directly from the values of the upper and lower asymptotes which are also presented. Since level of attention is a proportion, it was necessary to use the angular transform for statistical analysis. The estimated mean levels of attention are presented in part (c) of Figure 16 as a function of $\underline{p}(S2)$. The figure reveals interesting differences between the functions of the equal payoff and equal product groups. For the equal payoff groups the level of attention does not appear to vary monotonically with $\underline{p}(S2)$. However, for the equal product groups, level of attention appears to have a monotonic relation with $\underline{p}(S2)$. Group 33/65 had the lowest level of attention, followed in order by Groups 33/55, 39/65, 24/40, and 33/40. This is the reverse of most of the functions reported thus far.

The analysis of variance of the level of attention summarized in Table V (appendix) found significance, $\underline{F}(4,20) = 4.36$, $\underline{p} < .05$. Only one significant difference was indicated in the multiple comparisons: Group 33/40 was found to have a significantly higher level of attention than Group 33/65. These groups did not differ from each other in any measure of bias or sensitivity during generalization. No other differences were found between groups.

The observed differences in attention between Groups 33/65 and 33/40 can be attributed to differences in the probabilities of receiving reinforcement in the presence of each stimulus. Group 33/65 was reinforced after 100% of correct R1 responses and after 51% of correct R2 responses. Group 33/40 was reinforced after 37.5% of correct R1 responses, and after 82.5% of correct R2 responses. The other three groups were reinforced after 60% of both correct responses.

It has already been noted that the level of attention was found to have a significantly negative correlation with the length of the presolution period. The correlation statistic used was Spearman's rho, which is based upon the rank order of each variable. The results found

$r_s(23) = -.51$, $t(23) = 2.83$, $p < .01$. These results are especially interesting since the generalization test was given many days after the presolution period. The results suggest that the variable that controls attention also controls the length of the presolution period, and that the differences in the level of attention were maintained throughout training.

The last parameter derived from the theoretical data is k, the probability of responding R2 when a subject is in a nonattentional state. This parameter indicates how a subject responds on those trials when he is not attending to sound intensity. It is of interest to compare the values of k with the values of p(R2) made during the presolution period, when the subject is presumably not attending to the sounds.

The values of k for each bird obtained from the theoretical curves are presented in Table 6. A glance at the table shows that for most birds the value of k was extremely high. In fact, k was equal to 1.0 for nine birds. Because many of the obtained values of k were extreme, it was not possible to use the angular transform. The data are described rather than analyzed statistically.

The values of k are all considerably higher than the values of p(R2) obtained during the presolution period. With one exception (Bird 263) the values of k greatly exceed the values of p(E2) for each group. Based on the assumptions from the model, this means that the birds did not match on those trials when they were not attending to sound.

There appears to be considerable variability within groups in k. However, all birds from Group 39/65 had values of k greater than .95, while four of the birds from Group 24/40 had values of k lower than .95. Nevertheless, the values for Group 24/40 are quite high, suggesting that all birds were likely to respond R2 when not attending to sound.

The correlation between $\underline{p}$(S2) during the presolution period and $\underline{k}$ yielded $\underline{r}_s(23) = .30$, $\underline{t}(23) = 1.88$. There was no significant relationship between the two variables.

To summarize the generalization data, the major differences between groups appears to lie in the position of the decision criterion along the sound axis. Discriminability apparently did not vary between groups. Attention appears to have varied according to the relative probability of reinforcement in the presence of S1 and S2. Finally, all birds appear to have favored R2 on those trials when they were not attending to sound.

DISCUSSION

Presolution Period

The results from the presolution period provide evidence (a) that before they learned to discriminate, the subjects performed as they would in a probability learning task, and (b) that this behavior can be characterized as having matched the proportion of reinforcements given for each response. The results show that biases were established before the discrimination was learned.

