THE EFFECT OF PROPORTION OF REINFORCEMENT AND SCHEDULED UNREINFORCED RESPONSES ON PROBABILISTIC DISCRIMINATION AND STIMULUS GENERALIZATION IN THE PIGEON

by

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Abstract

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The purpose of this study was to examine parametrically (a) the effect of several reinforcement ratios on probabilistic choice behavior and (b) the effect of systematically varying percentages of scheduled nonreinforced trials on probabilistic discrimination learning.

Ten groups of pigeons were trained to discriminate between two intensities of white light (S1 and S2) projected on a transilluminated plastic screen (center key) by pecking one side key in the presence of S1 and the other side key in the presence of S2. The intensity difference between the stimuli was 1.1 logftl. A rerun procedure was used, where trails were repeated following incorrect (nonreinforced) choices.

Each discriminative stimulus signalled the presence of a positional probability learning task. Reinforcement for R1 side key was scheduled on proportion $\pi 1$ of all trials on which S1 was presented, and reinforcement for R2 was scheduled on proportion (1- $\pi 1$) of all S1 trials. Similarly, reinforcement for the R2 side key was scheduled on proportion $\pi 2$ of all S2 trials, and reinforcement for R1 was scheduled on proportion (1 - $\pi 2$) of all S2 trials. For groups A, B, & C

, $\pi 1$ was equal to $\pi 2$. For group A, $\pi 1 = \pi 2 = .60$; for group B, $\pi 1 = \pi 2 = .75$, and for group C, $\pi 1 = \pi 2 = 1.0$. For groups D, E, & F, $\pi 1 \neq \pi 2$. For group D, $\pi 1 = .75$ and $\pi 2 = .60$ for three subjects, and $\pi 2 = .75$ and $\pi 1 = .60$ for the remaining three subjects. For group E, $\pi 2 = 1.0$ and $\pi 1 = .75$ for three subjects, and $\pi 2 = .75$ and $\pi 1 = 1.0$ for the remaining three subjects. for group F, $\pi 2 = 1.0$ and $\pi 1 = .60$ for three subjects, and $\pi 2 = .60$ and $\pi 1 = 1.0$ for the remaining three subjects.

In four additional independent groups assigned π levels of .75 and .60 and counterbalanced as in group D, the percentage of interpolated unreinforced "no rerun" trials was varied. All interpolated unreinforced trials were scheduled in the presence of the stimulus (bright or dim) assigned $\pi = .75$. Specifically, for group G, in addition to eighty reinforced first trials, 3 of the subjects were assigned 30% unreinforced trials during bright stimulus (S2) presentations only, and the remaining three subjects were assigned 30% unreinforced trials during dim stimulus (S1) presentations only. The stimulus not scheduled for interpolated unreinforced trials retained the probabilistic schedule as described for group D. Similarly, 50% unreinforced trials were assigned for group H, 70% unreinforced trials were assigned for group I, and 90% unreinforced trials were assigned for group J.

All ten groups received eighty reinforced trials per session for fifty-one days. Then, postdiscrimination (reinforced) generalization tests were given. Eight luminance stimuli covering a 2.5 log unit range of light intensity were presented during fifteen generalization sessions.

Analyses were made of asymptotic response levels, sequential effects, and response latencies. The asymptotic data generated by probabilistic discrimination in groups without scheduled nonreinforced trials (π groups) exhibited the following characteristics: (a) nonhomogeneity of response proportions within all groups, (b) a nearly equal division of asymptotic response proportions (within subjects) between undershooting of π levels on both discriminative stimuli, undershooting on one stimulus and overshooting on the other stimulus, and undershooting on one stimulus and matching on the other, (c) across all groups, an asymptotic response proportion in the presence of one stimulus of constant π that did not vary with changing π values assigned to the other training stimulus.

For generalization testing following probabilistic discrimination in the π groups, the following results were obtained: (a) S - shaped generalization functions with flatter slopes in the probabilistic groups than in the nonprobabilistic (100:0/0:100) group and asymptotes in the probabilistic groups that departed from 0 and 1; (b) a group mean slope of the generalization functions that was monotonically related to the difference between π_1 and the quantity (1 - π_2) across groups; (c) reliably increased discrimination accuracy in generalization.

In the groups with scheduled nonreinforced trials, it was found that the percentage of nonreinforced trials did not affect asymptotic response proportions. On the other hand, a monotonically nondecreasing trend was found between the percentage of scheduled nonreinforced trials and group mean response latencies. A group tendency to repeat on trial N the reinforced response that was made on the prior trial, N-1, (reward following) was found in three of the four groups with scheduled nonreinforced trials.

Across all ten groups, sequential dependencies showed a systematic increase in the proportion of errors as rerun trials increased.

The compatibility of the results with theories of choice behavior and theories of probability learning was discussed.

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INTRODUCTION

Two types of discrete trial probability tasks may be distinguished. Probability learning typically involves a choice between two responses. A proportion of the total reinforcement available ($0 < \pi < 1$) is scheduled for each response. Probabilistic discrimination (or probabilistic choice) involves presentation of two or more successive probability learning tasks. A discriminative stimulus signals the presence of each probability task. For example, a red light may signal the presence of a 60/40 positional probability task, while a green light may signal the presence of a 25/75 positional probability task. The animal typically learns to discriminate the reinforcement ratios signalled by the red and green stimuli. Use of probabilistic discrimination has the advantage of reducing or eliminating position preferences which may impede learning of the probabilistic schedules.

Explaining animal performance on discrete trial probability tasks has presented a continuing challenge for theories of choice behavior. Estes' (1959, 1962) linear stochastic model predicts a direct correspondence between the probability of a response and the experimentally presented reinforcement ratio. According to stimulus sampling theory (Estes, 1959; Atkinson & Estes, 1963), stimulus elements are linked to a reinforced response through a conditioning process. Since reinforcements are intermittently delivered for both response alternatives in a discrete trial probability task, stimulus elements become conditioned to each of these responses. The number of stimulus elements attached to each response is proportional to the number of reinforcements collected for each response.

If it is assumed that changes in the probability of a response are due to changes in the proportion of stimulus elements conditioned to that response, it is predicted that subjects will distribute their choices so as to match the reinforcement ratio.

Bitterman (1960, 1965) believes that steady state behavior on probabilistically reinforced tasks will differ qualitatively according to the phyletic level of the subject. The "rat-fish" dichotomy classifies all organisms capable of probability learning as fish-like "matchers"[1] of reinforcement proportions or rat-like "maximizers" that almost exclusively select the response assigned the greater proportion of reinforcement. According to Bitterman, rats and monkeys maximize, birds (pigeons) match on some tasks while maximizing on others, and fish tend to match.

Sutherland and Mackintosh (1971) challenge Estes' matching assumption for its lack of cogent empirical support. They refer to early studies cited by Estes (e.g. Parducci & Polt, 1958) where group averages reflecting approximate matching obscured wide intersubject variability around actual matching levels. Sutherland & Mackintosh argue that Bitterman's phyletic hypothesis does not explain the influence of crucial learning parameters, e.g. discrimination difficulty, on asymptotic response levels. Sutherland & Mackintosh dismiss the matching vs. maximizing debate, and alternatively propose that interspecies differences in probability learning are quantitative indicators of the learning "efficiency" of the organism. Errors in probability learning, defined as choices of the minority response, are assumed to occur when responding is controlled by cues irrelevant to the probability task (see Discussion). Increasing phyletic complexity is

1. In general, matching occurs when the response proportion, p, equals the proportion of reinforcement, π, assigned to the majority (greater than 50% of the reinforcements) response alternative, i.e. $\pi \cong p$.

presumed to increase learning efficiency by strengthening attention to the relevant positional stimuli, which produces response proportions that approach maximizing. This attentional explanation assumes no probabilistic mechanism within the organism. The animal either attends to the relevant stimulus dimension (such as position) and maximizes, or fails to attend and bases his responding on cues that are irrelevant to the probability task (Mackintosh, 1976).

An elegant unifying principle proposed by Gibbon, Berryman & Thompson (1974) explains discrete trial probability matching as a special case of relative reinforcement matching under free operant concurrent schedules. "The VI schedules (of free operant procedures under concurrent schedules) represent a sort of generalized correction procedure in which corrections are not cued and not forced" (p.605). Gibbon et al. demonstrated mathematically that all matching to reinforcement behavior is equivalent to matching of error (unreinforced) frequencies on the response alternatives. Algebraic manipulation of the matching equation showed that the error matching relation is equivalent to zero statistical association between responses and consequences, assuming asymptotic performance[2]. To account for matching behavior in light of the demonstrated independence of responses and consequences, these authors suggest that matching behavior is maintained by the subject's detection of slight "imbalances" in the probability of reinforcement that tend to favor the response with the momentarily lower error probability. These "imbalances" occur in subsamples of trials drawn from the large asymptotic sample, where local reinforcement rates

2. The form of the matching equation showing the independence of responses and consequences if [p(R1)] [p(S1)] = p(R1S1); R1 represents a response choice and S1 denotes a reinforcing consequence that would occur after an R1 response (P. 602).

show some degree of response contingency.

Gibbon et al. argue further that departures from matching at asymptote in discrete trial designs are attributable to response selection strategies based on the subject's discrimination of choice and correction events. Under free operant concurrent schedules such differentiation cannot occur because "trials" are not cued; thus, matching of relative reinforcement rates occurs. Similarly, probability matching on discrete trial tasks occurs only when choice and correction events are completely indiscriminable. Immediate correction and guidance procedures, as well as time-delayed correction and guidance methods with very short intertrial intervals, are most likely to provide cues that enable the subject to discriminate between choice and correction events, and thus produce the frequently reported deviations from matching in the direction of maximizing.

Shimp (Shimp, 1966,1969,1973; Hale & Shimp, 1975) has stressed the importance of subsamples of overall reinforcement rates in the determination of response levels on probabilistic choice and probability learning tasks. Supporting evidence is obtained from event statistics showing that pigeons are more likely to repeat a given choice that initially delivered reinforcement (reward following), whether that choice was more likely or less likely to be reinforced, depending upon the π assignment (Shimp, 1966, experiment I). Further evidence for sequential dependencies between successive choices comes from analyses of discrete trial choice responses in rats (Shimp, 1970) that reveal a gradual within session shift from matching to maximizing. A similar but less marked phenomenon was reported in pigeons for the response proportion based on the first trial of each daily session, compared with the total trial response proportion (Shimp, 1973; experiment I).

In a more recent probabilistic choice study, Hale & Shimp (1975) scheduled 11 time-duration stimuli which were each assigned a unique probability of reinforcement. These authors argued that although averaging response proportions across the 11 stimuli for each subject resulted in a matching proportion, individual p values for each stimulus deviated widely from the matching average. In light of the above findings, a matching response proportion could be considered an artifact of averaging the effects of component response strategies that are the fundamental determinants of response outcomes on probabilistic tasks.

Shimp (1969) proposed a theory of choice behavior that describes and interrelates findings from several different kinds of operant experiments. The theory specifies that momentary choice probability is determined by the actual reinforcement probability multiplied by the associated value of a given choice. The value of a given choice is determined by the elapsed time since a preceding reinforced choice of either response alternative. A major premise of this theory is that pigeons tend to maximize on discrete trial probability tasks, although the strength of this tendency is unspecified.[3]

Probability Data for the Pigeon

Selective reinforcement learing experiments that test the aforementioned views have somewhat different designs which make forceful comparisons across studies difficult. Considering an intraspecies comparison for the pigeon, probabilistic tasks have yielded response proportions that undershoot (i.e. $p < \pi$) values (Friedberg & Brenner, unpublished), match reinforcement ratios ($p = \pi$) (Bullock & Bitterman, 1962; Graf, Bullock &

3. An earlier formulation of Shimp's theory of choice behavior, the principle of momentary maximizing, that also applies to discrete trial tasks with scheduled unreinforced trials is presented on page of this paper.

Bitterman, 1964; Shimp, 1966; experiments III & IV) and that exceed matching levels ($p > \pi$) (Graf et al., 1964; Shimp, 1966; experiment I; Friedberg, unpublished; Hale & Shimp, 1975).

No general agreement exists among researchers on what constitutes probability matching on discrete trial tasks. In fact, statistical tests comparing theoretical and observed matching levels are not reported in some studies, e.g. Graf et al., 1964 & Shimp, 1973, a striking error of omission considering the magnitude of intersubject variability. The present author will use the following criteria for response categorization on probabilistic tasks: undershooting applies to reliable departures from matching where $p < \pi$; overshooting refers to reliable departures from matching where $p > \pi$; no reliable departures in response proportions from π indicate matching; finally, to be considered maximizing, performance on a task assigned a probabilistic reinforcement ratio should not reliably differ from response levels achieved on the same task assigned a nonprobabilistic (100:0) reinforcement ratio (Sutherland & Mackintosh, 1971 p.407). Also maximizing may be said to occur if performance attains a 100/0 asymptote, which indicates exclusive selection of the majority reinforced response.

Retrospective analyses of studies without statistical reports suggest several errors in response level categorization according to the above criteria. Bullock & Bitterman (1961) characterize three sets of results on visual probability tasks as showing "matching". The only reported data are graphically presented group median percentages of responses to the majority or minority stimulus. Inspection of this graph reveals that 14 of the 22 points on the 70:30 task exceed the matching level, 21 out of 22 points exceed

matching on the 20:80 task, and 21 of 22 points also exceed matching levels in the 60:40 task. In the final set of results, these authors report estimations of the birds' asymptotes that all exceed matching. Visual inspection of the Graf et al. data plots for a visual probability task reveals similar discrepancies between reports of matching and the appearance of the plotted response levels. In one condition the plotted group mean response percentage to the majority key showed 15 out of 16 points above the matching value, and in another condition 11 out of 16 points above the matching value, and in another condition 11 out of 16 points exceeded matching. In a further condition, a successive probabilistic discrimination (70:30/30:70) showed that all 8 asymptotic response points exceeded the matching level on one stimulus, and 7 of 8 points undershot the π level for the other discriminative stimulus. Although visual inspection is less sensitive than a statistical test, it appears that all conditions of these studies yielded overshooting, rather than the reported matching.[4]

Sets of numerically presented data for individual subjects from pigeon experiments were statistically analyzed (chi square) by the present author. Further data from Graf et al. obtained for individual subjects on a 70:30 spatial task were characterized by these authors as showing "maximizing". The percentage of responses to the majority key for each subject were 70,70,92,90,85 and 85. According to the present author's criteria, 2 of the subjects matched and 3 overshot π levels. For the Shimp (1966, experiment I) data, 10 asymptotic response proportions overshot π levels, 1 p value matched, and 1 p value undershot the

4. My reliability criteria cannot be rigorously applied to all of the results of Graf et al. because asymptote propoertions were not always reported for individual subjects.

level. Finally, according to the present author's criteria, maximizing in birds occurred on the visual tasks in the studies of Mackintosh, Lord & Little (1971) and Shimp (1973, experiment I).

Even when responding on probability tasks is categorized in a consistent manner, as done above, wide variations in terminal response levels within a single species are still evident. It appears that any single assumption predicting asymptotic performance, such as matching, on probability tasks will fail to describe the diverse response outcomes reported. An analysis of experimental conditions across studies may shed light on the parameters contributing to the variability of response levels on probabilistic tasks. In my opinion, behavioral variation on probabilistic tasks principally derives from these sources: 1) the type of correction procedure employed, 2) the length of the intertrial interval, 3) the number of acquisition trials, and 4) discrimination difficulty. Factors (1) and (2) will receive primary emphasis.

Correction Procedures and Intertrial Times

The type of procedure may be the single most important variable influencing response outcomes in probability learning situations. In a noncorrection procedure, either a correct or an incorrect response terminates a trial; thus, all trials are independent of the previous response. Animal subjects typically show absorption to the response alternative rewarded more often when trained under a noncorrection procedure (Bitterman, Wodinsky & Candland, 1958; North & MacDonald, 1959; Graf et al., 1964; Weinstock, North, Brody & LoGuidice, 1965), although Weinstock et al., reported absorption on the minority reinforced response for some subjects.

Guidance and immediate correction procedures require a response to the reinforced alternative after a nonreinforced choice response and before the next choice trial. These procedures insure that all reinforcements assigned are collected. The subject, therefore, does not control the number or ratio of reinforcements per session. What kind of responding would constitute optimal behavior in this situation? One plausible way to define optimizing would specify that the animal collected the scheduled number of reinforcements in the least amount of time, i.e., the fewest number of trials, given a discrete trial task. Thus, an optimal strategy would promote the highest reinforcement density by minimizing the number of trials per reinforcement, assuming that unreinforced trials are aversive to the learner. If it is further assumed that the animal has perfect memory for response selections resulting in reinforcement within a session, minimizing the number of trials per reinforcement would involve exclusive selection of the majority reinforced response on the choice (initial) trial, and yield overall maximizing. Response proportions deviating from maximizing would then represent a transitory learning phenomenon that precedes an eventual rise to a maximizing asymptote. Intersubject variability of response levels would be attributable to individual differences in the number of trials necessary to adopt this maximizing strategy.

Under guidance and immediate correction designs employing rat subjects, the maximizing prediction is confirmed by numerous studies reporting majority response proportions that significantly exceed matching and approach maximizing (Witte, 1959; Roberts, 1966; Mackintosh, 1970; Bitterman et al., 1958; Calfee, 1968; Uhl, 1963; Gonzalez et al., 1964; Cole, Belinsky, Boucher & Myers, 1965; Wright, 1967).

For pigeon subjects, the results of Graf et al. and Bullock & Bitterman, previously analyzed by the present author (p.7), revealed overshooting or near maximizing for 4 out of 5 sets of results, all of which incorporated guidance procedures. For another set of results in Graf et al., the authors attributed overshooting on a probabilistic spatial task to the pigeon's superior ability on spatial tasks. The maximizing strategy, as outlined above, provides an alternate explanation for these results.

The correction rerun method inserts an intertrial interval between choice and correction trials, allows for repetitive errors and, excepting the delivery of reinforcement for "correct" responses, provides no differential cuing for choice and rerun trials. A strategy that maximizes reinforcement density would be characterized by exclusive selection of the majority stimulus on the initial choice trial and, if no reinforcement is delivered, switching to the reinforced alternative response following the intertrial interval. The animal must learn to discriminate between choice and correction events -- a task further complicated by long intertrial intervals between choice and correction trials. This is because a longer intertrial interval will reduce the likelihood that the animal will remember the prior choice response and its consequence.

On might expect a closer approximation to optimal behavior (minimizing the number of trials per reinforcement, p.9) given short intertrial times between choice and correction trials. Short intertrial intervals would facilitate a "lose-shift" strategy from the nonreinforced choice on the initial trial to the reinforced alternative on the rerun trial. Shimp (1973,

experiment I) reported maximizing (range of asymptotic response proportions: .95 - 1.0)[5] on a probabilistic choice task in pigeons with almost immediate response alternation on rerun trials after nonreinforced choice trials. Another pigeon experiment (Williams, 1972) reported immediate response alternation without maximizing on a probability learning task. In both experiments, intertrial intervals were less than three seconds. These results are not surprising. The pigeon can respond just as the rat does on probabilistic tasks, given a procedure that facilitates a maximizing strategy.

Probabilistic experiments employing long intertrial times would be likely to reduce sequential (trial-to-trial) dependencies such as "lose-shifting" and thus, impede optimal behavior. In fact, departures from maximizing are most consistently found in studies employing long intertrial intervals under correction-rerun methods. For rats, where maximizing is typically reported under immediate correction and guidance methods, Melera (1967) reported small, but reliable overshoots at the .05 level on a 60:40 probabilistic task and an 80:20 probabilistic task. Inspection of Melera's graphs (the only data presented) reveals that the highest p values were about 70% on the 60:40 task and 85% on the 80:20 task. In an earlier study, Revusky (1961) reported significant undershoots on a 67:33 spatial task. The intertrial intervals in the experiments of Melera and Revusky ranged from 3 to 24 hours. The reduced p values in these studies are associated with an experimental situation which impedes the previously described maximizing strategy.

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5. My criteria for maximizing cannot be directly applied to Shimp's study because individual data were not reported. However, the range of asymptotic response proportions is similar to that reported in 100:0/0:100 discrimination learning studies (e.g. Heinemann, Avin Sullivan & Chase, 1969).

It should be noted that the results of Melera and Revusky represent response levels achieved after 80-90 acquisition trials. Typically, several hundred to several thousand trials are given in studies reporting maximizing (e.g., Calfee, 1968; Mackintosh, Lord & Little, 1971). It could be argued that a larger number of acquisition trials in the above correction-rerun studies would have produced the "true" maximizing asymptote. However, if probability matching is observed most conspicuously under rerun conditions, the theoretical problem then becomes one of analyzing the controlling variables that produce matching behavior, rather than the more theoretically obvious overshooting and maximizing behavior.

Probabilistic Choice Tasks

Control of stimuli irrelevant to the discrimination may be enhanced under probabilistic choice conditions. Typically, such a task involves a successive two-stimulus discrimination with each stimulus signaling the complementary proportion of reinforcement for the response alternatives. In other words, two successive probability learning tasks are presented, and a discriminative stimulus signals the presence of each probability learning task. The animal typically learns to discriminate between the reinforcement ratio signaled by each discriminative stimulus. For example, if a bright light signals the presence of a 75/25 positional probability task, while a dim light signals the presence of a 25/75 positional probability task, the animal may learn to distribute his choice responses so that 75% are made to the "majority" reinforced key, and 25% are made to the "minority" reinforced key in the presence of the bright stimulus. This would be called matching in the presence of the bright stimulus. Furthermore, the animal may learn to distribute his choice responses in the presence of the dim

stimulus so that 35% are made to the minority reinforced key, and 65% are made to the majority reinforced key. This would be called undershooting (if statistically reliable) in the presence of the dim stimulus. This design has the effect of reducing or eliminating position preferences often implicated as controlling irrelevant cue of probabilistic responding (Sutherland & Mackintosh, 1971).

Response levels on probabilistic choice tasks may be partially determined by the difficulty of the stimulus discrimination. In an unpublished study (Friedberg & Brenner), a 1/2 log unit light intensity discrimination yielded reliable undershoots of matching in a 65:35/35:65 group and a 75:25/25:75 group of pigeons after 7600 trials. Under similar conditions (Friedberg) with a 1 log unit light intensity discrimination, a matching asymptote (pigeons) was achieved after 2400 trials on a 75:25/25:75 task. To minimize the influence of stimulus discrimination difficulty on probabilistic responding, a stimulus discrimination that produce near errorless behavior under nonprobabilistic (100:0/0:100) conditions is desirable.

In the unpublished probabilistic discrimination study by the present author, cited previously, two subjects matched and two subjects reliably undershot matching levels on a 75:25/24:75 discrete trial correction rerun task with a ten second intertrial interval. No overall position preferences were observed, and the total trial data, i.e. the total number of choice and correction trials, closely conformed to the number of trials expected if the subjects' probability of a response did not

change on rerun trials. Such an analysis suggests the absence of sequential effects on the probabilistic discrimination task. A 100:0/0:100 control condition showed a mean error rate of less than 1% (responses to the unreinforced key) at asymptote. This low error rate indicates a highly accurate stimulus discrimination. Thus, the probabilistic discrimination asymptote was not appreciably reduced by the successive light intensity discrimination.

Probability Data in Fish

It has been agreed by rival theorists Bitterman and Mackintosh that fish typically produce matching behavior on probabilistic tasks. In light of the above methodological considerations concerning correction procedures and intertrial times, the relative homogeneity of the fish data may be in part attributable to the similar designs among the seven studies found by the present author. All of these studies used guidance procedures, spatial tasks (with additional visual problems in some studies), a relatively small number of training trials (500-2440), short intertrial intervals (except Mackintosh, Lord & Little, 1971), and coincidentally, all used a 70:30 reinforcement ratio (with additional ratios in two studies).

Careful inspection and statistical analysis of the existing fish data show significant departures from matching for some subjects. Statistical analyses by the present author of the Bitterman et al. data shows that 2 of 5 subjects significantly exceeded the matching ratio. Although individual response levels were not reported, Behrend & Bitterman (1961, 1966) cited a response proportion range of .59-.76 and .60-.74 on spatial and visual probability tasks, respectively. A chi square test of the upper limit

of each range showed reliable departures from the matching level. In another study, Weitzman (1967) reported a group mean matching level of 70.6% on a 70:30 spatial task. However, Weitzman noted that individual subjects did not show matching. Only Mackintosh, Lord & Little (1971) reported no significant departures from matching for fish.