The similarity between performance during probability learning and the presolution period of discrimination learning suggests that learning to discriminate may occur in two stages: a stage of probability learning and a stage of discrimination learning. A theoretical account derives from a model of discrimination developed by Bush and Mosteller (1951). According to this model, discrimination improves as a subject responds less to the similarities, or overlap, between the available stimuli. At the start of training the weight attached to the overlap is maximal. Responding to the overlap is controlled primarily by the relative probability of reinforcement for each response (i.e., probability learning will occur). The weight attached to the overlap is assumed to decrease, or "shrink", with training. As this occurs subjects respond to the unique aspects of each stimulus rather than to the overlap (i.e., discrimination learning will occur).

The evidence of matching in a spatial task appears to contradict the conclusion of Graf et al. (1964) that birds maximize in a spatial task under rerun conditions. However, it has been noted previously that two of the six birds in that study did show matching behavior. The present results are compatible with the results of an experiment with pigeons reported by Shimp (1966, Experiment III), despite several differences in procedure. In the present experiment there was an ITI of 10 seconds, whereas in Shimp's experiment there was no ITI. Also, the procedures after incorrect responses differed. In Shimp's study there was no rerun following trials on which reinforcement was not scheduled. On these trials a response was considered neither correct nor incorrect, but only unreinforced. In the present study the birds were required to make a correct response whether or not reinforcement was scheduled before the next trial was presented.

The results of the present study differ from, but are actually not incompatible with the results reported by Graf et al. (1964), that four of the six birds in a spatial task responded substantially higher than the matching levels, despite the fact that these authors referred to their results as maximizing. The reason for this conclusion involves the usage of the term "maximize".

Mackintosh has noted that the term "maximize" may be used in two senses (Sutherland & Mackintosh, 1971, pp. 407-408): (a) when asymptotic performance is not significantly different from 100%, or (b) when asymptotic performance on a probability task is as accurate as either performance on a comparable 100:0 task (where one response is always reinforced and the other is never reinforced) or as performance on a comparable task with noncorrection training. The results obtained by Graf et al. in the spatial task cannot be considered maximizing in either sense. In the same way the results reported by Shimp in visual tasks (1966, Experiment I; 1973) cannot be considered maximizing. These results deviate from matching in the direction of maximizing, but qualitatively they resemble matching more than maximizing. This is because subjects trained in probability learning tasks with a rerun procedure do choose the less frequently reinforced response on a certain proportion of trials.

The subjects in the probability learning group were observed to be close to matching at the end of training. The matching found at the beginning of training was not transient. Shimp (1966) has cautioned that response proportions in a probability learning task may undergo considerable shifts during the course of an experiment. This is based on his own observation that birds appeared to be matching after 1400 trials, but that they tended to overshoot matching after 20,000 trials. In the present experiment the birds were trained for 9700 trials, and behavior appeared to be asymptotic.

In any case, it is clear that any general assertion about the behavior of pigeons in probability learning situations is incorrect. Under the conditions of the present experiment, the birds show matching behavior, at least to a first approximation. It is also clear that the results obtained depend on the details of the experimental procedure employed. In this sense the data from pigeons may parallel the data from rats, where it has been found that rats match under a rerun procedure (Weinstock et al., in press) and are absorbed under correction (Robbins, 1969) and noncorrection (Weinstock et al., 1965) procedures. For the rat the behavior displayed conforms, to a first approximation, to the appropriate one of the Bush and Mosteller (1955) models, depending on the procedure used. For the rerun procedure the model employed is the noncontingent equal θ model with the assumption that on unreinforced trials an identity operator applies (Bush & Mosteller, 1955, pp. 279-285). This means that if a response were followed by no reinforcement, either because it was incorrect or it was correct but not reinforced, there would be no changes in the value of p(R2). This model becomes mathematically identical to the Estes and Straughan (1953) model which they applied to probability learning in human subjects who also show matching.