It appears that a wide range of behaviors have been categorized under the rubric "matching", even in the relatively homogeneous fish data. In light of the procedural variables such as type of correction procedure, the near matching behavior of fish may not represent a learning capacity for matching, but rather a reflection of the similarity of experimental conditions across studies.

Optimal Strategy, Matching & Path Independence

Any empirical response tendency represented by changes in response probability from trial to trial, such as consistent choice of the response alternative rewarded on the previous trial (i.e., reward following) can be considered fundamental to matching only if matching behavior cannot occur without its presence. In fact, no such nonrandom sequential patterns are necessary, considering that matching with no sequential patterns has been reported for the rat (Calfee, 1968), for fish (e.g., Behrend & Bitterman, 1961), and for the pigeon (Graf et al. and Bullock & Bitterman as reported in Bitterman; 1965). Although evidence of trial independence for rats is scant relative to the total number of rat studies employing probabilistic tasks, virtually none of these studies attempted to minimize the occurrence of systematic response tendencies with appropriate controls, such as use of the correction rerun procedure.

To summarize, then, random matching replicated within and across genus boundaries shows that sequential (trial-to-trial) dependencies are not necessary for matching. If systematic response tendencies, in addition to the maintenance of a particular p level, are not requisite for matching, such response tendencies may be considered second-order effects. Focussing on random matching does not preclude consideration of nonmatching behavior under probabilistic schedules which shows no systematic response strategies (e.g. Shimp; 1973 and Mackintoch; 1969 in his retrospective analysis of the early Bitterman studies of pigeons).

A redefinition of optimal behavior arises when the animal's responding is uninfluenced by immediately prior trials. Such behavior implies no discrimination of choice and correction trials. Thus, the probability of selecting a response alternative may correspond to the probability of reinforcement for that alternative, but no trial-to-trial nonrandom response tendencies such as reward following or lose shifting, are displayed. If the discrete trial responses are truly independent, an optimal strategy, based on the assumption of minimizing the number of trials per reinforcement, may be formulated. Although the organism may not discriminate choice and correction trials, its memory may be capable of storing information about which responses were made and their outcomes for the last few trials. For instance, if reinforcement was delivered three times on the minority key and only twice on the majority key for the five prior reinforced trials, the animal may be more likely to respond to the minority key on the next choice trial. Condisering only these five trials (trials N-5 to N-1), minimizing the number of trials per reinforcement and involve choosing the minority key on subsequent choice trials (N, N=1, etc.). The probability of selecting the minority key would change as the number of choice trials on

which the majority key is reinforced increases relative to minority key reinforcement. Thus, optimal strategy is determined by the animal's memory for several immediately prior trials, instead of the entire session. Each "block" of trials, the size of a block determined by the animal's memory, is in itself a distinct probabilistic task for the animal who will maximize reinforcement density within each of these "blocks". The animal's response on any particular trial would be to the key that delivered the greater number of reinforcements in the prior block of trials. A relatively small block, say five trials, would result in more minority key selections than a larger block, say 15 trials. This is because smaller blocks will show greater sampling errors than larger blocks, from the reinforcement ratio. As training is extended on the probabilistic task the "block size" will increase, and thus, response levels will approach π and eventually overshoot π. Maximizing occurs when all blocks of trials have a greater number of majority reinforcements than minority reinforcements. Shimp's (1966, 1969) concept of momentary maximizing is similar to the present formulation; however, Shimp (1969) focuses on elapsed time since the last reinforcement (p.5) as a determinant of response choice, instead of the animals memory for prior trial outcomes.

Generalization

The generalization test is the conventional technique used for the assessment of behavioral control exerted by a discriminative stimulus. Generalization gradients for probabilistic choice behavior, as yet unreported, may shed light on the locus and precision of stimulus control, and stimulus discriminability attained under inconsistent reinforcement schedules.

Studies by Pierrel & Sherman (1960), Heinemann and co-workers (Heinemann, Avin, Sullivan & Chase, 1969; Heinemann & Chase, 1970a; Heinemann & Chase, 1970b; Chase & Heinemann, 1973), Stubbs (1968) and Mandell (1973) have found that generalization curves obtained after training to discriminate between two stimulus intensities under nonprobabilistic (100:0) reinforcement conditions have the typical sigmoidal form of psychometric functions. This is in contrast to the peaked generalization gradients which are usually obtained following discrimination training with metathetic stimuli (e.g. Hanson, 1959; Heinemann, Chase & Mandell, 1968; Blough, 1969).

In an unpublished study by the present author (p.), an experimental group (pigeons) received a probabilistically reinforced (75:25/25:75) light intensity discrimination, while a control series received nonprobabilistic (100:0/0:100) training for the same stimulus discrimination. After 4800 training trials divided into 60 daily sessions, generalization tests for the light intensity dimension were given. Comparison of the probabilistic and nonprobabilistic gradients revealed these differences: 2) the slopes of the probabilistic gradients were reliably flatter than the nonprobabilistic functions[6] and (b) the nonprobabilistic gradients were in the form of the normal ogive, while the gradients for the probabilistic group were roughly S-shaped and, in contrast to the normal ogive, showed asymptotes that reliably departed from 0 and 1.0.

Using signal recognition methods, Nevin, Olson, Mandell & Yarensky (1975) presented successive probabilistic choice tasks to rats and pigeons, and reported decreased sensitivity to visual (light intensity) signals in

6. According to Heinemann et al (1969), the slope of the sigmoidal generalization gradient reflects sensitivity to stimuli, or stimulus discriminability.

comparison to stimulus sensitivity under nonprobabilistic tasks. Isosensitivity plots showed reduced discriminability as a function of increasing levels of inconsistent reinforcement for rats and pigeons. This finding represents a confirmation of the present author's previously described study which found decreased discriminability in generalization under probabilistic conditions. In the Nevin et al. study, probabilistic reinforcement was imposed upon a partial reinforcement schedule. The probabilistic schedule for the minority key was systemically varied, while the majority key remained at $\pi = .50$. In other words, the probability of minority reinforcement was varied, while the majority reinforcement assignments remained constant. A noncorrection procedure and changing reinforcement probabilities throughout training sessions also distinguish the task in this study from the typical probabilistic training situation.

In several pilot studies conducted by the present author, the typical extinction procedure for the postdiscrimination generalization test (and variations of this procedure assigning differential reinforcement to training stimuli only, or extinction test probes interpolated during asymptotic discrimination performance) have yielded unstable generalization functions that deteriorate too rapidly for the evaluation of stimulus control attained during probabilistic discrimination training. In the previously cited probabilistic discrimination experiment by the present author, stable postdiscrimination gradients were obtained by maintenance of reinforcement ratios for all stimuli throughout generalization testing. Thus, a meaningful analysis of stimulus control was possible.

Probabilistic Schedules and Nonreinforced Trials

The effect of nonreinforced trials on probabilistic task performance has received scant attention in the animal literature. Assuming no differential cuing of nonreinforced trials, there would be no difference to the animal between a scheduled nonreinforced trial and a nonreinforced choice or rerun trial. As the number of scheduled nonreinforced trials is increased, reinforcement density would decrease. Understanding the role of nonreinforced trials may clarify the parameters that determine response levels on probabilistic tasks. For instance, if trial-to-trial sequential dependencies control responding under probabilistic schedules, it is plausible that the addition of scheduled nonreinforced trials would reduce the magnitude of these sequential effects, and possibly alter response levels.

The influence of nonreinforcement on discrete trial probability tasks has been considered by several theoreticians. Bush and Mosteller have elaborated a number of specialized versions of the basic linear operator learning models which differ primarily in the assumptions made concerning the effects of nonreinforced choice trials. For nonhuman subjects, there are a number of assumptions that have been made about the effects of nonreinforced trials on overall choice proportions. The identity operator model assumes that choice proportions are unchanged by unreinforced trials (Bush and Mosteller, 1955; pp. 183 and 289). The identity operator model has been applied to noncorrection probability learning in rats by Weinstock, North, Brody & LoGuidice (1965). The results of the experiment conformed

closely to the model's prediction that nonreinforced trials (additional scheduled unreinforced trials in this experiment) would have a negligible effect on choice probabilities.

Shimp (1966) examined the effect of nonreinforced trials on various probability learning tasks. When correction rerun trials were differentially cued (Shimp, 1966; experiment II) on a positional probability learning task ($\pi = .75$) with a partial reinforcement schedule gradually thinned from 100% reinforcement to 25% reinforcement, birds almost perfectly maxamized (errors $<$ 3%). The increase in scheduled nonreinforced trials from 0-75% of the total number of trials did not affect choice proportions.

The conditions of experiment III (Shimp, 1966) were identical to those of experiment II, except that reinforcement was available on only 25% of all choice trials, and correction-rerun trials were not differentially cued. Matching proportions were obtained.

Shimp formulated a "momentary maximizing" principle to explain the effect of nonreinforced trials on probability tasks. Under this strategy subjects tend to choose the response alternative that momentarily has the higher probability of reinforcement. Given a free operant procedure under concurrent VI schedules, reinforcement is more likely to be set up on a key the longer a bird pecks at the other key (Skinner, 1950). Similarly, on discrete trial tasks, the relative probability of reinforcement (i.e. "momentary probability") on a key increases with each unreinforced peck at the other key. The momentary maximizing sequence contains the less frequently reinforced response, or in other words, the less frequently reinformed choice sometimes has the greater probability of reinforcement. For instance, on a discrete trial probability learning task <u>without</u>

scheduled nonreinforced trials, the subject responds to the majority reinforced key on choice trials (first trials) because the relative probability of reinforcement is greater on the majority key than on the minority key on choice trials. If the choice response to the majority key is unreinforced, then the relative probability of reinforcement becomes greater on the minority key. In fact, the relative probability of reinforcement jumps to 1.0 for the minority key on the next (rerun_ trial. Thus, a momentary maximizing strategy would involve exclusive selection of the majority key on choice trials, and exclusive selection of the minority key, i.e., immediate switching, on the first rerun trial.

Assuming the addition of scheduled unreinforced trials with no differential cuing of choice, rerun or scheduled nonreinforced trials, the subject's momentary maximizing strategy would be altered. The ambiguous consequences of nonreinforcement will cause the animal to persist on the majority key, rather than immediately switch to the minority key on rerun trials. This occurs because a single nonreinforced choice on one key is no longer a perfect predictor of scheduled reinforcement on the other key, but only a predictor of increased likelihood that reinforcement will be set up on the other key. The bird continues to respond to the unreinforced majority key until it is more likely that reinforcement will be set up on the other key, at which time the bird switches to the other key.

A unique sequence of choices can be predicted under the momentary maximizing principle from knowledge of π and the probability that

reinforcement is available (r). Given a π level of .75 and r=.25 (the conditions of experiment III; Shimp, 1966), Shimp determined mathematically that momentary maximizing produces overall matching. The expected momentary maximizing sequences were observed in the data from experiments III & IV; however, the subjects showed several unpredicted response alternations.

To complete the parallel between relative reinforcement matching under concurrent VI schedules and probability matching on discrete trial tasks, Gibbon et al. (1974) considered the influence of scheduled non-reinforced trials on discrete trial probability tasks. On concurrent VI schedules, unreinforced trials exist in the sense that the animal will respond to the operanda and receive no reinforcement; however, "trials" are not cued as in discrete trial tasks. Gibbon et al. agree with Shimp that nonreinforced trials may be important to probability matching because they make choice and correction rerun trials less discriminable. Using the terminology of Gibbon et al., scheduled unreinforced trials cause subjects to develop an error matching strategy (p.3*), instead of a "lose shifting" strategy (switching to the reinforced key on a rerun trial after an unreinforced choice trial). A "lose shifting" strategy would cause departures from probability matching. According to Gibbon et al., when choice and correction trials are not discriminable on a discrete trial probability task, a close approximation of behavior generated under concurrent variable interval schedules is obtained, where there is no empirical distinction between choice and correction events, excepting the delivery of reinforcement.

On a discrete trial probability task, how will the addition of non-reinforced trials affect an asymptotic error matching (or probability matching) relationship? Although Gibbon et al. do not directly deal with this question, it appears that an empirical error matching relationship will not be affected by the addition of unreinforced trials. The subject will distribute unreinforced responses equally between the response alternatives -- a strategy which is entirely consistent with error matching behavior. In other words, reponses made on scheduled unreinforced trials may be considered errors; the subject will distribute its reponses in such a way as to equalize the number of errors between the response keys.

Parametric Data

Thorough parametric examinations of animal probability learning are lacking. Shimp (1973, experiment II) attempted to map choice proportions as a function of reinforcement probability by varying stimulus presentation rates and reinforcement probability within a single group of pigeons. All possible combinations of four tilted lines were used as discriminative stimuli. The data showed a marked overshooting (of π levels) tendency as a function of the average reinforcement probability of the component line-tilt stimuli. Hale & Shimp (1975), conducting a similar experiment using temporal discriminative stimuli, replicated the earlier findings for the line tilt stimuli. In both studies, however, discrimination difficulty was confounded with reinforcement probability. The most discriminable stimuli were assigned a 100:0/0:100 reinforcement schedule, while less discriminable stimuli were assigned probabilistic schedules with reinforcement ratios that approached 50:50/50:50.

Uhl (1963) has studied the relation between proportion of reinforcement on a spatial task and probability of response in the rat. Terminal response levels over the final six days of training were a linear positive function of the proportion of reinforcement. Significant overshooting occurred in all groups.

General constructs applicable to all organisms capable of probability learning are largely the products of extrapolation and inference from the results of dubiously comparable studies. As noted previously, intraspecies variability in probability task performance is considerable, even within a particular study. A firm understanding of this variation is an essential precursor of cross-species generalization and theory construction. Such considerations support the heuristic value of a thoroughgoing exploration of the effects of probabilistic reinforcement -- a project undertaken in the present parametrically designed experiment. The applicability of the results to theories of probability learning will be examined.

METHOD

Subjects. The subjects were 60 White Carneaux pigeons, 30 of them male and 30 female, obtained from the Palmetto Pigeon Farm in Sumter, South Carolina. They were kept at 80% of their free-feeding weight. All birds were experimentally naive at the beginning of the experiment and were approximately two years old.

Apparatus. The 4 pigeon chambers were standard Lehigh Valley models. Their interior dimensions were 20 inches X 13.8 inches X 13.8 inches. A three key response panel divided each 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 two translucent side keys were one inch in diameter. They were located 9.375 inches above the floor of the chamber, and 2.25 inches from either side of the vertical midline. White lights were located behind the side keys which were illuminated to approximately equal brightnesses on the keys. A 3 by 3 inch translucent plastic screen (center key) was located midway between the side keys and 8 inches above the chamber floor. This screen was illuminated from behind by a Kodak 800H carousal slide projector with a wide angle lens. Wratten neutral density filters mounted on glass slides were used to produce a series of white light stimuli with luminances covering a range of 0.9 - 3.4 logftl. Luminances were calibrated with a Spectra Pritchard photometer.

An opening 2.25 inches x 2 inches located 2.5 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 inch directly above the center key.

To prevent extraneous noise from reaching the animals during the experiment, three precautionary measures were used: a) each pigeon chamber was contained in a large wooden box lined with sound absorbing insulation; b) An exhause fan located on the top right rear wall of the chamber was in continuous operation throughout the experimental sessions; c) Two Grason-Stadler noise generators, both model 901B, provided a white noise masking stimulus intensity of approxiately 80 db re .002 dyne/cm^2. The speaker projecting the white noise was 3 inches in diameter and located behind the panel 3.5 inches to the left of the feeder. The sound intensity was 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.

For two of the boxes, a series of relays, timers and counters were used in conjunction with two tape readers to control experimental contingencies. The remaining two boxes were programmed by two inter-connected solid state systems which, in addition, recorded sequential data and latencies with a tape punch apparatus.

For each experimental condition, 12 programs of stimulus-reinforcement contingenices were scheduled for discrimination training and 10 such programs were scheduled for generalization. For the relay controlled boxes, programs were punched on paper tape, whereas the solid state system used photoconductivity cells.

Procedure. Six subjects were assigned to each of six experimental groups. The experiment was done in two replications with 30 birds in each replication. Within each replication, each subgroup contained 3 birds.

Preliminary training. Throughout pretraining, the house light was continuously on in the experimental chambers. Initially, preliminary training was conducted in chambers 1 and 2 in which continuous 80 db white noise and electric exhaust fans provided masking noise. During pretraining, 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 magazine training, one of the side keys was lighted and subjects were trained to peck this key by the method of successive approximations. A single peck to the key caused the key light to go off and the food magazine to be raised for a period of 2 seconds. For half of the subjects, the left key was lighted and for the other half, the right key.

Next, a series of trials was presented on which either one of the side keys, selected at random, was lighted and only a response to the lighted key was reinforced (phase 1). An FI-10 sec. schedule was then introduced during which only the house light was lighted and no access to food was possible. The end of the interval was marked by the onset of the side key light. These trials were continued until each subject reliably pecked the illuminated side key, regardless of its position.

During the second phase of preliminary training, all subjects received a reinforcement for a single peck to either lighted side key,

as described above and, in addition, on approximately 50% of the trials no reinforcement was scheduled. A single session of 80 reinforced trials was given to each bird. The 80 db masking noise was now absent during the intertrial interval and, thus, its onset signaled the start of a trial simultaneously with the onset of one lighted side key.

During the final session of 80 reinforcements (phase 3), the beginning of a trial was signaled only by the onset of the masking noise. A single peck at the dark translucent screen caused one of the side keys to light up, after a 0.70 second delay. The remaining trial and intertrial events followed the phase 2 pattern. The second and third phases were administered in chamber 3 for subjects magazine trained and shaped in chamber 1, and in chamber 4 for subjects magazine trained and shaped in chamber 2.

Discrimination training. Discrimination training began on the day following the completion of preliminary training. Every subject received discrimination training and generalization testing in 2 chambers, according to the daily alternation schedule used during preliminary training.

Trial and intertrial events were presented according to the sequencing of final phase preliminary training with these modifications: a) a correction rerun procedure was imposed on the schedule, thus insuring 80 reinforced trials per session for all conditions; b) In four experimental conditions, systemically varying percentages of scheduled nonreinforced trials were added to the 80 reinforced daily trials; c) a single peck at the dark projection screen brought about the appearance, after a 0.70 second delay, of a luminance stimulus of either 1.6 logftl. (dim) or 2.7

logft1. (bright) on the screen, the simultaneous onset of both side key lights, and the darkening of the house light. A peck at either of the side keys ended the trial by terminating the side key lights, the illumination on the projection screen, and the masking noise. In addition, if the response was made to the key defined as correct for the stimulus presented during the trial, it was always followed by reinforcement.

An "incorrect" response was defined as a side key peck that terminated a trial with no reinforcement when reinforcement was available. 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 each bird to make the same number of correct responses per session and, therefore, to receive an equal number of reinforcements for every session according to the assigned reinforcement ratio.

For subjects A13, A64, B04, B15, B54, B65, C10, C59, D01, D03, D52, D53, E07, F09, F28, F60, F78, G25, G66, G67, H20, H70, H77, I17, I68, J26, J73, and J75, R1 represents a response to the right key and R2, a response to the left key. For subjects A00, A02, A50, A51, B55, B06, C08, C29, C58, C79, D12, D62, E05, E14, E56, F11, F61, G16, G18, G76, H22, H27, H30, H77, I19, I24, I74, I69, J21, J23, and J72, R1 represents a response to the left key and R2, a response to the right key.

All subjects were trained to discriminate between the two light intensities. For each subject, 40 reinforcements were assigned in the presence of the dim stimulus (S1), and 40 reinforcements were assigned

in the presence of the bright stimulus (S2) for each session. Reinforcement for R1 was scheduled on proportion $\pi 1$ of all trials on which S1 was presented, and reinforcement for R2 was scheduled on proportion (1- $\pi 1$) of all S1 trials. Similarly, reinforcement for R2 was scheduled on proportion $\pi 2$ of all S2 trials, and reinforcement for R1 was scheduled on proportion (1- $\pi 2$) of all S2 trials. For groups A, B, & C (Table 1), $\pi 1$ was equal to $\pi 2$. This is called the symmetrical condition. For group A, $\pi 1 = \pi 2 = .60$; for group B, $\pi 1 = \pi 2 = .75$, and for group C, $\pi 1 = \pi 2 = 1.0$. For groups D, E, & F, $\pi 1 \neq \pi 2$. This is called the asymmetrical condition. For group D, $\pi 1 = .75$ and $\pi 2 = .60$ for three subjects, and $\pi 2 = .75$ and $\pi 1 = .60$ for the remaining three subjects. For group E, $\pi 2 = 1.0$ and $\pi 1 = .75$ for three subjects, and $\pi 2 = .75$ and $\pi 1 = 1.0$ for the remaining three subjects. For group F, $\pi 2 = 1.0$ and $\pi 1 = .60$ for three subjects, and $\pi 2 = .60$ and $\pi 1 = 1.0$ for the remaining three subjects. The "majority" key refers to the response key (R1 or R2) assigned π (R2S2 or R1S1) and the minority key refers to the response key (R2 or R1) assigned 1 - π (R2S1 or R1S2).

TABLE 1

Summary of Conditions for Each Group*

Group	Proportion (and number) of reinforcements assigned each response key in the presence of the dim stimulus (S1) 1		Proportion (and number) of reinforcements assigned each response key in the presence of the bright stimulus (S2) 2		percentage scheduled unreinforced trials
A	.60 / .40	(26 / 14)	.40 / .60	(14 / 26)	0
B	.75 / .25	(30 / 10)	.25 / .75	(10 / 30)	0
C	1.0 / 0	(40 / 0)	0 / 1.0	(0 / 40)	0
D	.60 / .40	(26 / 14)	.25 / .75	(10 / 30)	0
E	.75 / .25	(30 / 10)	0 / 1.0	(0 / 40)	0
F	1.0 / 0	(40 / 0)	.40 / .60	(14 / 26)	0
G	.60 / .40	(26 / 14)	.25 / .75	(10 / 30)	30
H	"	"	"	"	50
I	"	"	"	"	70
J	"	"	"	"	90

*Half of each experimental group is represented in the table; the remaining half of each group is counterbalanced by stimulus, i.e. the bright stimulus is assigned the column 2 ratios and the dim stimulus is assigned the column 1 ratios.

In four additional independent groups (G,H,I & J; Table 1) assigned levels of .75 and .60 and counterbalanced as in group D, the percentage of interpolated unreinforced "no rerun" trials was varied. All interpolated unreinforced trials were scheduled in the presence of the stimulus (bright or dim) assigned π = .75. Specifically, for group G, in addition to eighty reinforced first trials, 3 of the subjects were assigned 30% unreinforced trials during bright stimulus (S2) presentations only, and the remaining three subjects were assigned 30% unreinforced trials during dim stimulus (S1) presentations only. The stimulus not scheduled for interpolated unreinforced trials retained the probabilistic schedule as described for group D (p.). Similarly, 50% unreinforced trials were assigned for group H, 70% unreinforced trials were assigned for group I, and 90% unreinforced trials were assigned for group J.[7]

For all groups 4080 reinforced choice trials (first trials) were given, divided into 51 daily sessions of 80 choice trials each. The sequence of stimulus-reinforcement pairings was determined by 12 randomized programs. Visual inspection of the response curves (figures 1-6) indicated that the discriminative performance of nearly all subjects had stabilized by day 30.

Generalization testing. During generalization testing, subjects were presented white light stimuli with luminance levels ranging from 0.9 - 3.4 logftl. This group of eight stimuli included the stimuli

7. The percentage unreinforced trials was determined as follows: group G: (17 interpolated unreinforced trials) (40 reinforced trials + 17 interpolated unreinforced trials) = 17/57 = .30; H: 42/(40+42) =.50; I: 96/(40+96)= .70; J: 320/(40+320)= .90.

used during discrimination training.

The stimulus-reinforcement contingencies operative during discrimination training were maintained in generalization with the following provisions: a) all luminance stimuli were dichotimized such that the dim stimuli (less than 2.2 logftl.) were reinforced according to the reinforcement ratio associated with the dim stimulus during training, and the bright stimuli (greater than 2.2 logftl.) were reinforced according to the ratio assigned to the bright stimulus during discrimination training; b) For groups A, B. C, D, E & F, each stimulus used in generalization was presented 10 times per daily session. For the scheduled unreinforced groups (G, H, I & J), the nonreinforced trials assigned to the dim stimulus during training were approximately equally divided among the four dimmer stimuli in generalization. Similarly, the nonreinforced trials assigned to the bright stimulus during training were approximately equally divided among the four brighter stimuli in generalization.

The sequence of stimulus-reinforcement pairings was determined by ten randomized programs. Daily sessions of 80 choice trials with correction reruns continued for 15 days.

RESULTS[8]

Throughout the experiment, discriminative stimuli that produced an incorrect response were repeated on the next trial. All results reported, except sequential statistics and latencies, refer to the choice responses emitted during the first presentation of each stimulus. All statistical analyses on response proportions, except chi square tests, used a transformation that equalized their variances. Specifically, the angular transform of the arc sine of the square root of each proportion was found (Fisher & Yates, 1948). Statistical analyses were applied to the obtained values expressed in degrees. All multiple comparisons following variance analyses were performed with the procedure suggested by Tukey known as the Tukey (b) method (Winer, 1962, page 87).

Figures 1-6 show the values of R2/S2 and R2/S1 for each subject averaged over five day blocks for the duration of discrimination training. The pair of points farthest to the right on each curve represent the proportion of choice responses emitted in the presence of the training stimuli during generalization. The divergence of each pair of curves indicates the acquisition of the light intensity discrimination. Chi square tests, performed on daily response proportions converted to frequencies for the entire training period, showed a significant difference between the R2/S2 and R2/S1 response proportions for each subject, except A51. Thus, a reliable light intensity discrimination was present in all but one subject.

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8. The findings for groups with scheduled nonreinforced trials are presented in the final three sections of the results entitled nonreinforcement groups, latencies, and sequential statistics. Results presented prior to these sections refer exclusively to the groups without scheduled nonreinforced trials.

The results reported will focus on asymptotic responding. Visual inspection of figures 1-6 indicates that 33 of 36 subjects reached steady state performance by session 30. Thus the final 20 sessions provides a reasonable asymptote estimate for statistical comparisons.

Asymptotic P. Values

Two response measures were recorded for each subject: the proportion of choice responses made to the majority key in the presence of the bright stimulus, symbolized p(R2/S2) or P2, and the proportion of choice responses made to the minority reinforcement key in the presence of the dim stimulus, i.e. p(R2/S1) or (1 - P1). P value, or level, will refer to P2 or (1 - P1).

The probability learning literature typically characterizes steady state P values as matching, undershooting, or overshooting levels. Such labels applied to groups can be statistically justified if response proportions for a particular π level are shown to be derived from a comon population. Chi square tests for homogeneity of frequencies (frequency = response proportion at asymptote X number of trials for the final 20 days of training) showed nonhomogeneity of P values within all groups (summarized in Table A, appendix), thus invalidating a characterization of any group with such terms as matching, undershooting, or overshooting with respect to a particular π level. In other words, the variance of the asymptotic response proportions within groups is reliably greater than would be expected on the basis of binomial variance.

To describe steady state performance, then, asymptotic P levels were compared to assigned π values for individual subjects using chi square tests. In the presence of S2, exact matching is defined by p (R2/S2)

Figure 1. p(R2/S2) and p(R2/S1) in blocks of five days for subjects in Group A(60:40/40:60).

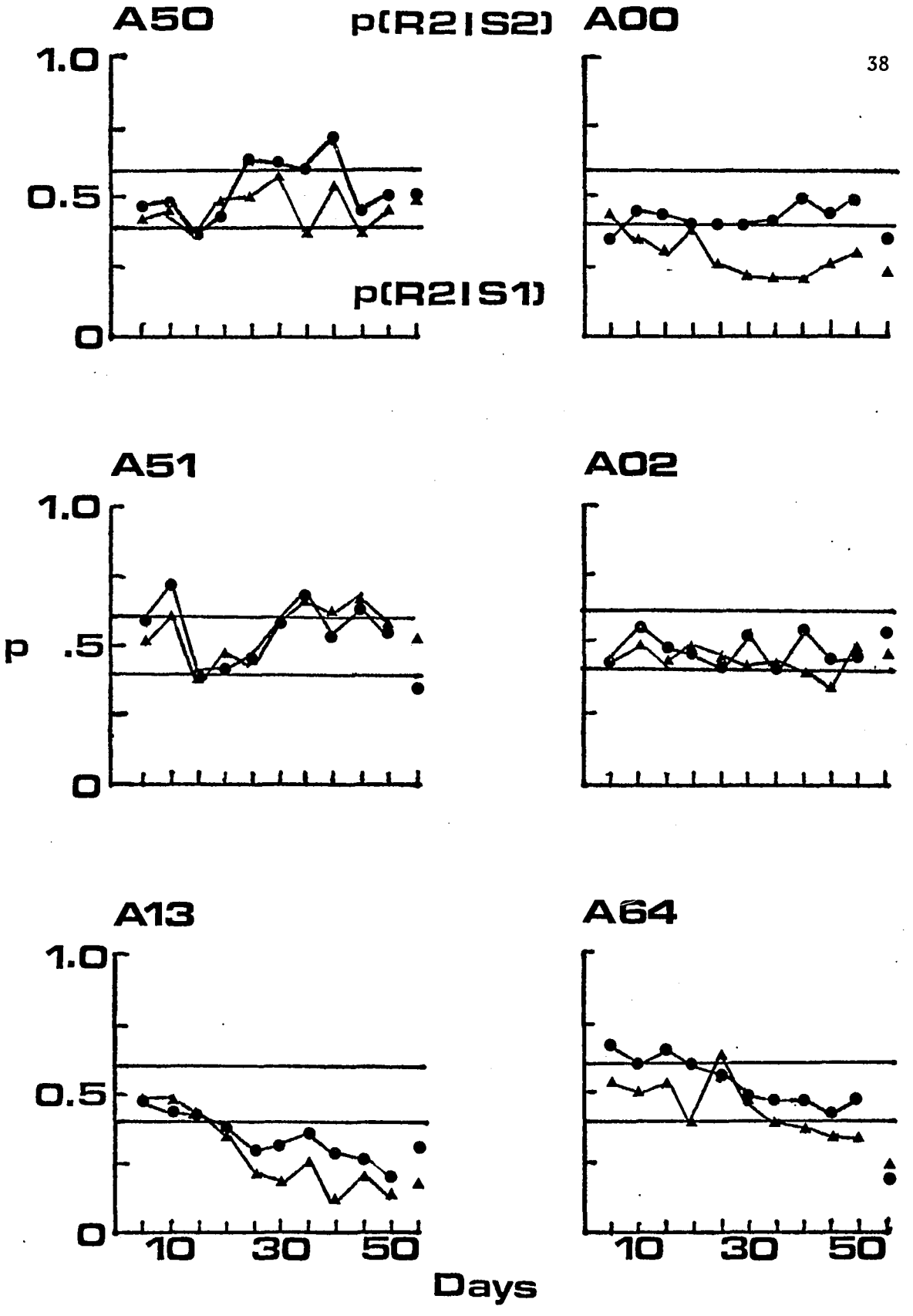

A50
p(R2|S2)
A00
1.0
0.5
0
p(R2|S1)
A51
A02
p .5
A13
A64
10
30
50
Days

Figure 2. $\underline{p}$(R2/S2) and $\underline{p}$(R2/S1) in blocks of five days for subjects in Group B(75:25/25:75).

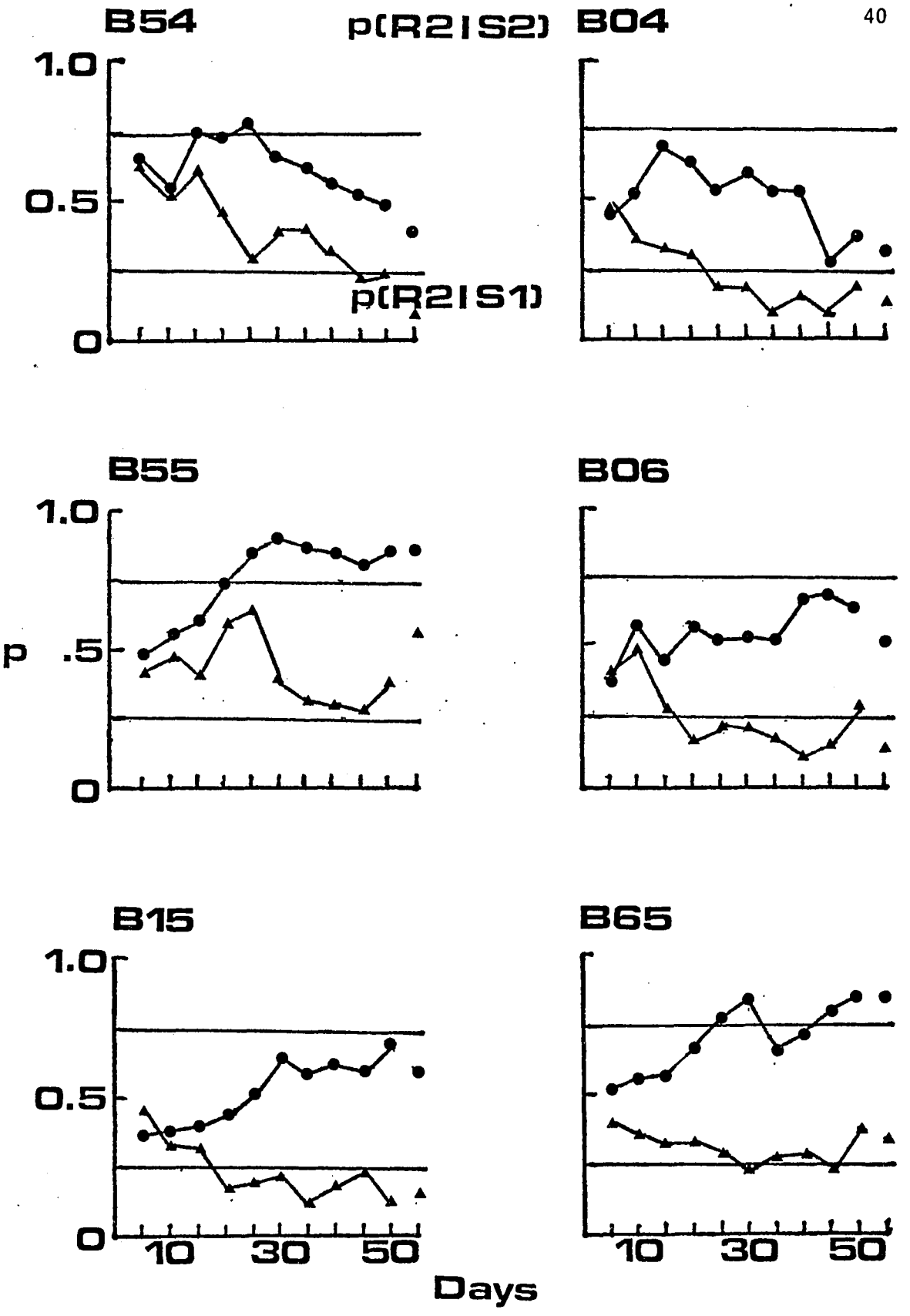

B54
p(R2|S2)
B04
1.0
0.5
0
p(R2|S1)
B55
B06
p .5
B15
B65
10
30
50
Days

Figure 3. $\underline{p}$(R2/S2) and $\underline{p}$(R2/S1) in blocks of five days for subjects in Group C(100:0/0:100).

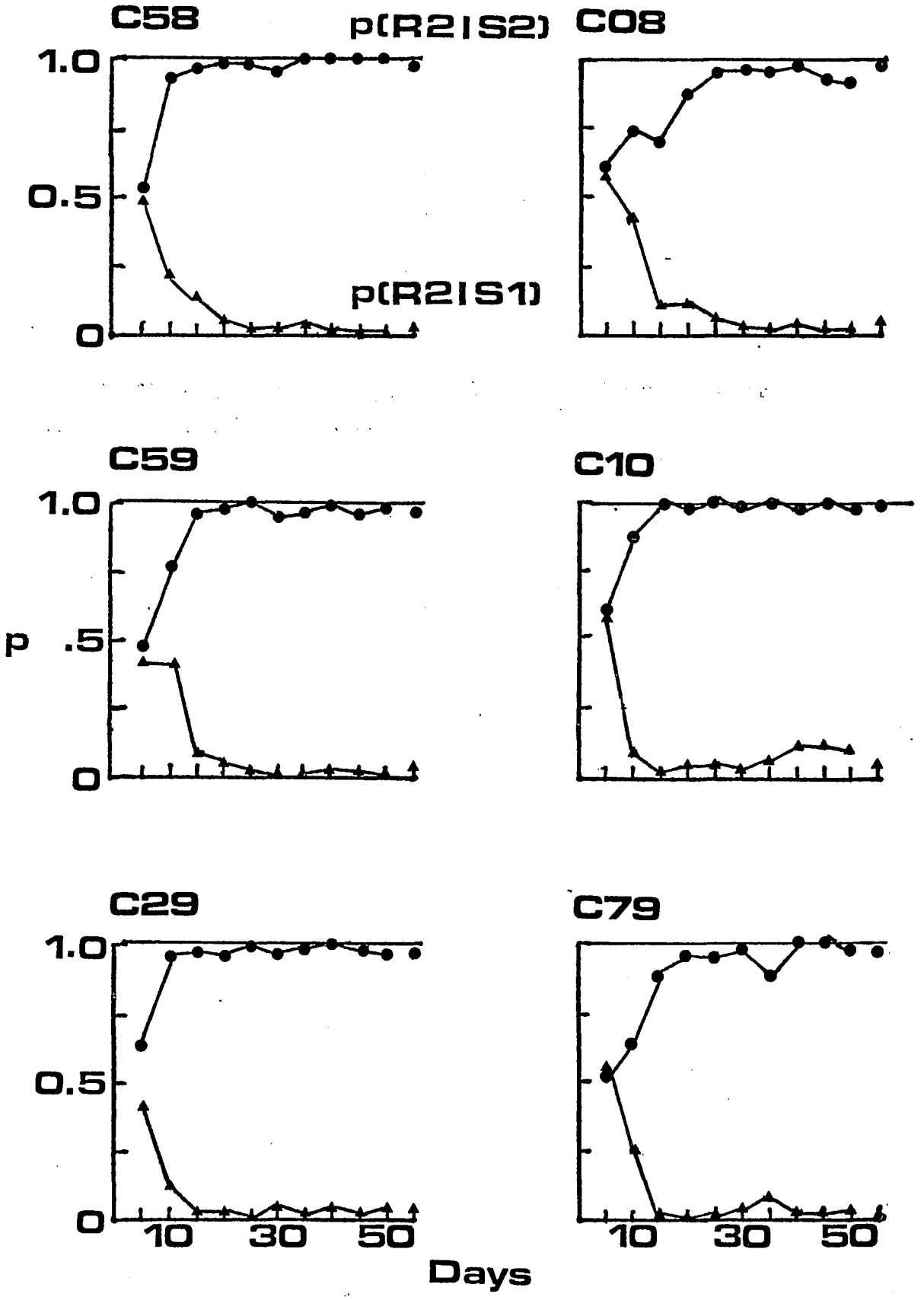

C58
p(R2|S2)
C08
1.0
0.5
0
p(R2|S1)
C59
C10
p .5
C29
C79
10
30
50
Days

Figure 4. p(R2/S2) and $\underline{p}$(R2/S1) in blocks of five days for subjects in Group D(75:25/40:60).

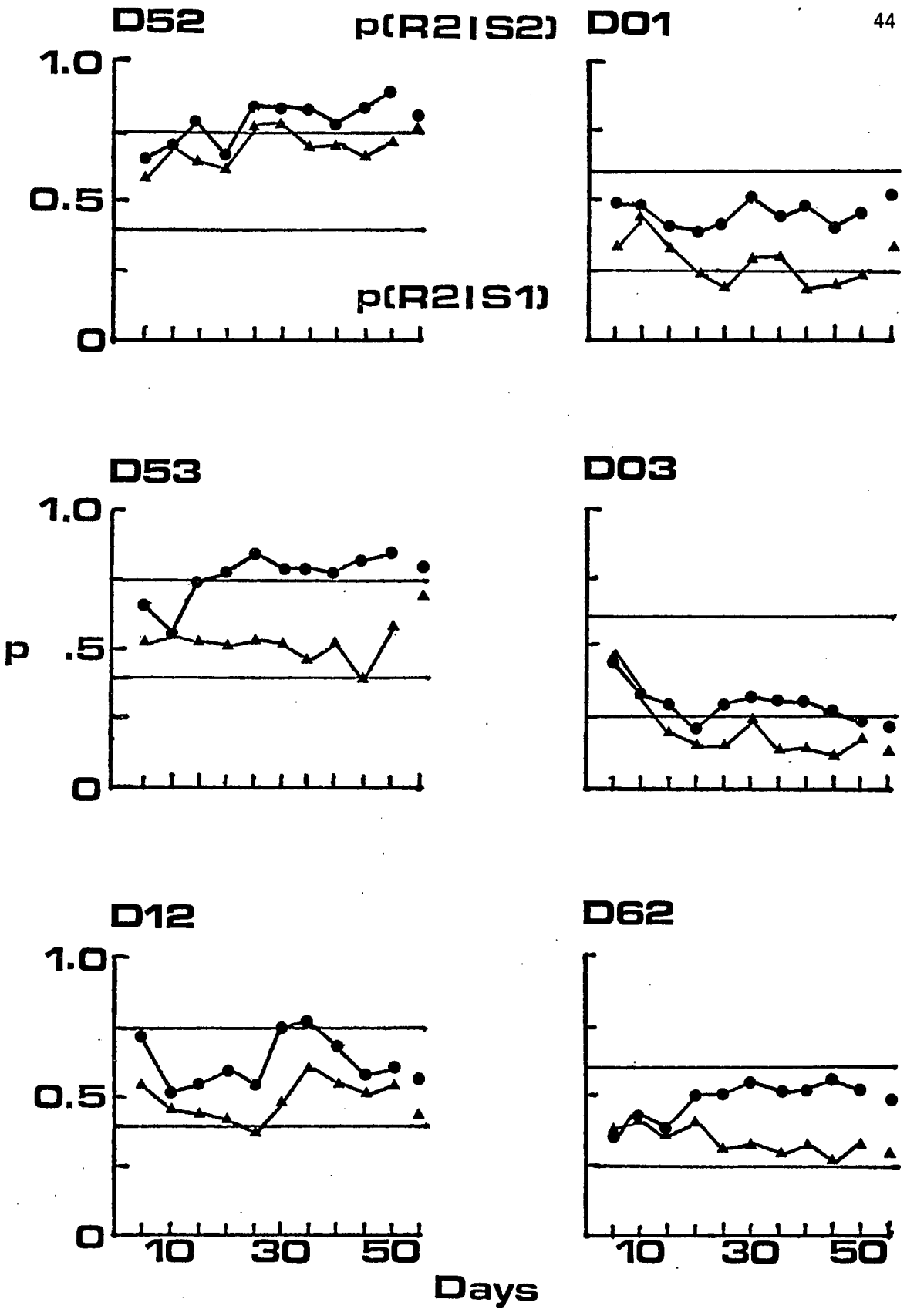

D52
p(R2|S2)
D01
1.0
0.5
0
p(R2|S1)
D53
D03
p .5
D12
D62
10
30
50
Days

Figure 5. $\underline{p}$(R2/S2) and $\underline{p}$(R2/S1) in blocks of five days for subjects in Group E(75:25/0:100).

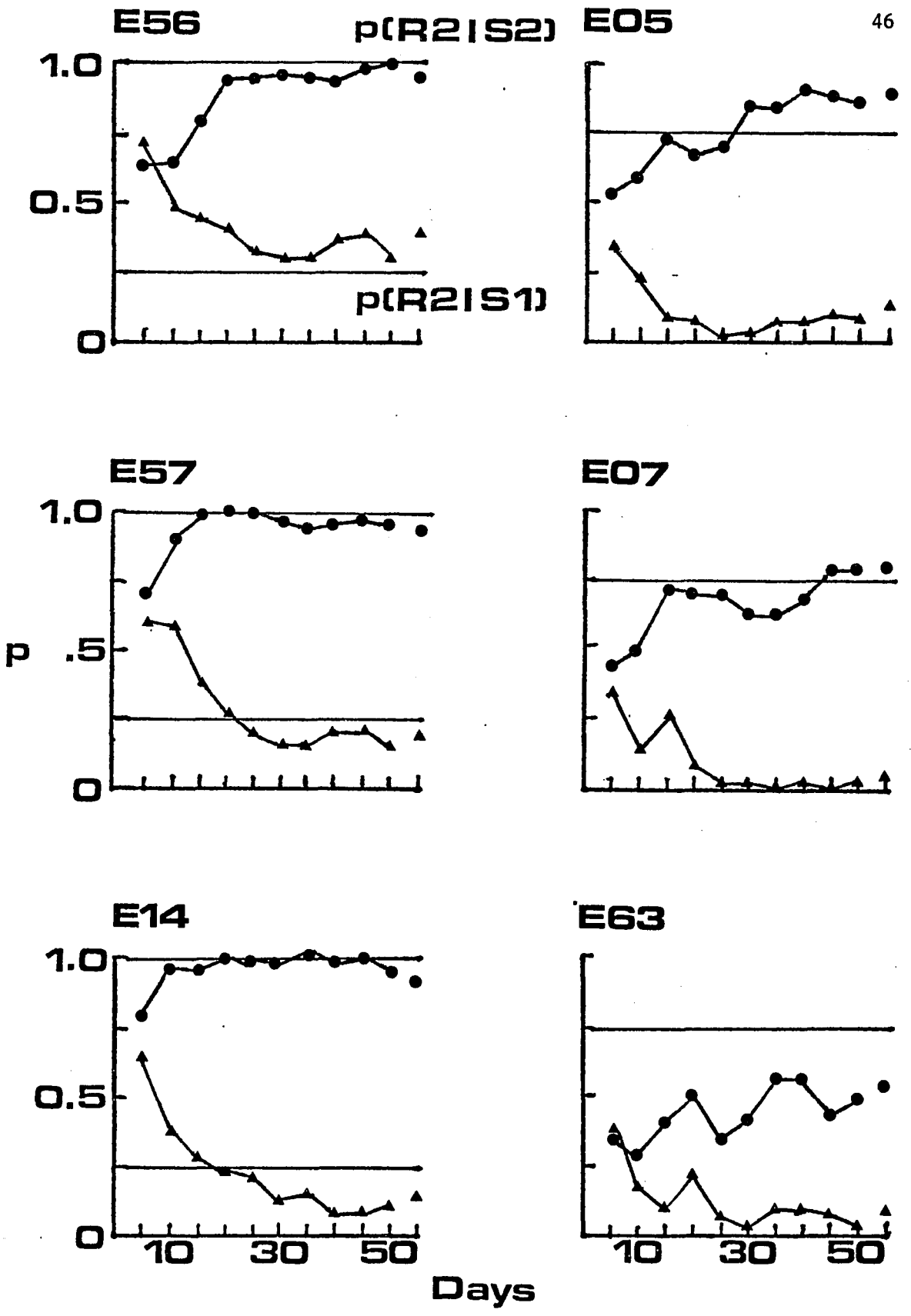
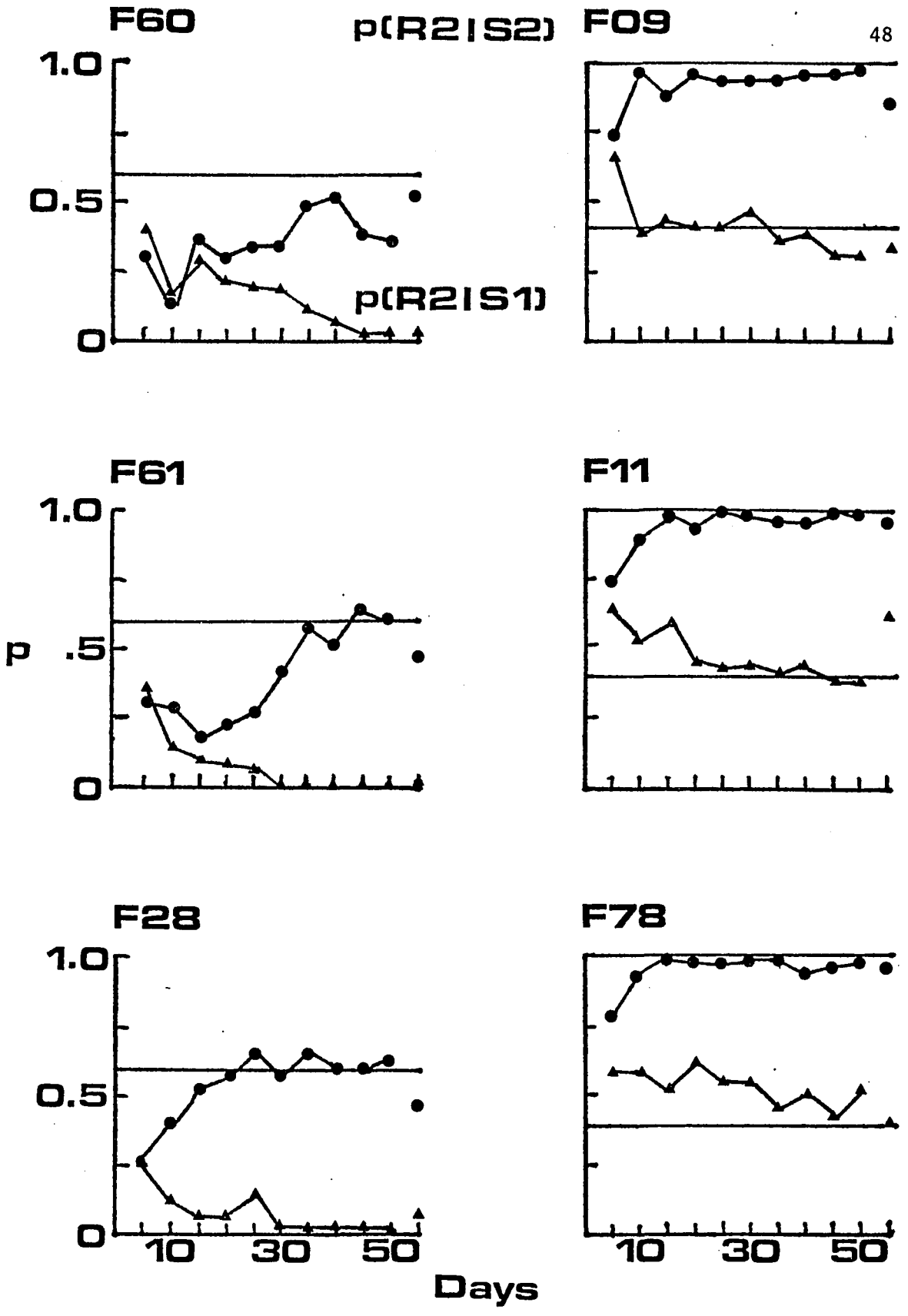

E56
p(R2|S2)
p(R2|S1)
E05
E57
E07
E14
E63
1.0
0.5
0
p .5
10
30
50
Days

Figure 6. $\underline{p}$(R2/S2) and $\underline{p}$(R2/S1) in blocks of five days for subjects in Group F(60:40/0:100).