Some evidence for the application of an identity operator for nonreinforced responses can be obtained from the results of the present experiment. Groups P, 33/55, 33/65, and 33/40 received the same number of reinforcements per session for each response, but they were required to make different numbers of each response per session. Of the four groups, the subjects in Group 33/40 were required to make the most R2 responses, and the subjects in Group 33/65 were required to make the fewest R1 responses. If nonreinforcement did not affect responding, as predicted by an identity operator assumption, the performance of these groups should be identical. If the number of correct responses which were required during a session affected responding, Group 33/40 should have the lowest values of p(R2), followed by Groups P and 33/55, and Group 33/65.

The results showed no statistical differences between these groups in p(R2) during the presolution period. However, the mean values of p(R2) are ordered in the direction predicted if the number of correct responses affected responding. The conclusion drawn is that the evidence tends to support the identity operator assumption, but that further research is necessary. Extended probability learning experiments, analogous to the discrimination tasks for Groups 33/65 and 33/40, could clarify the matter.

In addition to the stochastic learning model of Bush and Mosteller, several other models have attempted to account for probability matching. Shimp (1966) has proposed that matching actually represents momentary maximizing, which means that on each trial a subject chooses the response that has the greater probability of being reinforced. A subject who persisted in responding R2 incorrectly, for example, would eventually make R1 because it had the greater probability of being reinforced.

Mackintosh has rejected Shimp's theory (Sutherland & Mackintosh, 1971, p. 409). He assumes that matching is a result of imperfect attention to the relevant dimension due to attention to irrelevant dimensions. In terms of Mackintosh's model, position was the relevant dimension in the present experiment. Perfect attention to this dimension would result in the subjects having chosen R2 on every trial.

Although these theories are of interest, they are not easily testable in the present experiment. Shimp's theory can only be tested using detailed sequential statistics, and Mackintosh's theory depends upon measuring choice in the presence of variables which are uncorrelated with reinforcement during probability training.

Large Sound Difference Discrimination

The results from the large sound difference phase indicate that (a) the discriminability of the sound stimuli was not affected by differences in the presentation proportions of the stimuli or by differences in response payoff, and that (b) bias varied as a function of stimulus presentation, regardless of response payoff.

The findings that discriminability did not differ among groups supports previous findings. The observation that both mean error and $\underline{d}'$ yielded similar results strengthens the conclusion. The assumption that sensitivity is determined by physical properties of stimuli and physiological properties of the observer is supported.

The finding that bias varied with $\underline{p}(S2)$ rather than $\underline{p}(E2)$ during this phase of the experiment appears to contradict the assumption that constant products of presentation proportion and payoff would affect bias equally. Furthermore, the results also mean that the biases established during the presolution period underwent differential changes during the acquisition of the discrimination. The subjects from the three equal product groups (Groups 33/55, 33/65, and 33/40) appear to have maintained similar biases during the presolution period, as indicated by the values of *p*(R2). However, at the end of the large sound difference phase of the experiment, Groups 33/65 and 33/40 were found to differ in error difference, and Groups 33/55 and 33/65 were found to differ in criterion likelihood ratio.

The results provide another opportunity to examine the identity operator assumption discussed in the previous section. The identity operator is used in a signal detection model developed by Atkinson, Bower, and Crothers (1965, chap. 5).

Green and Swets' theory of signal detection deals primarily with performance after a discrimination has been established. It does not account for how responding changes during the acquisition of a discrimination. The theory of Atkinson et al. uses a stochastic learning model to account for the acquisition process. It makes assumptions similar to those of the theory of signal detection regarding the independence of sensitivity and bias, but it makes no assumptions regarding the underlying sensory distributions. According to the model by Atkinson et al., one of three sensory states can occur on each trial. One of these sensory states, *s*1, can occur only if S1 is presented, and another sensory state, *s*2, can occur only if S2 is presented. These are referred to as unambiguous sensory states. The third sensory state, *s*0, is ambiguous and can occur after either stimulus. The theory assumes that response bias represents a tendency to resolve the ambiguity of this sensory state. Bias is assumed to affect choice behavior only when an ambiguous state occurs.

Changes in response bias are assumed to occur only after an ambiguous state is followed by a reinforced response. Reinforcement following a response to an unambiguous state does not affect response bias. If no reinforcement occurs, the identity operator applies. Since responding during an ambiguous state depends upon response bias alone, performance on these trials should resemble responding in a probability learning task.

In terms of the present experiment, the theory predicts that Groups 33/40, 33/55, and 33/65 would have equivalent biases, as indicated by the error difference measurement. The likelihood ratio measurement is, of course, based upon assumptions of the theory of signal detection regarding underlying neural distributions.

The observed difference between Groups 33/65 and 33/40 contradicts the prediction. The results are complicated further by the finding that during the small sound difference phase of the experiment bias was affected by $\underline{p}(E2)$ rather than $\underline{p}(S2)$, thus supporting the identity operator assumption.

One explanation of the results lies in the fact that all subjects maintained a high level of discriminability of the 8 dB sound difference. It is obvious that if discriminability were perfect, bias effects would disappear. It is conceivable that the proportions of errors made were too small to yield reliable results.

An alternate explanation of the results is that presentation proportions had a stronger influence than payoff on response bias during the large sound difference phase of the experiment. This would indicate that bias did not depend only upon reinforcement following responses during an ambiguous sensory state. The proportion of trials when the unambiguous states occurred would also have influenced responding. This conclusion would lead to a rejection of Atkinson's model.

Finally, it is possible that the results reflect a sensitivity to the rerun procedure discussed in the previous section. It is known that subjects are sensitive to differences in reinforcement schedules. It is possible that subjects in the present experiment were sensitive to the total number of each response required per session. The finding that Group 33/40 had error difference values significantly closer to zero than Group 33/65 may reflect the fact that the subjects in Group 33/40 were required to make more R1 responses per session, even though both groups received the same number of reinforcements for each response. It was necessary to make correct responses, even if they were not reinforced, in order to collect all the reinforcements scheduled during a session. Therefore, nonreinforced correct responses may have had some rewarding effects.

The Bush and Mosteller (1951) model of discrimination previously described provides a means to predict asymptotic response levels if an estimate of overlap is available. Weinstock et al. (in press) estimated overlap from the proportion of errors made by a group of rats who were reinforced equally often for each response. From this estimate they accurately predicted the asymptotic levels of a group which was presented with different proportions of light stimuli. It is possible to apply a similar procedure to the present results, since error proportions did not differ between groups. Although there are no statistically significant differences between the predicted and obtained asymptotic response levels, the variability within groups, especially for $\underline{p}(R2/S1)$, indicates that the prediction is not supported.

Small Sound Difference Discrimination

The results of the small difference phase of the experiment indicate that (a) discriminability was reduced in all subjects as a result of the decrease in sound intensity difference, but there were no differences between groups in the amount of this reduction, (b) sensitivity differed between groups, but these differences were unsystematic, (c) there was a significant correlation between the values of $\underline{d}'$ for Days 91-100 and Days 113-122, (d) bias varied as a function of the product of presentation proportions and payoff, and (e) there was a tendency for subjects to adopt less extreme biases, as measured by likelihood ratio criteria, after the sound intensity difference was decreased, although there was a significant correlation between criterion values of likelihood ratio from Days 91-100 and Days 113-122.

The finding of differences in discriminability is completely unexpected. If the error difference measure alone yielded significant differences, it could be argued that bias was confounded with discriminability. However, differences were also found between the values of $\underline{d}'$, a measure which is theoretically independent of bias effects. Both sensitivity indices yielded similar results.

Since the relative sensitivity of subjects in both phases of the experiment was similar, as indicated by the significant correlation of $\underline{d}'$ from both phases, it is possible that the analyses reflect statistical error. Nevertheless, the observed statistical differences in sensitivity may be real.