F60
p(R2|S2)
1.0
0.5
0
p(R2|S1)
F09
F61
p .5
F11
F28
10
30
50
Days
F78

= π 2, or p(R1/S2) = 1 - π 2). In the presence of S1, exact matching is defined by p(R1/S1) = π 1, or p(R2/S1) = (1 - π 1). For the chi square tests, p(R2/S2) was compared to its assigned π 2 for each bird, and p(R2/S1) was compared to its assigned (1 - π 1) for each bird. Matching is present if P2 is not reliably different from π 2, or if the value of (1 - P1) is not reliably different from (1 - π 1). If P2 is significantly greater than π 2, or if (1 - P1) is significantly less than (1 - π 1), overshooting is present. If P2 is significantly less than π 2, or if (1 - P1) is significantly greater than (1 - π 1), undershooting is present. Table 2 shows that for 12 subjects, P overshot the π value for one stimulus while undershooting the π value in the presence of the other stimulus; 11 subjects undershot the π value for both discriminative stimuli, and 12 subjects undershot the π value for one stimulus and matched the π value in the presence of the other stimulus.

Asymptotic P levels in the presence of a particular stimulus appear to be determined by the π assignment of <u>that</u> stimulus and not by the π assignment for the other discriminative stimulus. Three analyses of variance (summarized in Table B, appendix) were performed to determine the effect of changing π 1(or 2) level across groups on asymptotic P2 (or 1) level attained under constant π 2(or 1). No reliable P level changes were found. For constant π =.60, F(2,15) = 1.17; for constant π =.75, F(2,15) π 1 and for constant π = 1.0, F(2,15) = 2.07. To summarize, the P level attained in the presence of one discriminative stimulus of constant π did not systemically change with changing values assigned to the other training stimulus.

TABLE 2

Asymptotic P Values and Their Relation to π Assignments°#

Group	2	P2	1	P1	Subject
A	.60	.50*	.40	.42**	A50
		.60		.63	A51
		.29*		.16***	A13
		.40*		.24***	A00
		.46*		.39**	A02
		.44*		.38**	A64
D	.75	.82***	.40	.66*	D52
		.77**		.52*	D53
		.65*		.53*	D12
	.60	.45*	.25	.21**	D01
		.27*		.14***	D03
		.52*		.31*	D62
B	.75	.54*	.25	.27**	B54
		.86***		.33*	B55
		.60*		.17***	B15
		.42*		.14***	B04
		.59*		.17***	B06
		.79**		.30*	B65
F	.60	.42*	.00	.06*	F60
		.58**		.01*	F61
		.63**		.03*	F28

(continued)

TABLE 2 (continued)

Group	2	P2	1	P1	Subject
F	1.0	.96*	.40	.33***	F09
		.98*		.40**	F11
		.97*		.47*	F78
E	1.0	.97*	.25	.34*	E56
		.97*		.20***	E57
		.98*		.10***	E14
	.75	.88***	.00	.08*	E05
		.73**		.01*	E07
		.53*		.09*	E63
C	1.0	1.0**	.00	.01*	C58
		.97*		.01*	C59
		.98*		.04*	C29
		.96*		.03*	C08
		.99*		.10*	C10
		.97*		.03*	C79

°When $\pi < .50$, P $< \pi$ in the case of overshooting, and P $> \pi$ for the undershooting instance.

++ α level adjusted for experimentwise error rate: $1 - (.95)^{72} = .0007$ (Winer, 1971)

*P value undershoots π assignment; significant at the .05 level

**P value matches π assignment within the limits of sampling error

***P value overshoots π assignment; significant at the .05 level

Subject did not exhibit reliable discrimination

Asymptotic P levels appear not to be effected by the value of the presented stimulus (bright or dim). For example, although $\pi 1 = \pi 2$ for the symmetrical groups, P1 (R1S1) and P2 (R2S2) may differ. Thus, the bright stimulus could produce an asymptotic response proportion different from that produced in the presence of the dim stimulus. An analysis of variance revealed that the discriminative stimuli, considered a control factor, did not differentially effect asymptotic P values, $F(1,4) = 2.052$ (summarized in Table C, appendix).

Response Bias

Pairs of P values for individual subjects may be viewed in terms of key preference. The asymmetry of the asymptotic response curves around $p(R2) = .50$ is a reflection of key preference or bias. The symmetry of response curves about the .50 level indicates the absence of key bias. One way to quantify bias is to determine the response proportion falling halfway between P2 and (1 - P1), i.e. the mean of the asymptotic response proportions, P2 + (1 - P1) /2. A mean P level of .50 reflects exact symmetry, while significant departures from 150 indicate key bias. The presence or absence of symmetry is simply another way to view P values in relation to assigned π levels.

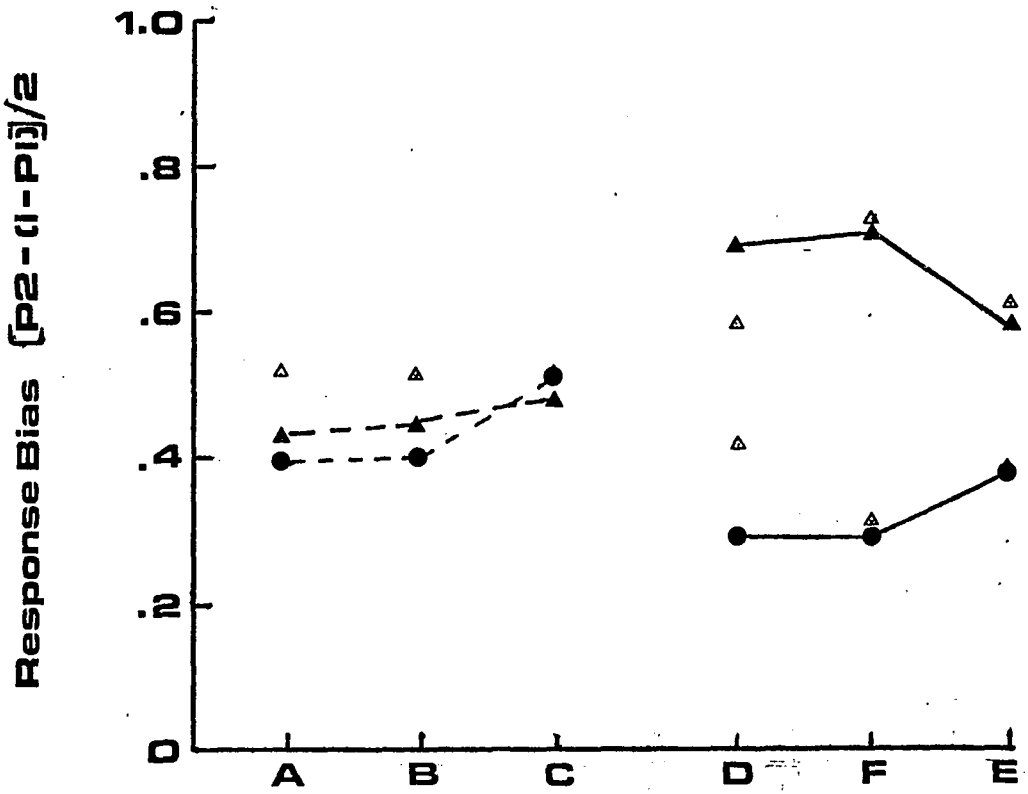
Visual inspection of the asymmetrical π groups in figures 4-6 suggests that the pair of response curves for each subject was displaced in the direction of the stimulus assigned the greater π . Figure 7 shows the mean response bias for each group. Curve S2 represents the mean bias for birds assigned the greater π for the bright stimulus, and curve S1 shows the mean bias for birds assigned the greater π to the dim stimulus. Response

bias is associated with asymmetry of the reinforcement assignment. An analysis of variance showed significant differences between the mean key biases of birds assigned the greater π for the bright stimulus, and the mean key biases of birds assigned the greater π for the dim stimulus, $F(1,24) = 39.19$, $p < .001$ (Table D, appendix). Multiple comparisons were significant for the asymmetrical groups only. Within asymmetrical groups, the direction of the bias was determined by the stimulus assigned the greater π .

In the symmetrical conditions, where the number of reinforcements was divided equally between the response keys, the mean π value is .50, determined from the expression $\pi 2 + (1 - \pi 1) /2$. Within asymmetrical conditions, the mean π values are .60 - (1 - .75) /2 = .425 for S2 assigned the smaller π , and .575 for S2 assigned the larger π in Group D; .75 + (1.0 - 1.0) /2 = .375 for S2 assigned the smaller π and .625 for S2 assigned the greater π in Group E; and for Group F, .60 + 1.0 - 0) /2 = .30 for S2 assigned the lesser π , and .70 for S2 assigned the greater π . Table 3 illustrates the determination of mean π for each experimental condition.

t-tests were performed to determine whether mean bias values differed from the mean π expected values (Table 3). The mean key bias values for each group did not reliably differ from the expected bias values (Table E, appendix reports all *t* values). The value of the standard error of the mean was obtained from the within groups variance of the analysis of variance performed on key bias. Finally, the aforementioned statistical

Figure 7. Mean response bias for each π group during probabilistic discrimination training.



MEAN RESPONSE BIAS FOR SUBJECTS ASSIGNED THE GREATER π VALUE IN THE PRESENCE OF DIM STIMULUS

MEAN RESPONSE BIAS FOR SUBJECTS ASSIGNED THE GREATER π VALUE IN THE PRESENCE OF BRIGHT STIMULUS

MEAN RESPONSE BIAS FOR SUBJECTS IN SYMMETRICAL π GROUPS, $\pi_1 = \pi_2$

RESPONSE BIAS EXPECTED (TABLE 3)

analysis (p.) showing stimulus intensity to be unrelated to asymptotic P level argues against key preference caused by stimulus intensity effects. These analyses strongly suggest that a reinforcement effect, and not a stimulus effect, was controlling the bias.

Signal detection theory describes a technique to estimate the degree of response bias. The bias index, B, represents the likelihood ratio established by a subject along the decision axis. This decision criterion is expressed as the ratio of the likelihood that a given event was due to S2 relative to S1. It is assumed that the size of the neural effect produced by any one stimulus intensity varies somewhat from presentation to presentation and that the probability density distribution of neural effects is normal. The distributions that correspond to the discriminative stimuli have different means, but all distributions are assumed to be of equal variance.

The decision criterion can be empirically derived from the proportion of responses made in the presence of each stimulus by using a table of the normal probability integral. In the present experiment P2 and (1 - P1) were used to derive these values. Prior to statistical analyses, likelihood ratios must be normalized by taking the natural log of the likelihood ratio (Tanner & Birdsall, 1964, p.149), i.e. lnLr. negative values indicate a preference for response R2 and positive values indicate a preference for response R1 (Table 4). Figure 8 presents the mean of the ln LR for each group according to the stimulus with the greater π assignment. The visual impression is that of symmetrically placed group mean criteria in symmetrical π groups A and B. The asymmetrical groups show mean criterion shifts toward the stimulus

TABLE 3

Mean Values for Each Experimental Group*

Group/of	Proportion Reinforcement/Stimulus R1	R2	
A	.60	.40	S1
	.40	.60	S2
	.50	.50	mean
B	.75	.25	S1
	.25	.75	S2
	.50	.50	mean
C	1.0	.00	S1
	.00	1.0	S2
	.50	.50	mean
D	.60	.40	S1
	.25	.75	S2
	.425	.575	mean
E	.75	.25	S1
	.00	1.0	S2
	.375	.625	mean
F	.60	.40	S1
	.00	1.0	S2
	.30	.70	mean

*Counterbalancing by stimulus in all groups shifts the greater mean to the R1 key for half of the subjects in the asymmetrical groups

assigned the greater π . An analysis of variance showed significant differences between the likelihood ratios of subjects with the greater assigned to the dim stimulus and subjects assigned the greater π to the bright stimulus, $F(1,24) = 11.39$, $p < .001$ (Table F, appendix).

Thus, the signal detection concept of likelihood ratio is consistent with the empirical bias measures and further supports the controlling influence of reinforcement on response bias.

Asymptotic P-difference

Response biases for some subjects were so marked that a "reverse" matching proportion was obtained. For example, subject A00 produced a P1 level of .40 for $\pi 1 = .60$. Such extreme response biases are also shown by subjects A02, A64, A13, B04, D52, and D03. The variability of the pairs of response curves for all subjects was greatly augmented by response biases. As a result, P values for individual subjects ranged from extreme undershooting to extreme overshooting of π assignments. To clarify asymptotic responding and assess discrimination accuracy, a measure that removes key bias variability is desirable. A convenient measure that removes the effects of key bias will be called P-difference. P-difference specifies the distance between the R2/S2 curve and the R2/S1 for each subject (figures 1-6), and is quantified by the expression P2 - (1 - P1). To compare P-difference with assignments, the quantity $\pi 2 - (1 - \pi 2)$ will be used and termed π-difference.

Data reduction by difference analysis, from P values to P-difference for subjects in groups A, B, and D resulted in a significant decrease in the variance of the response measure (Bartlett's test: $+\!+(1) = 30.32$, $p < .001$). As stated in the Method section, the experiment contained two

TABLE 4

Likelihood Ratios and Their Normalized Transformations for All Groups

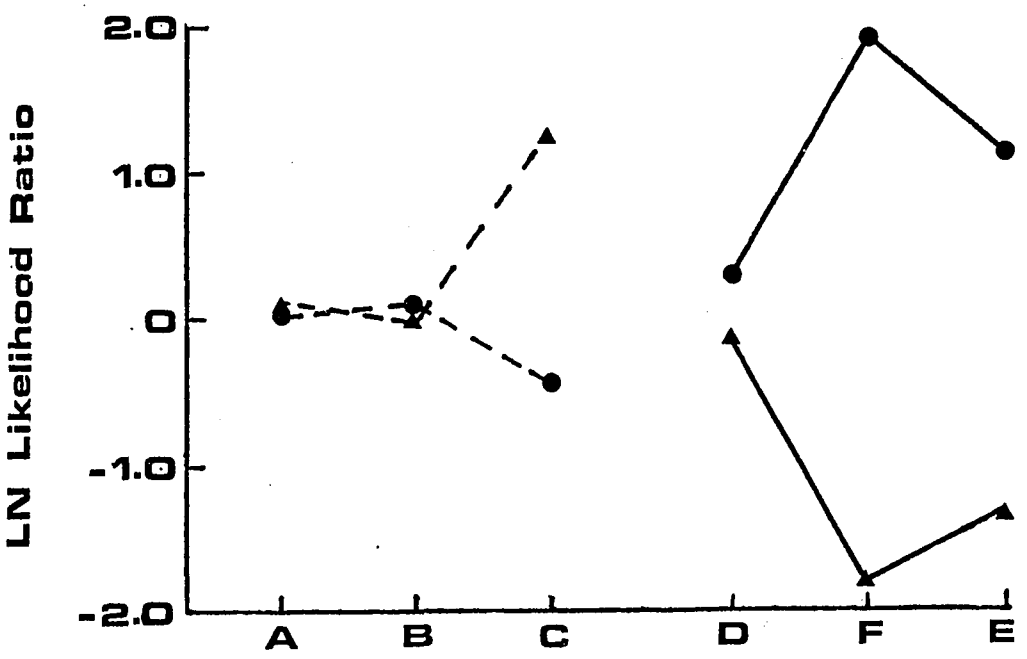
Group	Bird	Likelihood Ratio	In Likelihood Ratio	Stimulus with Greater
A	A50	1.020	0.020	
	A51	1.023	0.023	
	A13	1.379	0.321	
	A00	1.246	0.220	
	A02	1.035	0.034	
	A64	1.036	0.035	
	Mean		0.109	
B	B54	1.200	0.182	
	B55	0.615	-0.486	
	B15	1.504	0.408	
	B04	1.720	0.542	
	B06	1.510	0.408	
	B65	0.828	-0.189	
	Mean		0.144	
C	C58	0.015	-4.189	
	C59	2.580	0.948	
	C29	0.545	-0.607	
	C08	1.042	0.041	
	C10	0.150	-1.900	
	C79	1.266	0.236	
	Mean		-0.912	
D	D52	0.699	-0.358	S2
	D53	0.756	-0.280	
	D12	0.930	-0.073	
	Mean		-0.237	
	D01	1.368	0.326	S1
	D03	1.496	0.403	
	D62	1.130	0.122	
	Mean		0.284	
E	E56	0.186	-1.682	S2
	E57	0.243	-1.415	
	E14	0.253	-1.373	
	Mean		-1.490	
	E05	1.339	0.292	S1
	E07	9.305	2.231	
	E63	2.446	0.894	
	Mean		1.139	

(continued)

TABLE 4 (continued)

Group	Bird	Likelihood Ratio	In Likelihood Ratio	Stimulus with Greater
F	F09	0.232	-1.461	S2
	F11	0.130	-2.041	
	F78	0.171	-1.766	
	Mean		-1.756	
	F60	3.258	1.181	S1
	F61	14.750	2.691	
	F28	4.947	1.599	
	Mean		1.824	

Figure 8. Natural log of the criterion likelihood ratio for each π group during probabilistic discrimination training.



MEAN LN LIKELIHOOD RATIO FOR SUBJECTS ASSIGNED THE GREATER π VALUE IN THE PRESENCE OF DIM STIMULUS

MEAN LN LIKELIHOOD RATIO FOR SUBJECTS ASSIGNED THE GREATER π VALUE IN THE PRESENCE OF BRIGHT STIMULUS

MEAN LIKELIHOOD RATIO FOR SUBJECTS IN SYMMETRICAL π GROUPS, π I = π 2

replications with three subjects per group in each replication. An analysis of variance for replication effects on asymptotic P-difference revealed no statistically significant difference, $F(1,24) = 1.25$ (summarized in Table G, appendix).

An analysis of variance showed that the mean P-difference for each group systemically increased as the π -difference increased, $F(5,30) = 68.94$, $p < .001$ (summarized in Table H, appendix). All multiple comparisons were significant at the .05 level except A vs. D and F vs. E. Figure 9 graphically represents the group mean P-difference as a function of π -difference. Trend analysis using orthogonal polynomials revealed that 99.3% of the variance of the function was removed by the linear component.

If we call the quantity π 2 - (1 - π 1) matching, then P-differences significantly smaller than π -difference can be termed undershooting and P-differences significantly larger than π -difference can be called overshooting. Visual inspection of Figure 9 suggests that the mean P-difference for each group undershoots the corresponding π -difference. Statistical comparisons using chi square tests showed that 23 birds undershot the corresponding π -difference, 12 birds matched and 1 bird overshot its assigned π -difference.

Generalization

Empirical results. Figures 10-15 show the relation between the proportion of responses made to the majority reinforcement key for the high intensity stimuli and stimulus intensity for each bird during generalization. The proportions for each point represent 150 responses to that stimulus averaged over 15 testing sessions.

Figure 9. Group mean P-difference as a function of π -difference for probabilistic discrimination and generalization in the π groups.