Atkinson (1963) has developed a model of signal detection which allows for changes in sensitivity level. The model was developed prior to the one previously discussed. According to most theories of signal detection, such as Green and Swets' theory, a subject's sensitivity level is fixed. Discriminability of a given sound difference should therefore remain constant. If this assumption is made, it is impossible to explain how a subject's performance in a discrimination task improves from no discriminability at the start of the experiment. It is apparent from the acquisition data of the present experiment (Figures 2 through 6) that, in terms of performance, discriminability improved.

One axiom of Atkinson's theory is that a subject's sensitivity level is bounded by zero and the maximum sensitivity level. On a given trial a stimulus pattern is sampled, and the sensory states $\underline{s}1$ or $\underline{s}2$ may be activated. A subject may make his response based upon the sensory states $\underline{s}1$ and $\underline{s}2$ as previously discussed. However, it is also possible for a subject to ignore these sensory patterns and respond in terms of some other "background cue". The momentary sensitivity level depends on the outcomes associated with maintaining a high level of sensitivity and with lowering sensitivity level. The parameters which specify increments and decrements in sensitivity are assumed to change with changes in motivation (payoff and presentation proportions in the present experiment).

The concept of a subject responding to relevant sensory cues or irrelevant background cues resembles the concept of attention discussed earlier. Although Atkinson never uses the word attention, it appears that he is stating that the value of momentary sensitivity may be an interaction between the maximum potential sensitivity of a subject and his level of attention.

Using this theory it is possible to account for apparent changes in sensitivity during the acquisition of a discrimination while still holding the viewpoint that discriminability is purely a function of stimulus paramenters. As a subject learns to respond more to the relevant sensory cues, the momentary sensitivity level approaches the maximum sensitivity level.

It is conceivable that the observed differences in sensitivity during the small sound difference phase reflect differences in attention. Unfortunately, it was not possible to measure the level of attention during training.

The finding that bias varied as a function of the product of payoff and presentation proportions is in accordance with predictions from Green and Swets' theory as well as from Atkinson's theories. The results provide evidence that the identity operator applies when responses are not reinforced.

The results of the bias analysis from the small sound difference phase of the experiment conflict with the results from the previous phase of the experiment, which showed that p(S2) alone controlled bias. It is likely that the discrepancy is due to the difference in accuracy between the two phases of the experiment. Because the stimuli provided almost complete information for responding during the large sound difference discrimination, the bias data from the small sound difference phase should be considered more illustrative of response bias.

Generalization

The results of generalization, as analyzed using the model developed by Heinemann and co-workers, indicate that (a) discriminability, as measured by the slope of the generalization gradient, was unaffected by variations in payoff and presentation proportions, (b) response bias, as measured by criterion intensity, was under control of the product of the independent variables, (c) the level of attention to sound intensity, as measured by the distance between the two generalization gradient asymptotes, varied as a function of relative payoff, (d) a subject's level of attention during generalization and the length of the presolution period were controlled by the same variable, and (e) subjects tended to respond R2 on trials when they did not attend to the sound stimuli. The results also indicate that performance in the presence of the training stimuli deteriorated during generalization. Finally, there was no evidence that sound intensity had any control over choice behavior in subjects trained with the probability task.

The absence of control by sound intensity in subjects trained with the probability task supports previous findings (e.g. Jenkins & Harrison, 1960) that discrimination training is necessary to establish control along a stimulus dimension. Weinstock et al. (in press) have also obtained flat generalization gradients for brightness from rats trained with a probability learning task under a rerun procedure.

The finding that discrimination performance deteriorated during generalization is similar to results obtained by Heinemann et al. (1969). In that study it was found that performance deteriorated during generalization following training with small sound differences (2.3 dB or 7 dB), but not following training with a large sound difference (29 dB).

The finding that the slopes of the generalization gradients did not differ between groups provides further evidence that sensitivity was not affected by the proportions of reinforcement received for correct responses. The results support the findings of Mandell (1973) that varying proportions of reinforcements within subjects did not produce systematic changes in the slopes of sound intensity generalization gradients.