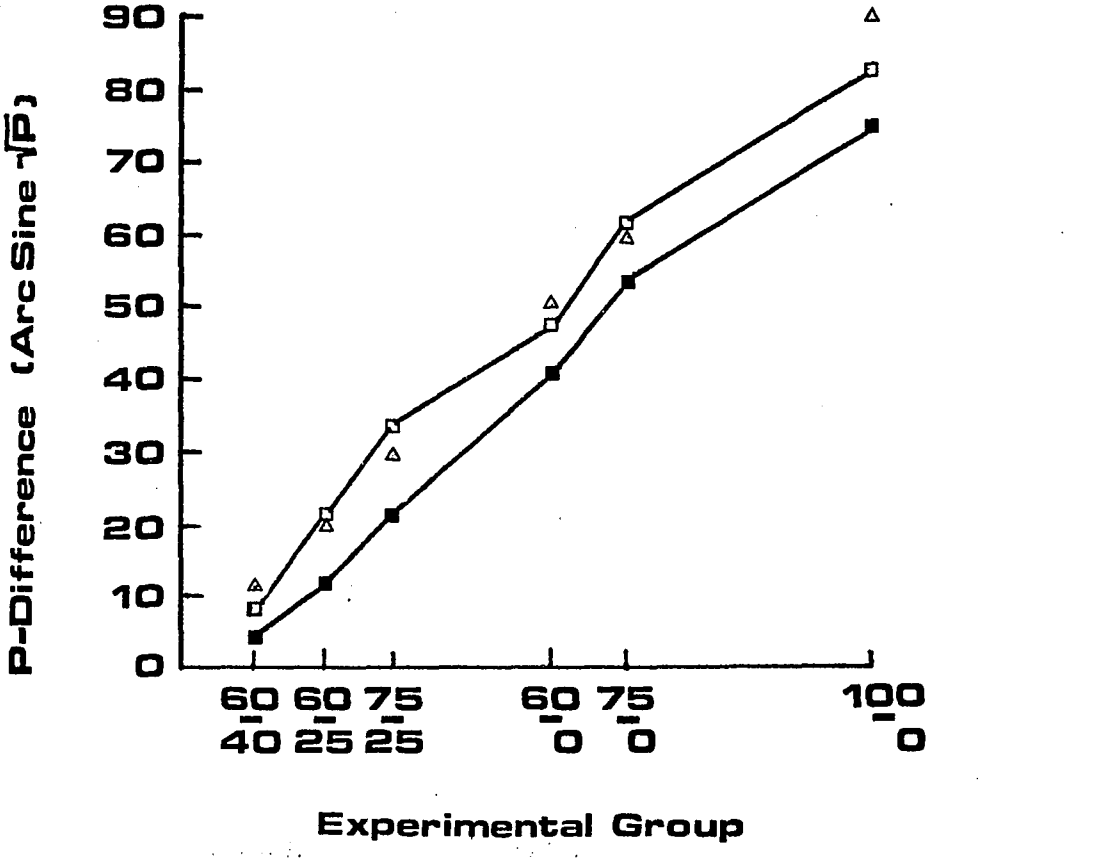
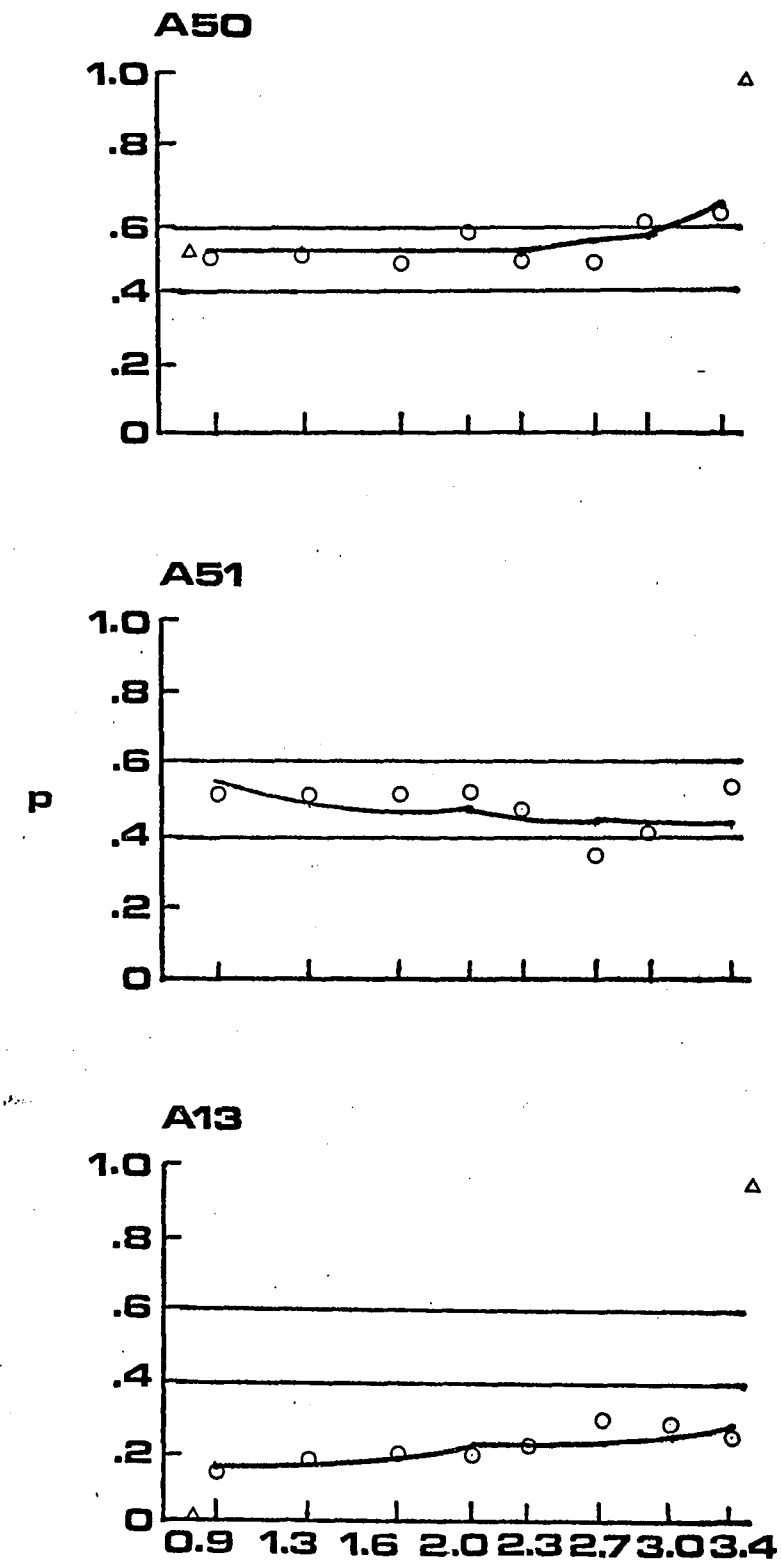

P-Difference (Arc Sine √P)
90
80
70
60
50
40
30
20
10
0
60 60 75 60 75 100
40 25 25 0 0 0
Experimental Group
π-Difference
P-Difference (Training)
P-Difference (Generalization)

Figure 10. Generalization: p(R2) as a function of light intensity for subjects in Group A(60:40/40:60).


A50
1.0
.8
.6
.4
.2
0
A51
p
1.0
.8
.6
.4
.2
0
A13
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

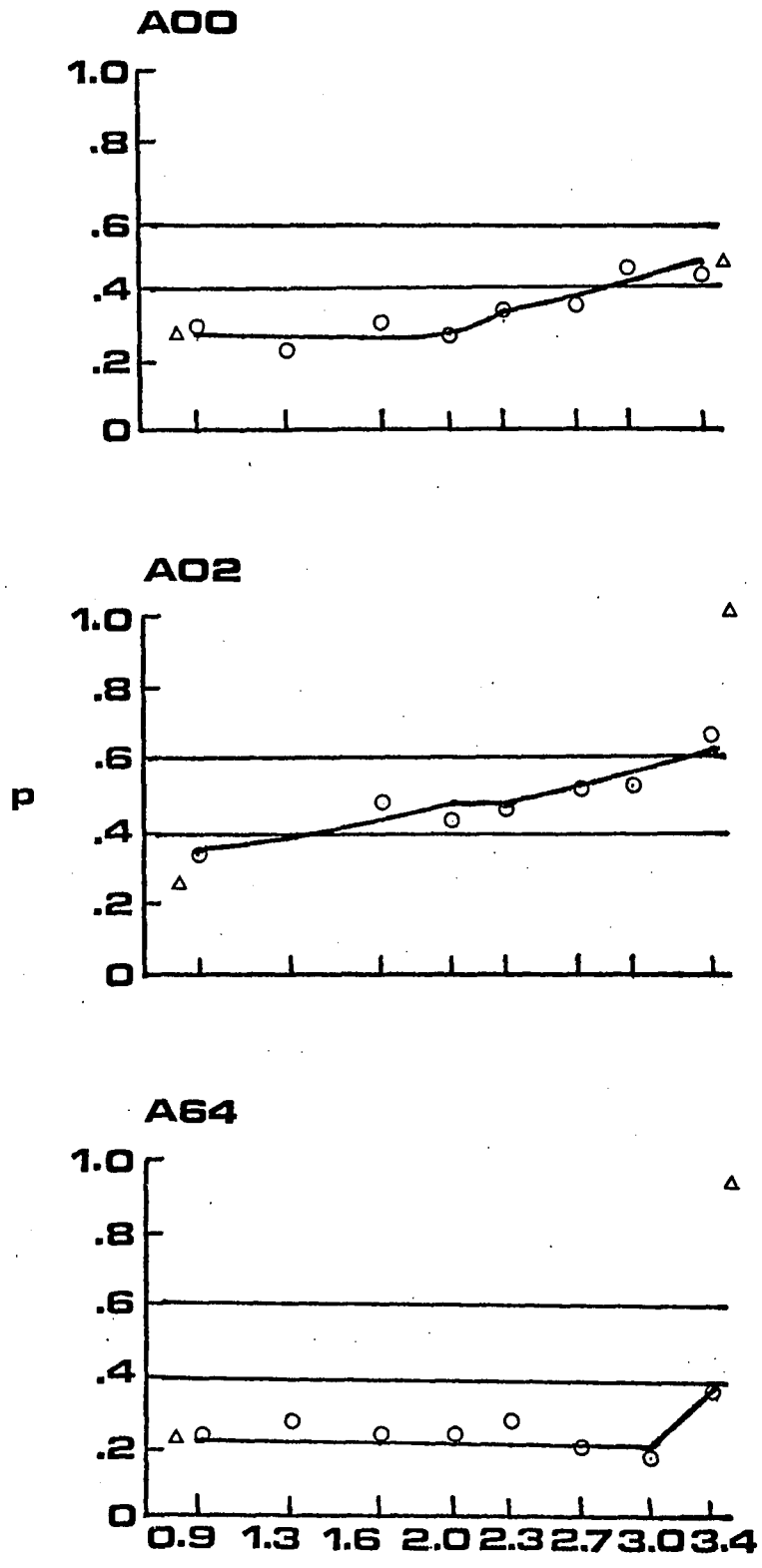
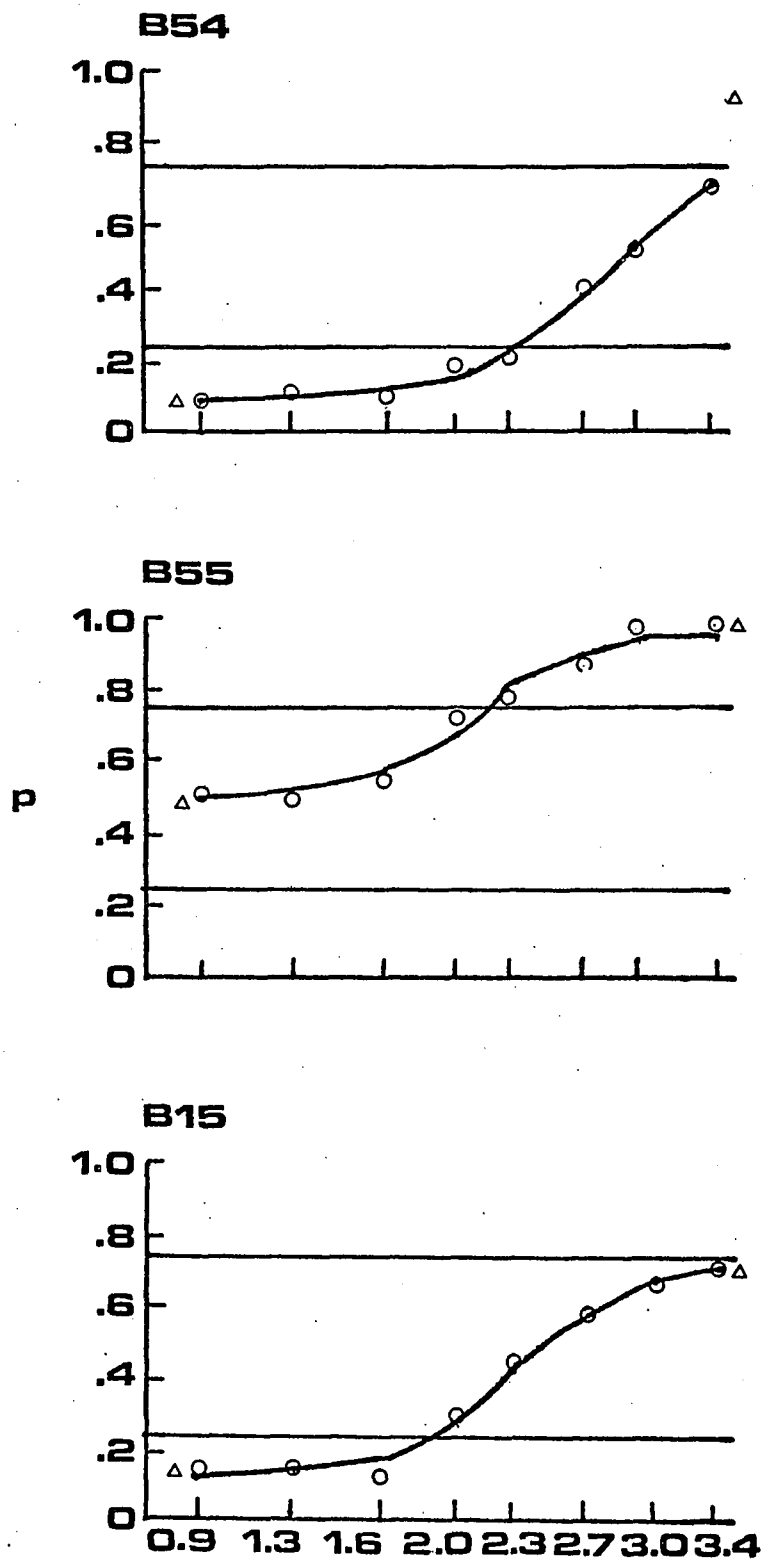

A00
1.0
.8
.6
.4
.2
0
A02
p
1.0
.8
.6
.4
.2
0
A64
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

Figure 11. Generalization: p(R2) as a function of light intensity for subjects in Group B(75:25/25:75).


B54
1.0
.8
.6
.4
.2
0
B55
p
1.0
.8
.6
.4
.2
0
B15
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

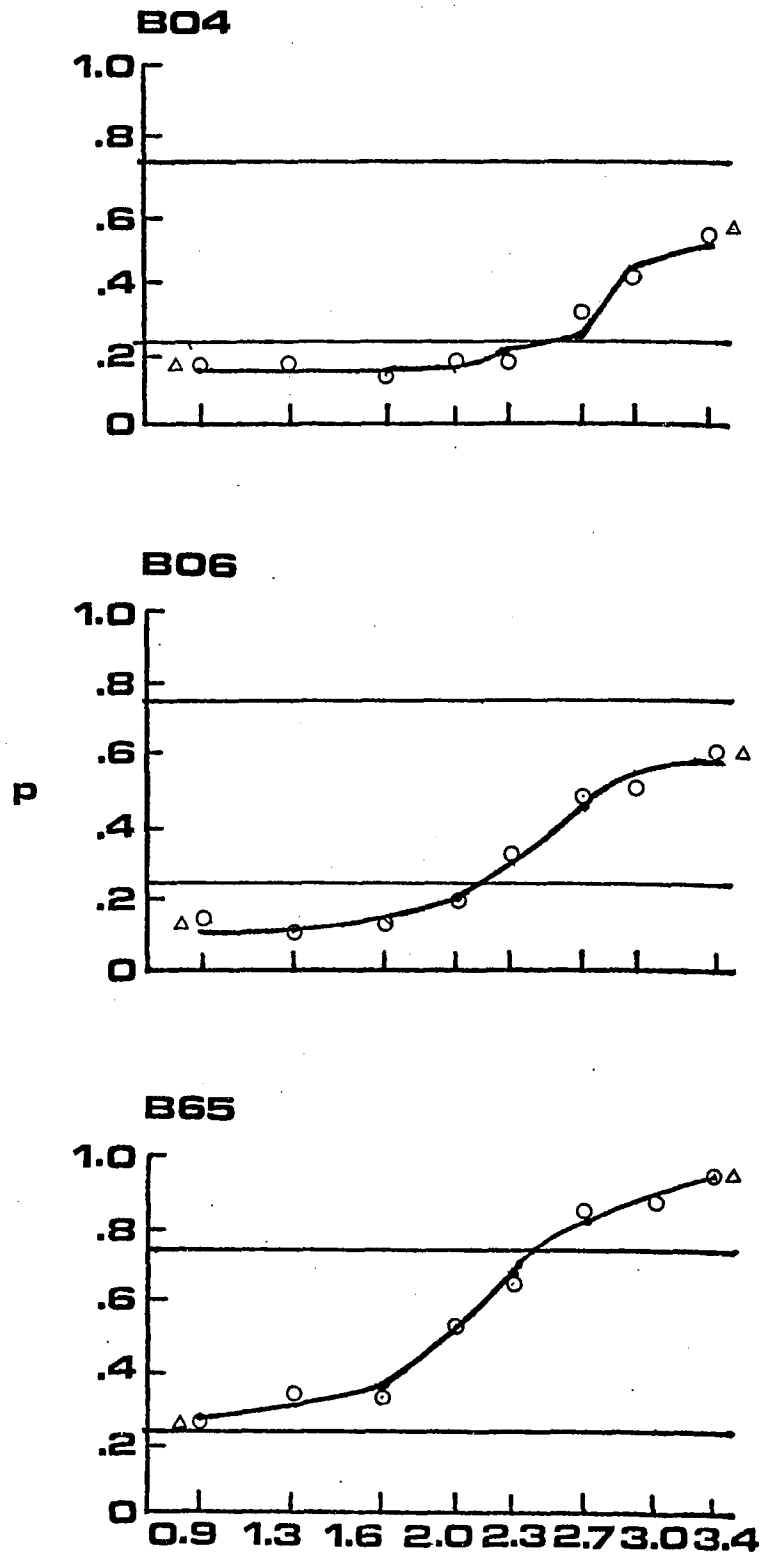
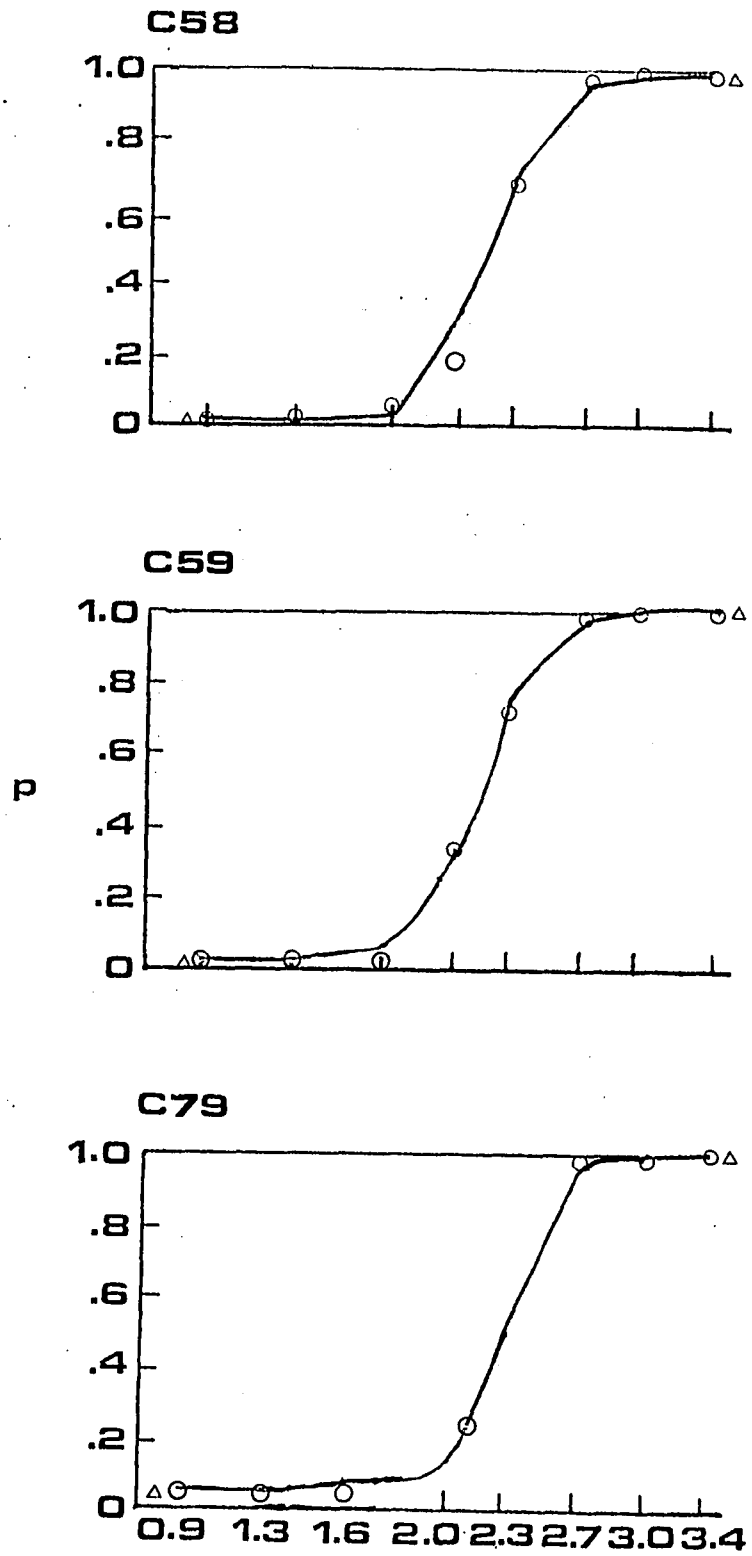

B04
1.0
.8
.6
.4
.2
0
B06
p
1.0
.8
.6
.4
.2
0
B65
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

Figure 12. Generalization: p(R2) as a function of light intensity for subjects in Group C(100:0/0:100).


C58
1.0
.8
.6
.4
.2
0
C59
p
1.0
.8
.6
.4
.2
0
C79
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