The results of the generalization tests cast further doubts over the obtained differences in the discriminability indices from Days 113-122.

The differences in intensity criterion provide clear evidence that bias was under control of the product of stimulus presentation proportions and reinforcement proportions. These results can be accounted for in terms of the identity operator assumption. Mandell (1973) also found shifts in the criterion intensity within subjects as a result of changes in biasing operations, but there were considerable individual differences. The discrepancy between the clarity of the present results and the variability of Mandell's results regarding criterion intensity may be a function of the difficulty of the discrimination preceding generalization testing. Mandell presented subjects with a 12 dB intensity difference discrimination and selected the six most accurate subjects for generalization testing. Heinemann et al. (1969) have suggested that training on an easy discrimination may cause subjects to adopt more variable criteria than training on a difficult discrimination. Perhaps Mandell would have obtained clearer results if she had presented subjects with a more difficult discrimination.

Parenthetically, further research was conducted with the subjects from the present study. Stimulus presentation proportions and reinforcement contingencies were reversed for the training stimuli. Generalization tests were given following 2 days of reversal training. The results thus far indicate that there were systematic reversals in the criterion intensity.

The finding of differences in the level of attention in the present study is unexpected. These are the only results in the present study where performance was found to be affected by the relative probability of receiving reinforcement for making a correct response in the presence of each stimulus. It is not clear why this variable should affect stimulus control by sound intensity. Heinemann's model does not specify the independent variables that govern attention.

Stubbs (1968) obtained generalization gradients for stimulus durations which have the sigmoidal form of the gradients in the present study. Some of these gradients differed from each other systematically in the range of the asymptotic levels. Stubbs discussed these differences in terms of differences in the accuracy of responding, rather than in terms of the level of attention.

In one part of Stubb's experiment, reinforcement was presented for every sixth correct choice response. Gradients for each position of the six response sequence indicated that the asymptotic range increased as a function of position number. In terms of Heinemann's concept of attention, the level of attention increased with the likelihood that a correct response would be reinforced.

There is another example of variation in asymptotic range in Stubbs' results. In one condition reinforcement was eliminated completely for correct responses to stimuli of long durations. The obtained gradients reveal a sharp decrease in the height of the upper asymptote. This suggests that the level of attention to the duration of the stimuli decreased when only one response was reinforced.

Although Stubbs discusses the differences in asymptotic levels as differences in accuracy, he does suggest that asymptotic level might be used as an index of the degree of control by experimental contingencies to separate the effects of reinforcement contingencies and the stimulus dimension. Stubbs' findings can thus be interpreted as showing that the level of attention varied with the likelihood of reinforcement. In the the present experiment all subjects received the same number of reinforcements per session. However, it is possible that the differences might be due to the relative proportions of reinforcement received for correct responses.

The observed relationship between the length of the presolution period and the level of attention is in agreement with unpublished findings reported by Heinemann. However, further research is necessary to fully understand the paramenters which control attention.

The observation that all subjects tended to respond R2 when they were in a nonattentional state is similar to previous findings from studies where sound intensity, stimulus presentation proportions, and reinforcement proportions were equal (Heinemann et al., 1969; Heinemann & Chase, 1970b). Since the tendency to favor the correct response for the high intensity sound was found under conditions not designed to produce bias effects, the results cannot be attributed to variations in the independent variables.

Differences between response proportions in a nonattentional state can be observed in Stubbs' study of time discrimination (1968). In one condition, one of the incorrect responses resulted in resetting the six response sequence required for reinforcement. The other incorrect response did not reset the sequence. In the other condition, the contingencies were reversed. The two sets of gradients obtained appear to have the same asymptotic range, suggesting equal levels of attention, but they differ in the position along the ordinate. In the language of the present experiment, Stubbs' subjects tended to make R1 (the response which was correct for short durations) when in a nonattentional state, if the consequences of an incorrect R2 (the response which was correct for long durations) resulted in a delay of reinforcement. They tended to make the correct response for long durations in a nonattentional state if the consequences of an incorrect response for short durations resulted in a delay of reinforcement.