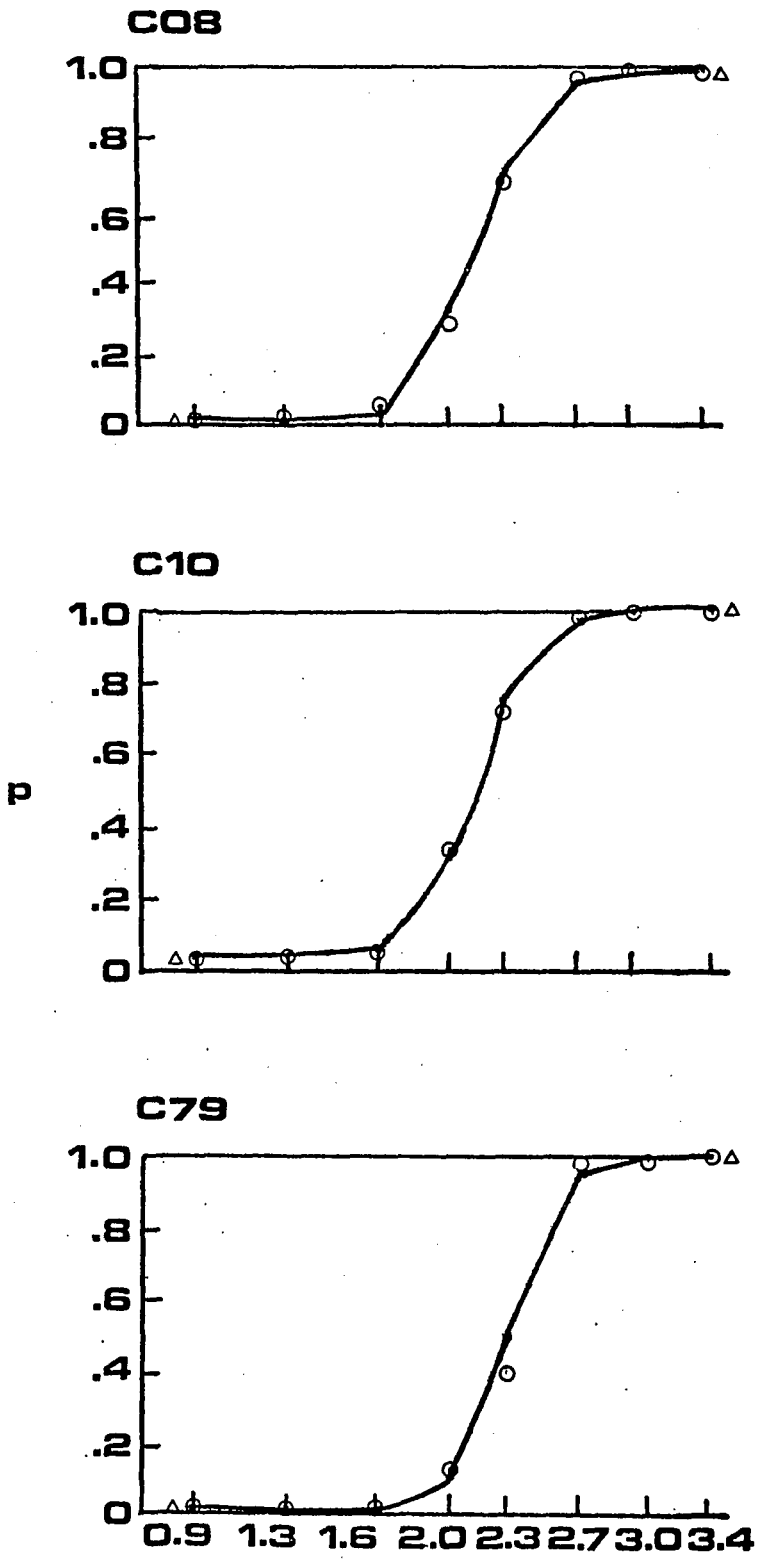
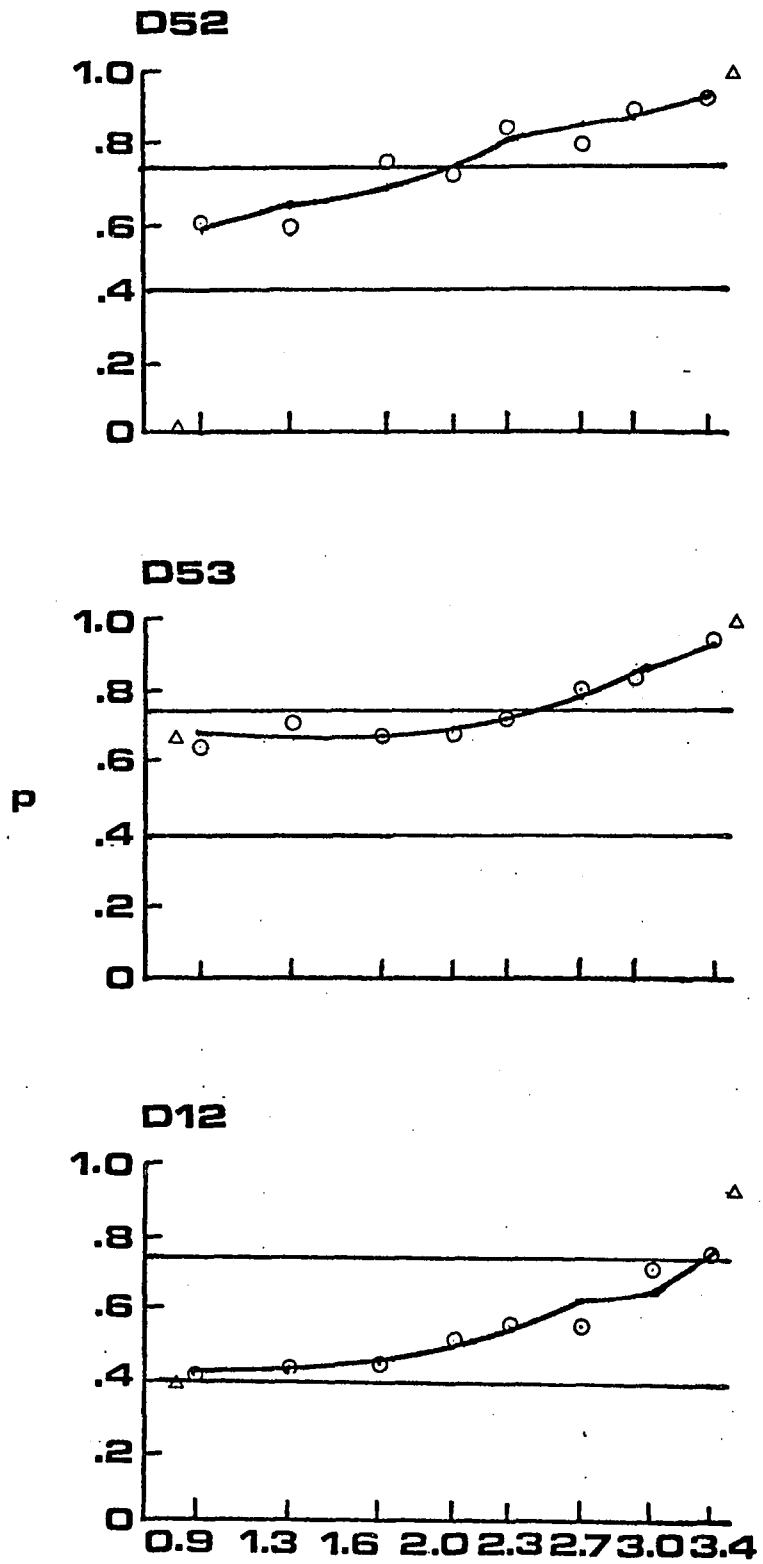

C08
1.0
.8
.6
.4
.2
0
C10
p
1.0
.8
.6
.4
.2
0
C79
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

Figure 13. Generalization: p(R2) as a function of light intensity for subjects in Group D(75:25/40:60).


D52
1.0
.8
.6
.4
.2
0
D53
P
1.0
.8
.6
.4
.2
0
D12
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

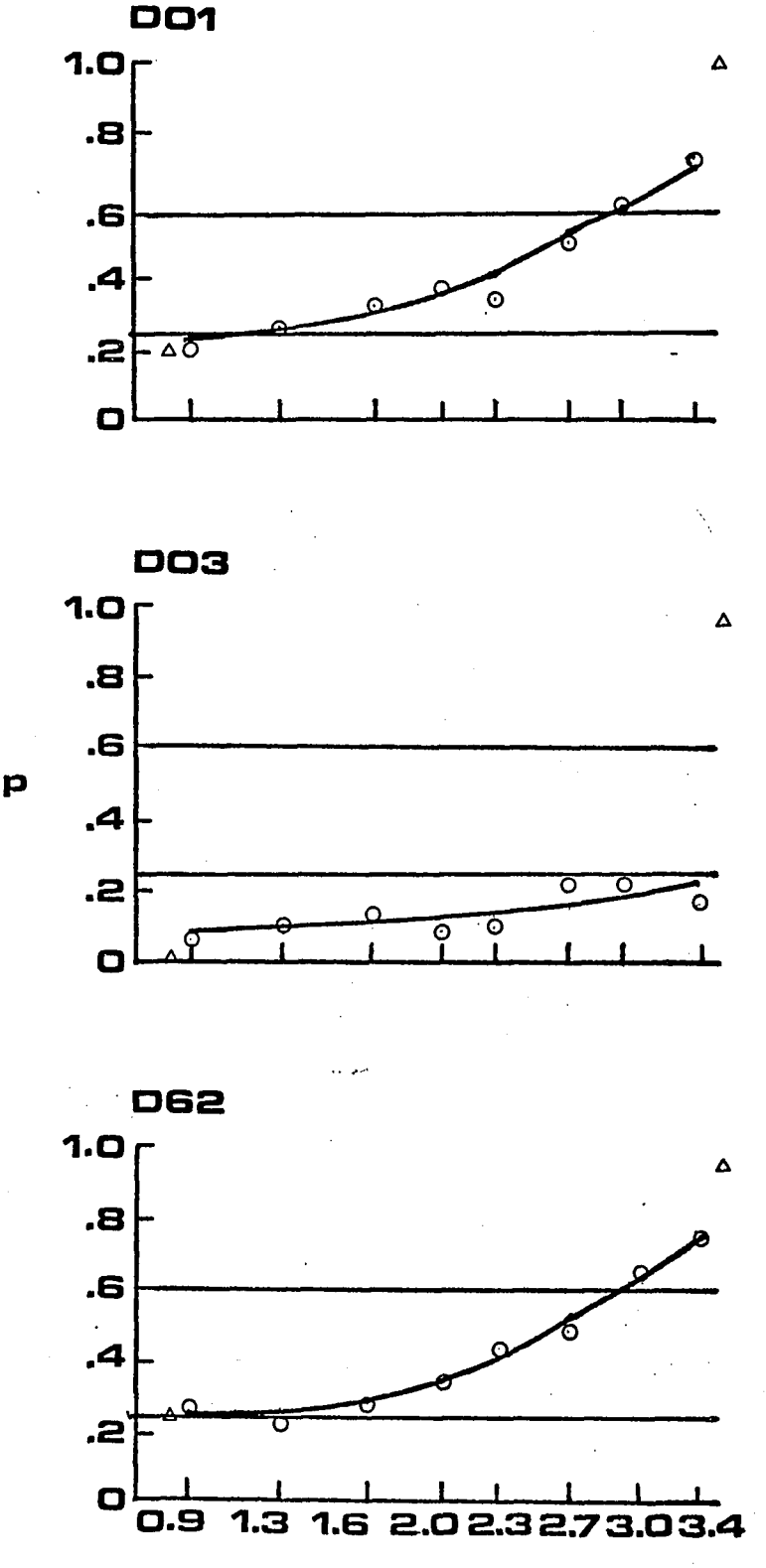
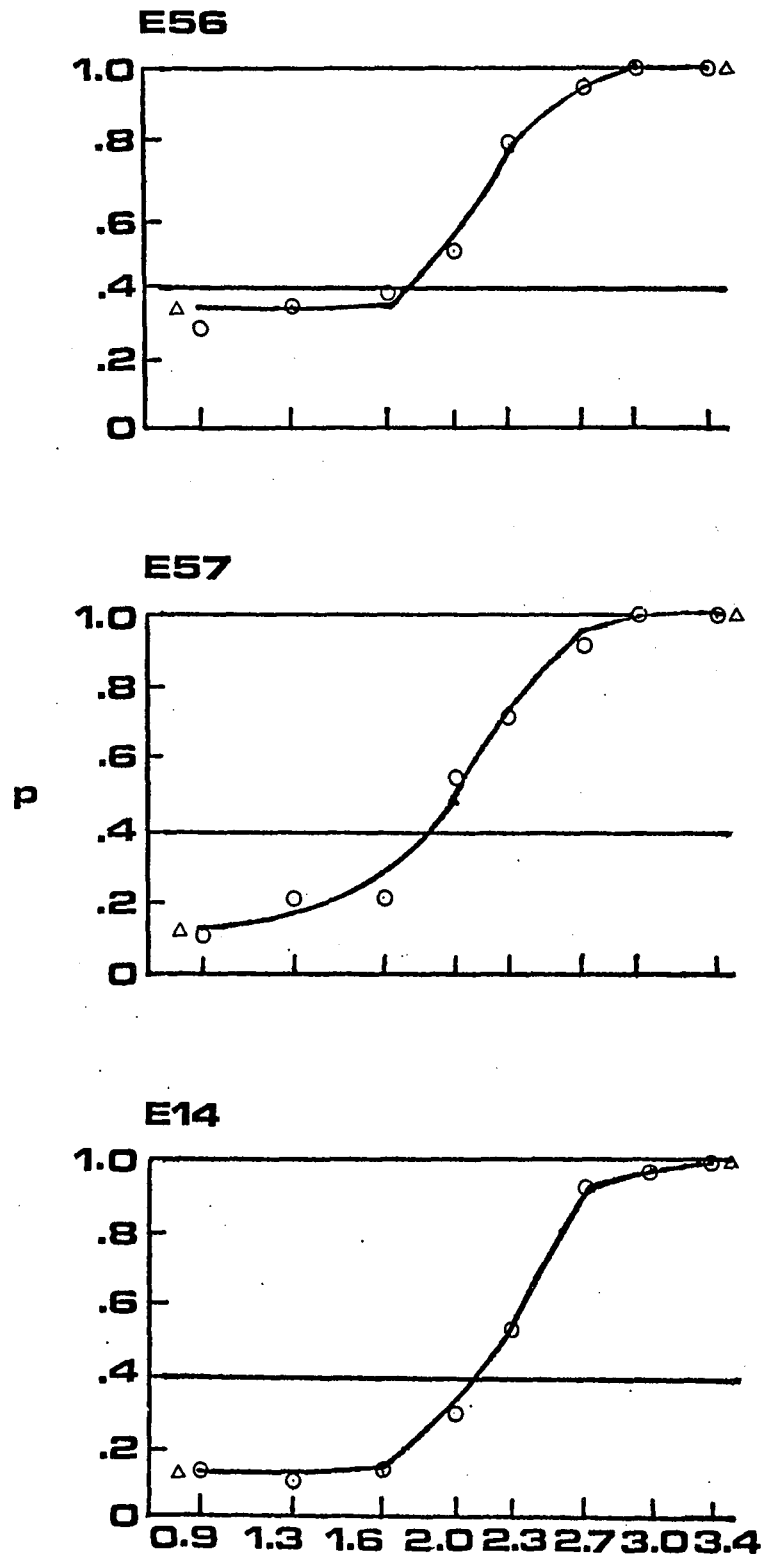

D01
1.0
.8
.6
.4
.2
0
D03
1.0
.8
.6
.4
.2
0
p
D62
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

Figure 14. Generalization: p(R2) as a function of light intensity for subjects in Group E(75:25/0:100).


E56
1.0
.8
.6
.4
.2
0
E57
p
1.0
.8
.6
.4
.2
0
E14
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

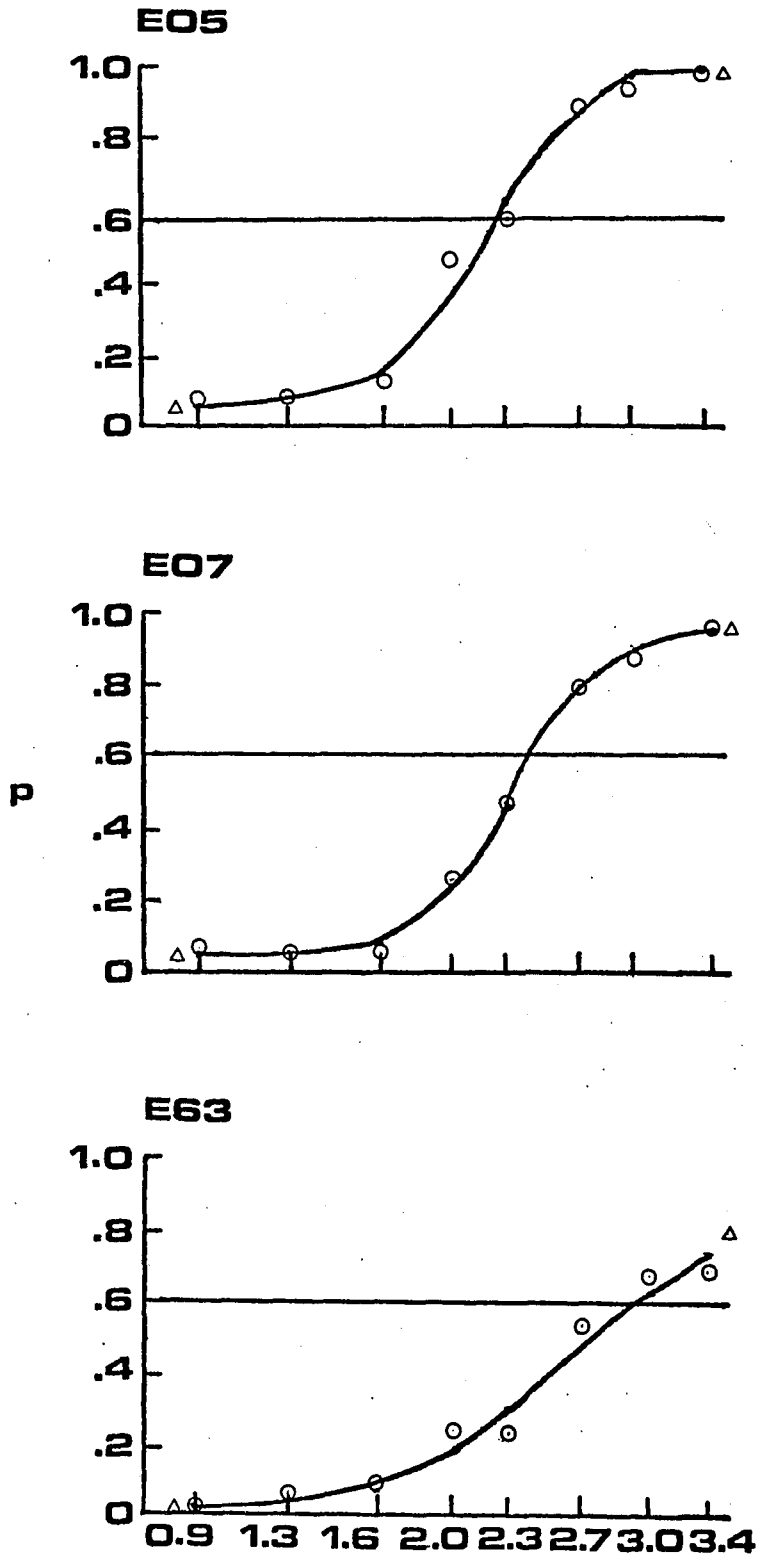
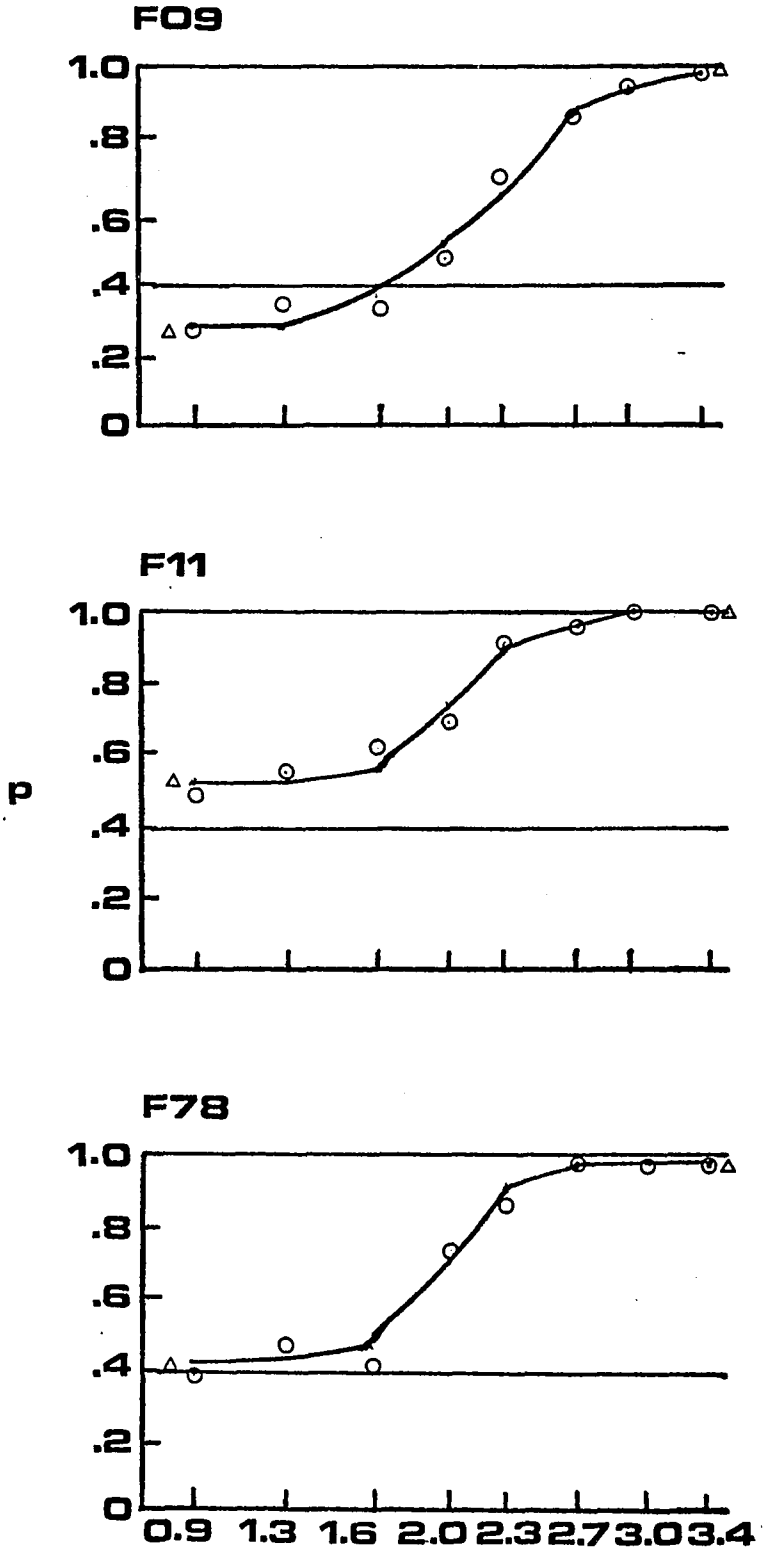
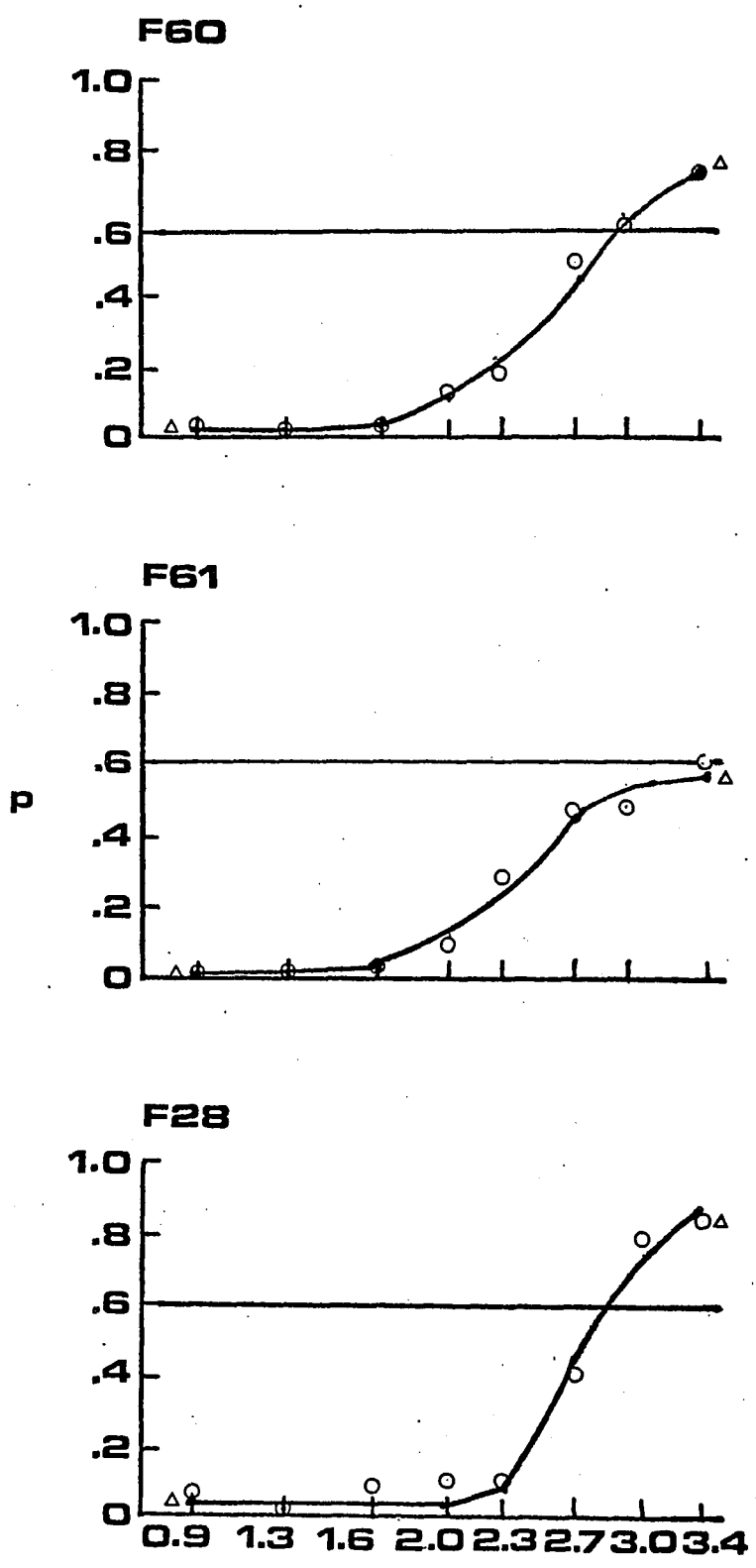

E05
1.0
.8
.6
.4
.2
0
E07
p
1.0
.8
.6
.4
.2
0
E63
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

Figure 15. Generalization: p(R2) as a function of light intensity for subjects in Group F(60:40/0:100).


F09
1.0
.8
.6
.4
.2
0
F11
p
1.0
.8
.6
.4
.2
0
F78
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)


F60
1.0
.8
.6
.4
.2
0
F61
p
1.0
.8
.6
.4
.2
0
F28
1.0
.8
.6
.4
.2
0
0.9 1.3 1.6 2.0 2.3 2.7 3.0 3.4
Log Luminance (ft.L.)

The quantitative characteristics of the curves can be summarized with four properties: a) the vertical range of the function; b) the slopes of the middle segments; c) the location of the function along the x axis, and d) the location of the curve along the y axis.

The generalization curves obtained under the nonprobabilistic reinforcement schedule (Group C, figure 12) are in the form of normal ogives with steep slopes, comparable to gradients obtained previously under similar conditions (Heinemann, Avin, Sullivan & Chase, 1969; Heinemann & Chase, 1970a; Heinemann & Chase, 1970b; Chase & Heinemann, 1972). The gradients for the probabilistic choice groups (A, B, D, E, & F) are characterized by flatter slopes and response proportions to the extreme stimuli that depart from 0 and 1.0. The flatter slopes and the reduced (from 0 and 1.0) asymptotes appear to be related to π -difference magnitude. Specifically, as π -difference increases across groups, the slopes of the middle segments of the gradients appear to steepen, and the response proportions in the presence of the extreme stimuli approach 0 and 1.0. The location of the functions along the y axis is quite variable in the symmetrical conditions, with some curves displaced toward p(R2) = 1.0 and others displaced toward p(R2) = 0. The curves in the asymmetrical π groups show displacement toward the majority response key with the greater π assignment.

An analysis of variance revealed that the P-differences for the outer stimuli, i.e. P8 - (1 - P1), showed no reliable change between the replications of the experiment, $F(1,24) < 1$ (Table 1, appendix). Figure 9 displays the group mean P-differences for generalization and training. The group mean P-difference in generalization, P8 - (1 - P1), systematically increased as π -differences increased, $F(5,30) = 118.72$, $p < .001$ (analysis of variance summarized in Table J, appendix). All multiple comparisons were significant

at the .05 level. Trend analysis using orthogonal polyomials showed that 98.2% of the variance for the group mean P-difference function was removed by the linear component.

An analysis of variance showed that generalization P-differences, P8 - (1 - P1), reliably exceeded asymptotic P-differences obtained during discrimination training, $F(1,24) = 69.90$, $p < .001$ (Table k, appendix). All multiple comparisons were significant beyond the .05 level except training vs. generalization P-differences for Group A. On the other hand, the training stimulus P-differences obtained in generalization, P6 - (1 - P3), were reliably smaller than the asymptotic P-differences attained during discrimination training, $F(1,24) = 12.79$, $p < .01$ (Table L, appendix). All multiple comparisons were nonsignificant at the .05 level except for training vs. generalization P-differences in Groups E & F.

P values for the extreme stimuli in generalization, i.e. P8 & P1, were extremely variable within groups. Data reduction by difference analysis from P value to P-difference performed on all groups resulted in a significant decrease in the variance of the response measure ($H(1) = 4.64$, $p < .05$, Bartlett's test). If we call the quantity $\pi 8 - (1 - \pi 1)$ matching, then P-differences significantly smaller than π-difference can be termed undershooting and P-differences significantly larger than π-difference can be called overshooting. Visual inspection of figure 9 suggests that the mean P-difference matches the π-difference. Statistical comparisons using chi square tests showed that 7 birds undershot the corresponding π-difference, 23 birds matched the π-difference, and 5 birds overshot the π-difference.

P values. As in training (p.) P values were compared to assigned values for individual subjects using chi square tests. The definitions of

matching, undershooting, and overshooting of π levels are given on page 6. Specifically, P8 vs. π 8 and P1 vs. π 1 comparisons were made. The results of the comparisons (Table 5) showed that 1 bird undershot π on both stimuli, 12 birds undershot on one stimulus and matched on the other stimulus, 13 subjects undershot on one stimulus and overshot the π level on the other stimulus, 7 birds matched on both stimuli, and 3 birds matched on one stimulus, while overshooting in the presence of the other stimulus.

As in training (p.), cross-group comparisons showed that the P level attained for a constant π assignment in the presence of one stimulus group (brighter or dimmer) did not vary as a function of a changing π level for the other stimulus group. For constant π = .60, $\underline{F}(2,15) < 1$; for constant π = .75, $\underline{F}(2,15) = 1.19$; and for constant π = 1.0, $\underline{F}(2,15) = 3.40$ (analyses of variance summarized in Table M, appendix). Finally, generalization P levels appear not to be effected by the stimulus group presented, i.e. brighter or dimmer. Specifically, the bright stimulus group (S5-S8) did not yield a mean response proportion different from that produced in the presence of the dim stimulus group (S1-S4), $\underline{F}(1,18) < 1$ (analysis of variance in Table N, appendix). This finding parallels an analysis of the training data which showed that the discriminative stimuli did not differentially effect asymptotic P values (p.).

Slopes. The slopes of the approximately linear middle segments of the generalization functions were quantified by the method of least squares applied to the empirical points P3 through P6. In other words, the slope of the straight line that made the sum of squared deviations a minimum about

TABLE 5

Asymptotic P Values for the Extreme Stimuli in Generalization and Their Relation to π Assignments

Group	2	P2	1	P1	Subject
A	.60	.62**	.40	.51**	A50
		.53		.53	A51
		.25*		.15***	A13
		.43*		.30**	A00
		.64**		.34**	A02
		.38*		.25***	A64
D	.75	.91***	.40	.61*	D52
		.93***		.63*	D53
		.76**		.41**	D12
	.60	.72**	.25	.21**	D01
		.18*		.06***	D03
		.75***		.27**	D62
B	.75	.69**	.25	.11***	B54
		.97***		.51*	B55
		.72**		.17**	B15
		.53		.18**	B04
		.60*		.15**	B06
		.95***		.27**	B65
F	.60	.73***	.00	.03*	F60
		.60**		.01*	F61
		.85***		.05*	F28

(continued)

TABLE 5 (continued)

Group	2	P2	1	P1	Subject
F	1.0	.98*	.40	.27***	F09
		1.0**		.49**	F11
		.97*		.39**	F78
E	1.0	1.0**	.25	.29**	E56
		.99*		.11***	E57
		.99*		.13***	E14
	.75	.97***	.00	.07*	E05
		.96***		.06*	E07
		.69**		.01*	E63
C	1.0	1.0**	.00	.01*	C58
		.99*		.01*	C59
		1.0**		.04*	C29
		.99*		.00**	C08
		1.0**		.03*	C10
		1.0**		.03*	C79

When $\pi < .50$, P $< \pi$ in the case of overshooting, and P $> \pi$ for the undershooting instance

++ α level adjusted for experimentwise error rate: for =.05 and 72 chi square tests, $1 - (.95)^{72} = .0007$ (Winer, 1971; p.)

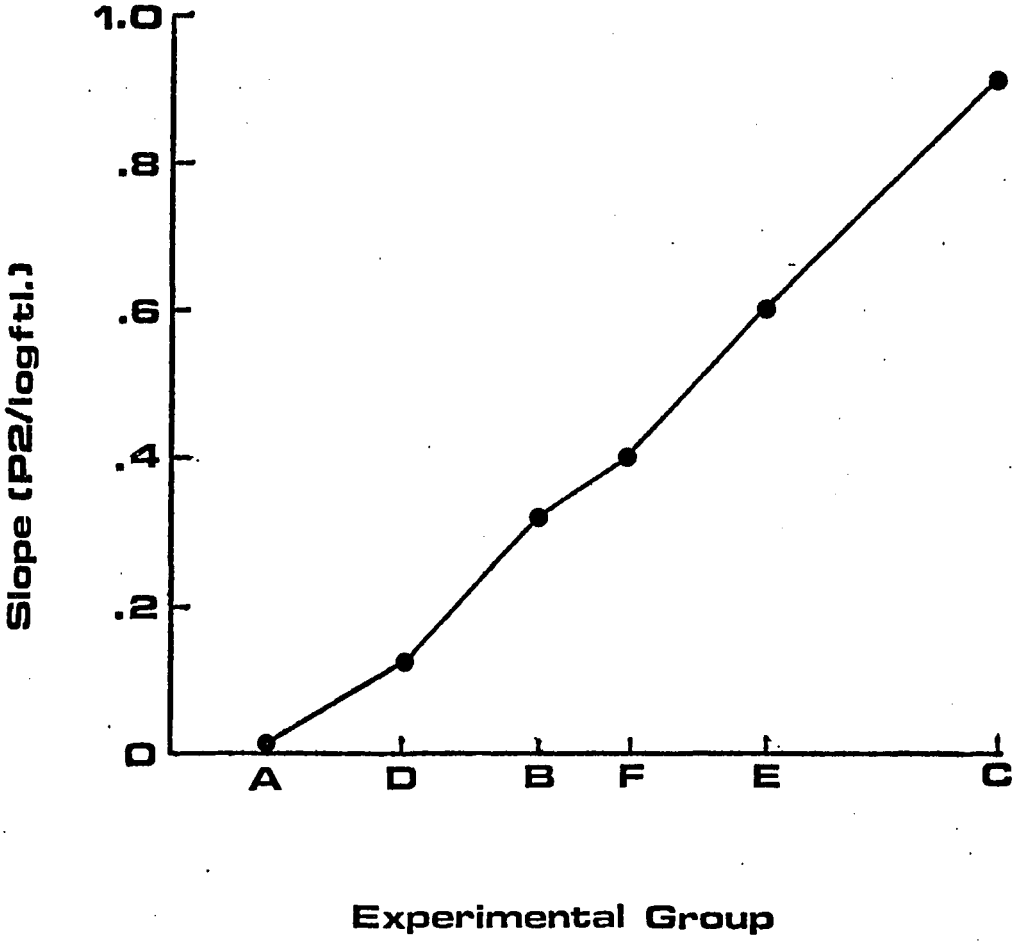
*P value undershoots π assignments; significant at the .05 level (adjusted)

**P value matches π assignment within the limits of sampling error

***P value overshoots π assignment; significant at the .05 level (adjusted)

+ Subject did not exhibit reliable discrimination

Figure 16. Group mean slopes of the middle segments of the generalization gradients for each π group.


1.0
.8
.6
.4
.2
0
Slope (P2/log ftl.)
A
D
B
F
E
C
Experimental Group

the empirical proportions P3, P4, P5 & P6 was used to compare slope differences across groups. Steeper slopes indicate increased discrimination accuracy. A Kruskal-Wallis one-way analysis of variance on the effect of π-difference on slopes showed a statistically significant difference, $H(5) = 32.04$, $p < .001$. Figure 16 displays the group mean slope as a function of π group. A reliable monotonic trend was found, $z = 7.12$, $p < .001$.

Response bias. Response bias in generalization was quantitatively given by the expression $[P8 - (1 - P1)]/2$. Descriptively, the mean of the response proportions in the presence of the extreme stimuli, S8 and S1, served as the empirical specification of the location of the generalization function along the y axis. A value of $p(R2) = .50$ indicates symmetrical placement of the curve with respect to the y axis, while significant departures from .50 indicates an asymmetry that reflects response bias. This measure corresponds to the method of response bias determination used in training (p.23). During discrimination training, however, stimulus effects (x axis) could not be definitively separated from reinforcement effects (y axis) due to the constraint of response proportions based on only two stimuli. The analysis of asymptotic P levels during training strongly suggested that reinforcement assignment, not stimulus intensity, controlled the placement of the empirical points. The separation of stimulus and reinforcement effects made possible with the generalization gradient offers a more precise delineation of these controlling variables.

As in training, the generalization functions were displaced in the direction of the majority reinforcement key assigned the greater π.

The results of an analysis of variance and subsequent multiple comparisons showed significant differences between response biases of birds assigned the greater π to the brightest stimulus (S8), and response biases of birds assigned the greater π in the presence of the dimmest stimulus (S1), $F(1,24) = 15.20$, $p < .001$ (Table O, appendix). As in training, the empirical response biases were shown not to reliably differ from the expected values (t tests summarized in Table P, appendix). Table 3 shows the derivation of expected response bias values from π assignments. The controlling effect of reinforcement on the location of the generalization function is further supported by these analyses.

Nonreinforcement Groups

In the experimental groups with scheduled unreinforced trials, the addition of scheduled unreinforced trials created unequal numbers of trials across groups. Within groups, unequal numbers of trials were created by the assignment of all scheduled nonreinforced trials to one discriminative stimulus, while the other discriminative stimulus was assigned scheduled choice trials only (rerun procedure). Because of the unequal numbers of trials, all statistical analyses were performed with nonparametric tests. Analyses of the group nonreinforcement data will focus on response latencies and sequential effects, which are presented in the next two sections. Groups with scheduled nonreinforced trials will be referred to as NR groups and groups without scheduled nonreinforced trials will be called probabilistic (or π) groups.

Asymptotic P values for each subject in the NR groups are presented in Table 6. No reliable difference in asymptote P-difference was found across the NR groups (Kruskal-Wallis one-way analysis of variance: H(4) = 8,472,

TABLE 6

Asymptotic P Values for Nonreinforcement Groups and Their Relation to π *

Group	2	P2	(1 - 1)	(1 - P1)	Subject
G (30%)	.60	.65	.25	.57	G66
		.32		.22	G67
		.34		.12	G25
	.75	.73	.40	.57	G16
		.89		.75	G18
		.79		.41	G76
H (50%)	.60	.43	.25	.29	H70
		.39		.12	H71
		.76		.31	H27
		.50		.25	H30
	.75	.73	.40	.68	H20
		.69		.62	H22
		.74		.57	H77
I (70%)	.60	.52	.25	.17	I17
		.77		.22	I19
		.64		.24	I74
	.75	.77	.40	.40	I68
		.84		.36	I69
		.57		.27	I24
J (90%)	.60	.78	.25	.20	J21
		.32		.17	J23
		.19		.09	J75

(continued)

TABLE 6 (continued)

Group	2	P2	(1 - 1)	(1 - P1)	Subject
J (90%)	.75	.78	.40	.43	J72
		.82		.66	J73
		.74		.66	J26

* The percentage of scheduled nonreinforced trials, indicated in parentheses, are assigned to the stimulus with the π value of .75. The total number of scheduled trials, choice trials + scheduled nonreinforced trials, were used to calculate the proportions in the table; therefore, the P2 and (1 - P1) columns are based on unequal numbers of trials.

$p > .05$). In other words, the percentage of scheduled nonreinforced trials, ranging from 0 - 90% across groups, did not affect discrimination accuracy.

Latencies[8]

Response latency is defined as the elapsed time between a center key response (after the onset of a trial) and the subsequent side key response. It will be recalled that after the onset of a trial, a center key response brings about the presence of the discriminative stimulus. The subject then responds to one of the side keys. Latencies were recorded on alternate days for all subjects throughout training and generalization testing. The following analyses will use latencies for all asymptotic responses (days 30-51) recorded during training and all latencies recorded during generalization. Ten sessions of training data and seven sessions of generalization data were available for analysis.

The mean latencies for each subject and the group mean latencies during training are presented in Tables 7, 8, 9, & 10. An analysis of variance performed on the latency data revealed no reliable latency differences across groups in the $\overline{\Pi}$ conditions, $F(5,30) = 1.738$, $p > .05$ (Table Q, appendix). On the other hand, a reliable latency difference across groups in the NR conditions was found (Kruskal-Wallis one-way analysis of variance: $H(4) = 11.822$, $p < .05$). Inspection of the group mean latencies for the NR groups (Figure 18) suggests the presence of a monotonically nondecreasing trend. In the $\overline{\Pi}$ groups, response latencies were not significantly

8. In the NR groups, the addition of scheduled nonreinforced trials created unequal numbers of scheduled trials assigned to each discriminative stimulus; Therefore, all statistical analyses on NR groups were performed with nonparametric tests. Also, nonparametric tests were used on $\overline{\Pi}$ groups when comparing response latencies based on unequal numbers of trials.

TABLE 7

Individual Mean and Group Mean Response Latencies (msec) for the R2 Key in Probabilistic (π) Groups*

Group	2	R2S2	(1 - π 1)	R2S1	Subject
A	.60	1406	.40	1352	A50
		1593		1546	A51
		2081		2301	A13
		1291		1360	A00
		1071		1152	A02
		1006		996	A64
		$\bar{X}$ = 1375		$\bar{X}$= 1400	
D	.75	1662	.40	662	D52
		560		598	D53
		978		819	D12
	.60	1313	.25	1377	D01
		1056		975	D03
		645		1191	D62
		$\bar{X}$ =840		$\bar{X}$ = 881	
B	.75	2083	.25	1728	B54
		1718		1450	B55
		910		1002	B15
		1751		1749	B04
		765		790	B06
		1138		1310	B65
		$\bar{X}$ = 1332		$\bar{X}$ =1473	
F	.60	1655	.00	1518	F60
		811		431	F61
		1075		1035	F28

TABLE 7 (continued)

Group	2	R2S2	(1 - π1)	R2S1	Subject
F	1.0	826	.40	947	F09
		994		925	F11
		779		805	F78
		$\bar{X}$ = 1007		$\bar{X}$ = 895	
E	1.0	802	.25	790	E56
		1297		1598	E57
		729		867	F14
	.75	1052	.00	1097	E05
		1552		1147	E07
		1094		1332	E63
		$\bar{X}$ = 1081		$\bar{X}$ = 1068	
C	1.0	1506	.00	3293	C58
		1101		1461	C59
		1413		1161	C29
		811		1058	C08
		900		596	C10
		664		915	C79
		$\bar{X}$ = 1082		$\bar{X}$ = 1298	

*Group mean latencies were calculated from individual latencies weighted by the number of asymptotic responses per subject.

TABLE 8

Individual Mean and Group Mean Response Latencies(msec) for the R1 Key in Probabilistic (π) Groups*

Group	π_2	R1S1	$(1 - \pi_2)$	R1S2	Subject
A	.60	1255	.40	1169	A50
		1239		1263	A51
		1024		910	A13
		838		933	A00
		1012		983	A02
		1139		1119	A64
		$\bar{X}$ = 1086		$\bar{X}$ = 1048	
D	.60	797	.25	775	D52
		821		834	D53
		888		750	D12
	.75	1114	.40	1207	D01
		886		879	D03
		760		769	D62
		$\bar{X}$ = 820		$\bar{X}$ = 879	
B	.75	1367	.25	1384	B54
		2194		2085	B55
		815		838	B15
		652		677	B04
		805		827	B06
		1518		1416	B65
		$\bar{X}$ = 1219		$\bar{X}$ = 1116	

TABLE 8 (continued)

Group	π_2	R1S1	$(1 - \pi_2)$	R1S2	Subject
F	1.0	935	.40	1048	F60
		751		820	F61
		1035		988	F28
	.60	731	.00	742	F09
		986		943	F11
		612		632	F78
		$\bar{X}$ = 838		$\bar{X}$ = 995	
E	.75	890	.00	891	E56
		1556		1767	E57
		628		663	E14
	1.0	829	.25	1121	E05
		1291		1301	E07
		602		619	E63
		$\bar{X}$ = 1005		$\bar{X}$ = 916	
C	1.0	1274	.00	no trials	C58
		1255		1848	C59
		1166		1678	C29
		895		942	C08
		1511		962	C10
		618		1923	C79
		$\bar{X}$ = 1131		$\bar{X}$ = 1467	

* Group mean latencies were calculated from individual latencies weighted by the number of asymptote responses per subject.

Figure 17. Group mean latencies for probabilistic groups divided into symmetrical and asymmetrical π assignments.

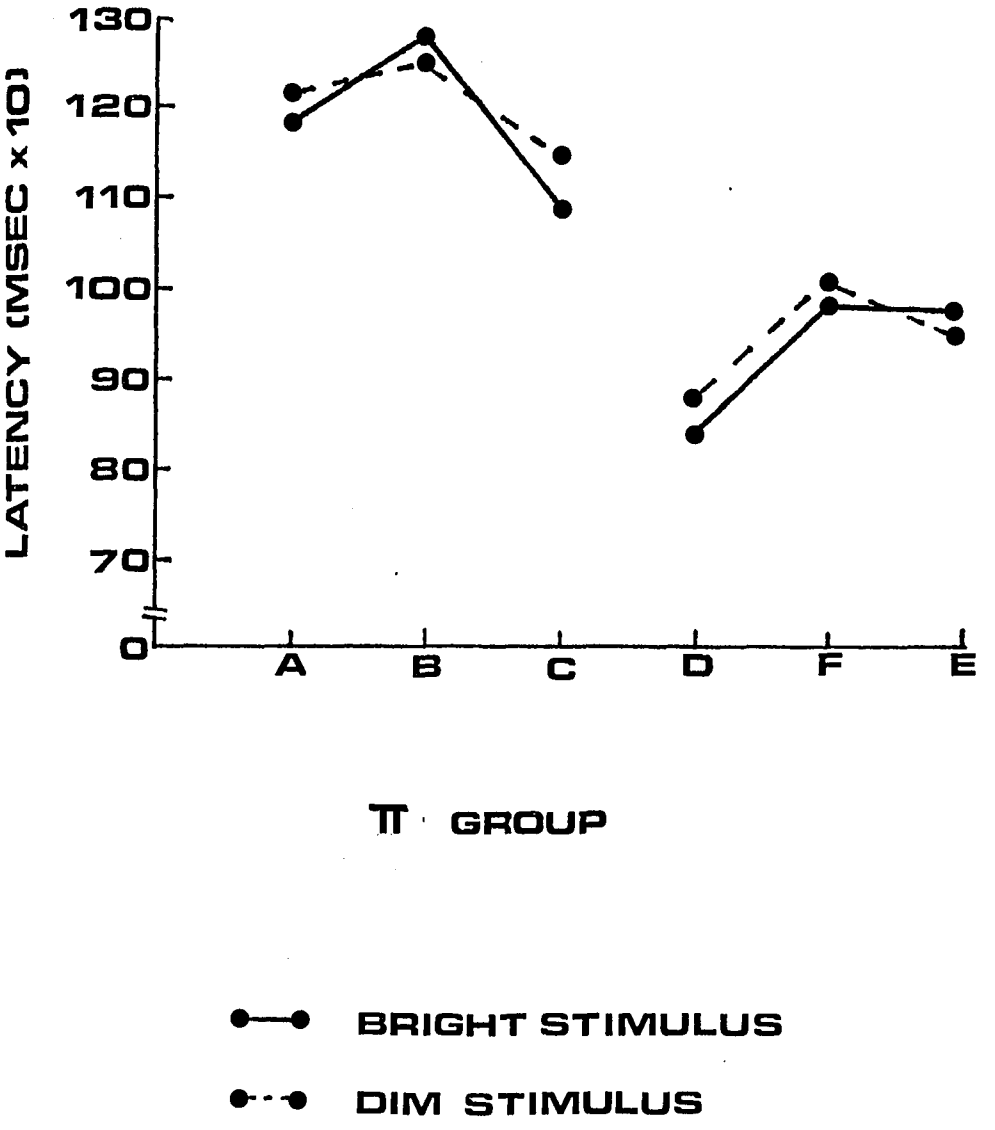

LATENCY (MSEC x 10)
130
120
110
100
90
80
70
0
A
B
C
D
F
E
GROUP
BRIGHT STIMULUS
DIM STIMULUS

Figure 18. The relationship between group median latencies (msec) and percentage nonreinforced trials in nonreinforcement groups.