The present research has provided evidence that, at least with difficult discriminations, response bias is a function of the product of the presentation proportion of stimuli and the payoff for responding correctly. Payoff was varied in the present experiment by varying reinforcement probabilities. Hobson (1970) has found that varying the amount of reinforcement provided has similar effects on response bias as varying reinforcement probabilities. Furthermore, the present research has shown that responding in a recognition task prior to acquiring the discrimination resembles responding in a probability learning task. This behavior may be characterized as matching the reinforcement proportions. Generalization has been shown to be useful in measuring response bias, sensitivity, and the level of attention. Further research is necessary to account for the observation that payoff did not affect bias with an easy discrimination, and that payoff appeared to affect the level of attention during generalization.

APPENDIX

TABLE A

Analysis of Variance of Length of Presolution Period

Source	SS	df	MS	F
Between	337.04	5	84.26	1.25
Within	1344.40	24	67.22	
Total	1681.44	29		

TABLE B

Analysis of Variance of p(R2) from Days 2 through 5

Source	SS	df	MS	F
Between	1140.2212	5	228.0442	10.38***
Within	527.3446	24	21.9726	
Total	1667.5658	29		

24/40 33/40 P 33/55 33/65 39/65

TABLE C

Analysis of Variance of p(R2/S1) from Days 91-100

Source	SS	df	MS	F
Between	715.4456	4	178.4402	3.09*
Within	1155.9946	20	57.7997	
Total	1871.4402	24		

Analysis of Variance of p(R2/S2) from Days 91-100

Source	SS	df	MS	F
Between	265.6273	4	66.4068	4.42*
Within	300.6922	20	15.0346	
Total	566.3195	24		

24/40 33/55 33/40 39/65 33/65

* p .05
*** p .001

TABLE D

Analysis of Variance of Mean Proportions of Errors - Days 91-100

Source	SS	df	MS	F
Between	171.9437	4	42.9859	1.84
Within	466.5476	20	23.3228	
Total	638;4013	24		

TABLE E

Analysis of Variance of _d_' - Days 91-100

Source	SS	df	MS	F
Between	2.2390	4	.5597	1.70
Within	6.5858	20	.3292	
Total	8.8248	24		

TABLE F

Analysis of Variance of Error Differences - Days 91-100

Source	SS	df	MS	F
Between	1274.3524	4	318.5881	6.08**
Within	1047.5911	20	52.3796	
Total	2321.9434	24		

24/40 33/40 33/55 39/65 33/65

TABLE G

Analysis of Variance of Criterion Values of ln likelihood Ratio - Days 91-100

Source	SS	df	MS	F
Between	8.5760	4	2.1440	6.72**
Within	6.3767	20	0.3188	
Total	114.9528	24		

24/40 33/55 33/40 39/65 33/65

**_p_ .01

TABLE H

Analysis of Variance of p(R2/S1) from Days 113-122

Source	SS	df	MS	F
Between	919.7627	4	229.9406	8.33***
Within	552.0111	20	27.6075	
Total	1471.7738			

24/40 33/40 33/65 33/55 39/65

Analysis of Variance of p(R2/S2) from Days 113-122

Source	SS	df	MS	F
Between	547.9883	4	136.9970	11.52***
Within	237.8208	20	11.8910	
Total	785.8091			

24/40 33/55 33/40 33/65 39/65

TABLE I

Analysis of Variance of Mean Proportions of Errors - Days 113-122

Source	SS	df	MS	F
Between	80.5307	4	20.1326	3.57*
Within	112.9088	20	5.6454	
Total	193.4395			

33/65 33/40 24/40 33/55 39/65

* p .05
*** p .001

TABLE J

Analysis of Variance of *d*' - Days 113-122

Source	SS	df	MS	F
Between	0.6747	4	0.1686	3.37*
Within	0.9115	20	0.0455	
Total	1.5862	24		

39/65 33/55 24/40 33/40 33/65

TABLE K

Analysis of Variance of Differences between *d*' on Days 91-100 and Days 113-122

Source	SS	df	MS	F
Between	1.3877	4	0.3469	1.64
Within	4.2424	20	0.2121	
Total	5.6301	24		

TABLE L

Analysis of Variance of Error Differences - Days 113-122

Source	SS	df	MS	F
Between	2598.9906	4	649.7476	11.39***
Within	1140.4175	20	57.0208	
Total	3739.4081	24		

24/40 33/55 33/40 33/65 39/65

* *p* .05
*** *p* .001

TABLE M

Analysis of Variance of Criterion Values of ln Likelihood ratio - Days 113-122

Source	SS	df	MS	F
Between	1.0511	4	0.2627	9.35***
Within	0.5631	20	0.0281	
Total	1.6142	24		

24/40 33/55 33/40 39/65 33/65

TABLE N

Analysis of Variance of Differences in *p*(R2/S1) between Days 113-122 and Generalization

Source	SS	df	MS	F
Between	78.2255	4	19.5563	1.00
Within	391.0396	20	19.5519	
Total	469.2651	24		

Analysis of Variance of Differences in *p*(R2/S2) between Days 113-122 and Generalization

Source	SS	df	MS	F
Between	142.7017	4	35.6754	1.52
Within	468.8296	20	23.4414	
Total	611.5313	24		

*** *p* .001

TABLE O

Analysis of Variance of *p*(R2/S1) from Generalization

Source	SS	df	MS	F
Between	1410.5787	4	352.6446	17.59***
Within	400.9897	20	20.0494	
Total	1811.5682	24		

24/40 33/40 33/65 33/55 39/65

Analysis of Variance of *p*(R2/S2) from Generalization

Source	SS	df	MS	F
Between	977.9706	4	244.4926	20.93***
Within	233.5944	20	11.6797	
Total	1211.5650	24		

24/40 33/55 33/40 33/65 39/65

TABLE P

Analysis of Variance of Mean Proportions of Errors - Generalization

Source	SS	df	MS	F
Between	33.6030	4	8.4007	2.20
Within	76.2093	20	3.8104	
Total	109.8123	24		

TABLE Q

Analysis of Variance of *d*' - Generalization

Source	SS	df	MS	F
Between	0.2206	4	0.0551	1.53
Within	0.7227	20	0.0361	
Total	0.9433	24		

*** *p* .001

TABLE R

Analysis of Variance of Error Differences - Generalization

Source	SS	df	MS	F
Between	4644.7385	4	1161.1846	24.05***
Within	965.6188	20	48.2809	
Total	5610.3573	24		

24/40 33/40 33/55 33/65 39/65

TABLE S

Analysis of Variance of Criterion Values of ln Likelihood Ratio - Generalization

Source	SS	df	MS	F
Between	1.1613	4	0.2903	8.99***
Within	0.6473	20	0.0323	
Total	1.8086	24		

24/40 33/55 33/40 33/65 39/65

TABLE T

Analysis of Variance of Slopes from Generalization Curves

Source	SS	df	MS	F
Between	76.3886	4	19.0971	1.08
Within	353.6843	20	17.6842	
Total	430.0729	24		

*** *p* .001

TABLE U

Analysis of Variance of Criterion Intensity Levels

Source	SS	df	MS	F
Between	34.9068	4	8.7267	20.07***
Within	8.6962	20	0.4348	
Total	43.6030	24		

39/65 33/40 33/65 33/55 24/40

TABLE V

Analysis of Variance of Attention Levels

Source	SS	df	MS	F
Between	909.7656	4	227.4414	4.36*
Within	1043.2644	20	52.1632	
Total	1953.0300	24		

33/65 33/55 39/65 24/40 33/40

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* *p* .05
*** *p* .001

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