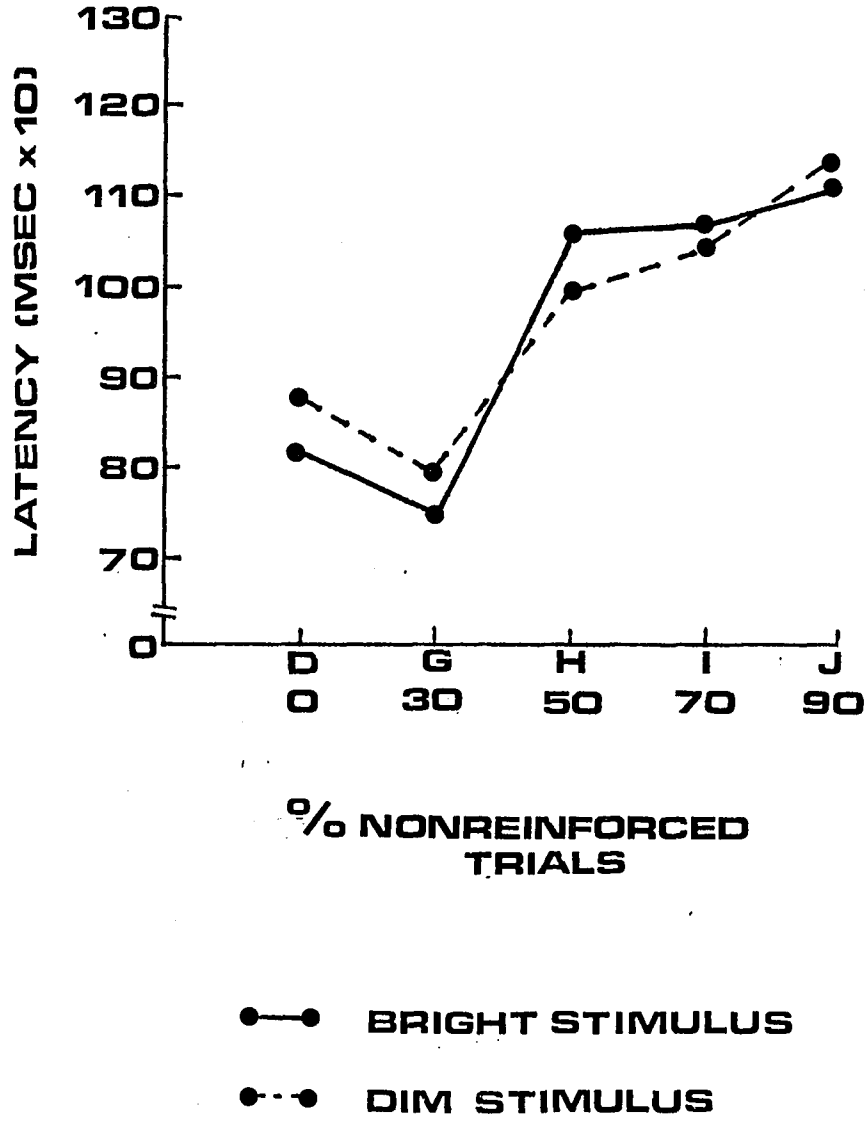

LATENCY (MSEC x 10)
130
120
110
100
90
80
70
0
D
0
G
30
H
50
I
70
J
90
% NONREINFORCED TRIALS
BRIGHT STIMULUS
DIM STIMULUS

TABLE 9

Individual Mean and Group Mean Response Latencies (msec) for the R2 Key in Nonreinforcement Groups*

Group (%NR)	2	R2S2	(1 - π1)	R2S1	Subject
D (0)	.60	1313	.25	1377	D01
		1056		975	D03
		645		1191	D62
	.75	1662	.40	662	D52
		560		598	D53
		978		819	D12
	$\bar{X}$ =	840	$\bar{X}$=	881	
G (30)	.60	449	.25	458	G66
		1082		1121	G67
		1927		2134	G25
	.75	597	.40	660	G16
		678		668	G18
		959		1057	G76
	$\bar{X}$ =	833	$\bar{X}$=	835	
H (50)	.60	1013	.25	1034	H70
		1265		1009	H71
		1195		1390	H27
		1162		1167	H30
	.75	931	.40	1105	H20
		1795		1749	H22
		733		724	H77
	$\bar{X}$ =	1216	$\bar{X}$=	1233	

(continued)

TABLE 9 (continued)

Group (%NR)	2	R2S2	(1 -π1)	R2S1	Subject
I (70)	.60	1306	.25	1531	I17
		1104		1152	I19
		1001		987	I74
	.75	636	.40	793	I68
		1758		2050	I69
		1074		1180	I24
	$\bar{X}$ =	1160		$\bar{X}$= 1285	
J (90)	.60	1544	.25	1450	J21
		1160		1230	J23
		1116		1157	J75
	.75	710	.40	1093	J72
		1189		1302	J73
		1080		1270	J26
	$\bar{X}$ =	1028		$\bar{X}$= 1268	

* Group mean latencies were calculated from individual latencies weighted by the number of asymptotic responses per subject.

TABLE 10

Individual Mean and Group Mean Response Latencies(msec) for the R1 Key in Nonreinforcement Groups*

Group(%NR)	2	R1S1	(1 - 2)	R1S2	Subject
D (0)	.75	1114	.40	1207	D01
		886		879	D03
		760		769	D62
	.60	797	.25	775	D52
		821		834	D53
		888		750	D12
		$\bar{X}$ = 878		$\bar{X}$ = 879	
G (30)	.75	663	.40	562	G66
		765		755	G67
		479		401	G25
	.60	594	.25	544	G16
		903		925	G18
		1019		779	G76
		$\bar{X}$ = 737		$\bar{X}$ = 661	
H (50)	.75	706	.40	705	H70
		735		839	H71
		971		1011	H27
		1242		1310	H30
	.60	1352	.25	1275	H20
		1275		1159	H22
		848		770	H77
		$\bar{X}$ = 1018		$\bar{X}$ =1010	

(continued)

TABLE 10 (continued)

Group(%NR)	π_2	R1S1	$(1 - \pi_2)$	R1S2	Subject
I (70)	.75	937	.40	999	I17
		926		1169	I19
		917		1090	I74
	.60	821	.25	695	I68
		1246		1099	I69
		858		737	I24
		$\bar{X}$ = 940		$\bar{X}$ = 825	
J (90)	.75	971	.40	1025	J21
		1043		1121	J23
		870		955	J75
	.60	999	.25	824	J72
		1258		1055	J73
		1040		1307	J26
		$\bar{X}$ =835		$\bar{X}$ = 880	

* Group mean latencies were calculated from individual latencies weighted by the number of asymptote responses per subject.

different between bright stimulus and dim stimulus presentations, $F(1,30) < 1$ (Table Q, appendix and Figure 17). Also, in the NR groups, non reliable difference was found between bright stimulus and dim stimulus latencies, (Wilcoxon signed ranks test: W+ = 133, N = 23, $p > .05$), which are plotted in Figure 18.

No significant differences were found between response latencies to the majority reinforced key and the minority reinforced key in either the probabilistic groups (Wilcoxon signed ranks test: W+ = 7, N = 6, $p \geq .05$) or the NR groups (Wilcoxon signed ranks test: W+ = 4, N = 4, $p > .05$); however, majority key response latencies in the 100:0/0:100 group were reliably shorter than the minority key latencies (Wilcoxon signed ranks test: W+ = 0, N = 6, $p < .05$).

In the NR groups, the stimulus, either bright or dim, that was assigned scheduled nonreinforced trials showed reliably shorter response latencies than the stimulus not assigned nonreinforced trials (Wilcoxon signed ranks test: W+ = 53, N = 26, $p < .01$).

The mean response latency for each stimulus in generalization for and NR groups averaged across all subjects is presented in Tables 11 and 12. No reliable differences were found between response latencies across generalization stimuli in the π groups (Friedman two-way analysis of variance, $\chi^2(5) = 6.75$, $p > .05$) or in the NR groups (Friedman two-way analysis of variance, $\chi^2(5) = 3.21$, $p > .05$).

Sequential Statistics

Event statistics were recorded on alternate days for all subjects throughout discrimination training and generalization testing. Sequential

analyses to be presented will focus upon asymptotic responding, i.e. responses recorded during the final twenty days of discrimination training. Since sequential data were recorded on alternate days, 10 sessions (800 choice trials + rerun trials) of sequential data are available for analysis.

The subject's responses were categorized according to the following scheme: Given a reinforced response, R1 or R2, on trial N - 1, the probability of an R2 response on trials N, N+1, N+2, N+3, and N+4 were recorded. For example, if on trial N - 1, a reinforced R2 (or R1) response was emitted, the probability on trial N of an R2S2 response and an R2S1 response was determined. If the trial N response was then reinforced, this response was also classified as an N - 1 trial <u>because</u> it was reinforced. If the response on trial N was unreinforced, the next trial response was classified under trial N+1. If the response on trial N+1 was reinforced, it was then <u>also</u> classified as an N - 1 trial, as all reinforced responses were. If the response on trial N+1 was unreinforced, the next response was classified under trial N+2. This classification logic applied in the same manner through trial N+4. Unreinforced trial sequences were recorded through the fourth rerun, i.e. trial N+4. Rerun trials equal to or exceeding trial N+5 were not recorded. (All scheduled nonreinforced trials were omitted from this analysis).

In sum, all reinforced responses were classified as R2 or R1 responses on trial N - 1, and were classified under the choice trial (N) or the particular rerun trial (N+1, N+2, or N+4) where reinforcement was delivered. Unreinforced trials were classified under the choice trial (N) or rerun trial where they occurred.

TABLE 11

Mean Response Latencies (msec) for Each Generalization Stimulus Averaged Across All Subjects in the Probabilistic (π) Groups

Stimulus	S1	S2	S3	S4	S5	S6	S7	S8
Latency (msec)	1054	903	1132	1082	1094	1080	961	1110
Total Trials	4544	4776	4868	4266	4369	4580	4991	4560

TABLE 12

Mean Response Latencies (msec) for Each Generalization Stimulus Averaged Across All Subjects in the Nonreinforcement Groups*

Stimulus	S1	S2	S3	S4	S5	S6	S7	S8
Latency (msec)	987	1010	1018	956	938	1038	924	987
Total Trials	4024	3819	3417	2879	3780	4205	2851	3548

*Scheduled unreinforced trials were exclused from this table

Evidence for sequential effects is based upon statistical analyses (chi square) of the group data for each experimental group. Three types of sequential effects were observed: (a) a tendency to increase the likelihood of responding to the unreinforced key after an unreinforced response; (b) reward following, or the tendency to repeat a response that was reinforced on the immediately prior trial and (c) negative recency, or the tendency to not repeat a response (i.e. switch to the other key) that was reinforced on the immediately prior trial.

All ten experimental groups (π and NR) showed a significantly greater proportion of successes (reinforced responses) on choice trials than on rerun trials (chi square values in Table R, appendix). Tables 13 and 14 show how the proportion of successes in each group tends to decrease from trial N (choice trial) to trial N+3 (third rerun trial).

The rerun trend of reduced successes contrasts with the typical "lose shifting" strategy in which subjects shift their response from the unreinforced key on the choice trial to the reinforced key on the rerun trial (e.g. Shimp, 1973). Such a lose shift strategy would be observed as an increase in the proportion of successes (reinforced responses) on rerun trials (see Discussion).

Statistical analyses using chi square were performed to test for the presence of a group tendency to repeat on trial N the reinforced response that was made on the prior trial, trial N - 1, i.e. the probability of an R1 response given an R1 reinforced response on the prior trial [p(R1/R1+)], and the probability of an R2 response given an R2 reinforced response on the previous trial [p(R2/R2+)]. This tendency is called reward following.

TABLE 13

Proportion of Trials Reinforced (Successes) and Unreinforced (Failures) on Choice Trials (N) and Rerun Trials (N+1,N+2,N+3) for Each π Group

Group	N	N+1	N+2	N+3	
A	.59	.48	.45	.41	Proportion of Reinforced Trials
	.41	.52	.55	.59	Proportion of Unreinforced Trials
	4786	1959	1021	563	Total Trials
D	.59	.51	.43	.37	Proportion of Reinforced Trials
	.41	.49	.57	.63	Proportion of Unreinforced Trials
	4519	1833	901	514	Total Trials
B	.59	.51	.43	.40	Proportion of Reinforced Trials
	.41	.49	.57	.60	Proportion of Unreinforced Trials
	4568	1889	928	528	Total Trials
F	.74	.54	.54	.49	Proportion of Reinforced Trials
	.26	.46	.46	.52	Proportion of Unreinforced Trials
	4826	1256	575	265	Total Trials
E	.78	.56	.54	.50	Proportion of Reinforced Trials
	.22	.44	.46	.50	Proportion of Unreinforced Trials
	5053	1123	499	232	Total Trials
C	.96	.75	.63	.68	Proportion of Reinforced Trials
	.04	.25	.37	.32	Proportion of Unreinforced Trials
	4788	206	151	19	Total Trials

TABLE 14

Proportion of Trials Reinforced (Successes) and Unreinforced (Failures) on Choice Trials (N) and Rerun Trials (N+1,N+2,N+3) for Each NR Group*

Group	N	N+1	N+2	N+3	
G (30)	.599	.48	.39	.44	Proportion of Reinforced Trials
	.41	.52	.61	.56	Proportion of Unreinforced Trials
	5107	2118	1100	672	Total Trials
H (50)	.65	.39	.35	.34	Proportion of Reinforced Trials
	.35	.61	.65	.66	Proportion of Unreinforced Trials
	5586	1982	1218	791	Total Trials
I (70)	.61	.42	.39	.31	Proportion of Reinforced Trials
	.39	.58	.61	.69	Proportion of Unreinforced Trials
	4984	1929	1119	679	Total Trials
J (90)	.62	.49	.40	.38	Proportion of Reinforced Trials
	.38	.51	.60	.62	Proportion of Unreinforced Trials
	5260	1976	1016	608	Total Trials

*Scheduled unreinforced trials were excluded from this table

One π group, F (60/0), showed significant reward following ($\chi^2(6) = 78.780$, $p < .001$) and three of the four NR groups showed significant reward following (G(30): $\chi^2(6) = 21.259$, $p < .01$; H (50): $\chi^2(6) = 219.521$, $p < .001$; J (90): $\chi^2(6) = 178.878$, $p < .001$). Probabilistic groups D (60/25), E(75/0) and A(60/40) showed no reliable reward following (D: $\chi^2(6) = 3.882$, $p > .05$; E: $\chi^2(6) = 1.712$, $p > .05$; A: $\chi^2(6) = 5.349$, $p > .05$) nor did NR group I (70) (I: $\chi^2(6) = 1.221$, $p > .05$). A reliable tendency to switch from the reinforced response key on trial N - 1 to the other response key on trial N (negative recency) was found in π groups B (75/25) and C(100/0) (B: $\chi^2(6) = 78,780$, $p < .001$, C: $\chi^2(6) = 19.628$, $p < .01$).

In sum, trial independence was not found; however, the sequential trend of an increased proportion of errors as rerun trials increased is opposite to the lose shifting strategy found in correction rerun designs.

DISCUSSION

Summary of Results

Asymptotic P Values. The present asymptotic data generated by probabilistic discrimination training exhibit the following characteristics: (a) nonhomogeneity of response proportions within all groups, i.e. the response proportions for a particular π level were not drawn from a common population. This means that characterization of any π group with such terms as matching, undershooting or overshooting (with respect to a particular π level) cannot be statistically justified. As an alternative to group description of response levels, steady state performance was assessed by comparing asymptotic P levels to assigned π values for individual subjects; (b) A nearly equal division of asymptotic response proportions among three response classes:
(1) undershooting (of π levels) on both stimuli, (2) undershooting on one stimulus and overshooting on the other stimulus and (3) undershooting on one stimulus and matching on the other; (c) Across all groups, an asymptotic P level in the presence of one discriminative stimulus of constant π that did not vary with changing π values assigned to the other training stimulus.

Response Bias. The asymmetry of the asymptotic response curves around $p(R2) = .50$ is a reflection of response bias. Significant biases were found in the asymmetrical groups only. The pair of response curves for each subject in the asymmetrical groups was displaced in the direction of the stimulus assigned the greater π value. (Displacement of the response curves refers to the visual representation of response bias in figures 1-6.) An analysis of response bias within the framework of signal detection theory further supported the controlling influence of reinforcement assignment on response bias.

Asymptotic P-Difference. The P-difference measure, defined by the quantity P2 - (1 - P1), removed all variability due to response bias from the pairs of response curves. With key bias variability removed, the accuracy of the stimulus discrimination was clarified. The group mean P-difference plotted as a function of π-difference (figure 7) showed a significant positive linear trend. In comparing P-difference to π-difference (π 2 - (1 - π 1), it was found that about two-thirds of the subjects undershot the π difference and the remaining one-third matched the π-difference.

Generalization. During generalization testing, the 100:0/0:100 group displayed the sigmoidal functions typically obtained on successive discrimination tasks under similar conditions, e.g. Heinemann et al. (1969). The probabilistic groups displayed S-shaped functions with flatter slopes than the nonprobabilistic group (100:0/0:100), and asymptotes that departed from 0 and 1. The slopes were defined by the approximately linear middle segment of each generalization function. The group mean slope of the generalization functions was monotonically related to π-difference. The vertical distance between asymptotes within subjects was directly related to π-difference and showed a reliable linear trend as a function of increasing π-difference.

P-differences for the extreme stimuli in generalization significantly exceeded P-differences for the training stimuli during training. P-difference vs. π-difference statistical comparisons for the extreme stimuli revealed that most birds matched the π-difference, while the remaining subjects were about equally divided between undershooting and overshooting of π-differences.

Analysis of generalization P values showed that most birds undershot levels for one stimulus and overshot π levels on the other stimulus, while a minority of subjects undershot π levels on one stimulus and matched π levels on the other stimulus. All combinations of response levels, i.e. undershooting, overshoting and matching of levels were found, except overshooting of π levels on both stimuli. As in training, the P level for one stimulus group (the brightest four stimuli or the dimmest four stimuli) was found to be independent of the π assignment for the other group.

An analysis of response bias revealed that, as in training, reinforcement assignment determined the location of the generalization function on the Y-axis. Specifically, the generalization functions were displaced in the direction of the response key assigned the greater π value.

Latencies. No systematic differences in latencies across groups were found in the conditions; however, a reliable group difference in response latencies was found in the nonreinforcement (NR) conditions. A monotonically nondecreasing trend as a function of percentage nonreinforced trials was apparent in the NR groups. In both π and NR groups, response latencies were not related to stimulus intensity. No reliable difference in response latency was found within subjects between the majority and minority reinforced keys, except in the 100:0/0:100 group, for which minority key latencies were significantly greater than majority key latencies.

In the NR groups, the stimulus assigned nonreinforced trials showed reliably shorter latencies than the stimulus without nonreinforced trials. Response latencies in generalization for all groups did not vary systematically across the generalization stimuli.

Data Comparisons for Sequential Effects and Nonreinforcement Group Results

The sequential data for all groups, ⊓ and NR, showed a systematic increase in the proportion of errors as rerun trials increased.[9] This finding contrasts with all similar date from discrete trial designs (e.g. Shimp, 1973) which report reliable switching("lose shifting") to the reinforced alternative after an unreinforced choice response. The major procedural difference between my experiment and similar discrete trial designs reporting "lose shifting" is the relatively long intertrial intervals (10 seconds) used in the present experiment compared to the shorter intertrial intervals (less than five seconds) used in other studies (e.g. Shimp, 1966, 1973).

Significant reward following was found in one ⊓ group and in three of the four NR groups. Two groups, 75:25/25:75 and 100:0/0:100, showed a reliable negative recency effect, i.e. the tendency to switch from the reinforced response key to the other response key between successive trials. Graf et al. (1964) reported "the probability that the pigeon will choose a given alternative on any trial is independent of which of the two has been reinforced on the previous trial". Unfortunately, such a generalization does not take into account the procedural variables that may influence the magnitude of sequential effects. For instance, Shimp (1966; experiment 1) reported reward following on a 75:25/25:75 probabilistic choice task using a 1.5 second intertrial interval. Under similar conditions, a reliable negative recency effect was observed in the present study in the 75:25/25:75 group with a 10 second intertrial interval. Also, the interpolation of nonreinforced trials in the present study was associated with reliable reward following in three of the four nonreinforcement groups, while only one of the six ⊓ groups showed reliable reward following. The interpolation of nonreinforced trials in Shimp (1966; Experiments II, III, IV) cannot be assessed for reward following since sequential data were reported

9. Recent analysis of sequential data from Friedberg & Brenner (p.) has revealed the sequential tendency for pigeons given a probabilistic discrimination.

for "momentary maximizing" sequences only, which did not include specific response-reinforcement outcomes.

In the NR groups of the present study, the percentage of scheduled nonreinforced trials, ranging from 0-90%, was found not to reliably affect discrimination accuracy. This finding is consistent with the identity operator model of Bush and Mosteller (p. *). which predicts that choice proportions on discrete trial tasks will not be changed by the addition of nonreinforced trials.

Shimp (1966, experiment II) increased the proportion of nonreinforced trials from 0 to 50% on a spatial probability task (pigeons) and found that choice proportions remained at a nearly perfect maximizing level. Matching proportions were observed in experiments III & IV (Shimp; 1966) where the percentages of scheduled nonreinforced trials were 75 and 87.5, respectively. Correction rerun trials were differentially cued in experiment II, but not in experiments III and IV. This procedural difference probably accounts for the difference in terminal response levels. Cued correction trials will cause subjects to approach more rapidly a response proportion that equals and eventually exceeds matching.

In Shimp's experiment I (Shimp; 1966), which did not schedule nonreinforced trials, an overshooting proportion was attained after 16.000 reinforced trials. In contrast, only 1100 reinforced trials (estimated) were given in two subsequent experiments, III & IV, where matching was found. The response levels attained after 1000 reinforced trials in experiment I (graphically presented data available for 2 out of 6 birds) also approximated a matching

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proportion. Thus, extended training in experiment I, and not interpolated unreinforced trials in experiments III & IV, probably accounts for the difference in response levels between these experiments.

Data from the present experiment and additional unpublished data support the above analysis of Shimp's (1966) results. Reliable overshooting of levels after 12,000 reinforced trials was found in pilot data (Friedberg) from six pigeons given a 65:35/35:65 light intensity probabilistic discrimination. Also, interpolated nonreinforced trials in the present experiment did not reliably change response proportions. Specifically, the probabilistic group assigned the same reinforcement ratio as the NR groups and equal numbers of reinforced trials showed no reliable difference from the NR groups in terminal response levels. To summarize, overshooting of π levels is most reliably produced by extended training; Convincing evidence that scheduled nonreinforced trials influence response is lacking.

Data Comparisons for Probabilistic Groups

Two prior studies (Uhl, 1963; Shimp, 1973, experiment II) have generated parametric data somewhat comparable to those of the present study. Uhl employed a two-lever Skinner box for a spatial probability task with four independent groups of rats under schedules of π = .60, .70, .80, and .90. Terminal performance for 1000 training trials showed significant overshooting in all groups, and a positive linear trend as a function of increasing level. The group mean P-difference in the present study showed a similar linear trend. The π = .60 group in the Uhl study showed less overshooting than the remaining groups ($p < .05$ for the π =.60 group vs. $p < .001$ for the remaining groups) -- a finding similar to the consistently poorer

discrimination accuracy, relative to the π assignment, in the 60:40/40:60 group of the present study.

The Shimp study scheduled all possible combinations of four line tilt stimuli in a probabilistic discrimination. A unique probability of reinforcement was associated with each line tilt stimulus. Reinforcement probability and stimulus presentation rate were varied within a single group of pigeons. The data showed marked overshooting (of levels) of the average reinforcement probability of the component, line tilt, stimuli. Overshooting of π assignments increased as reinforcement probability deviated from π =.50. In contrast, group P-differences remained at an undershooting level for all groups in the present study. The difference in results may be attributed to the greater number of training trials given in the Shimp study. All subjects were originally trained (Shimp; 1973, experiment I) on a 90:10/10:90 probabilistic choice task for an average of 5700 reinforced trials before completion of 7000 reinforced acquisition trials in experiment II. In the present study, only 4000 acquisition trials were given. As discussed previously, extended training increases the likelihood of overshooting proportions on discrete trial probability tasks.

With regard to response bias, visual inspection of prior probabilistic discrimination studies (Shimp, 1966, experiment I; Graf et al. , 1964) showed the presence of key preferences -- a finding also reported in the present study.

The Friedberg (1975, unpublished) study showed generalization gradients with response proportions to the extreme stimuli that exceeded the asymptotic response proportions in the presence of the training stimuli during discrimination training. Also, the generalization gradient slopes for the probabilistic

(75:25/25:75) group were significantly flatter than the slopes for the nonprobabilistic (100:0/0:100) group. The present study showed that gradient slopes decreased as a function of decreasing π differences, and that response proportions to the extreme stimuli exceeded response proportions produced in the presence of the training stimuli during discrimination training.

An important theoretical question is raised by the increased discrimination accuracy in generalization as compared to the discrimination accuracy achieved at the end of training. Although there was some reduction in errors (unreinforced choice responses) in the 100:0/0:100 group during generalization (error reduction achieved: 4.2% to 2.3%), error reduction was far greater in the other probabilistic groups during generalization. This finding replicates comparable data from the unpublished experiment noted previously (p.). Attributing the increased discrimination accuracy in the probabilistic groups during generalization to an easier stimulus discrimination would seem to be incompatible with the nonsignificant increase in discrimination accuracy in the 100:0/0:100 control condition.

Theories of Probability Learning

Clearly, Estes' matching assumption is too narrow to describe the diversity of asymptotic response proportions found in the present experiment and the animal probability learning literature in general. The matching assumption receives its strongest support from studies that report an absence of sequential trial effects. Such studies (e.g. Calfee, 1968: rats; Behrend and Bitterman, 1961: fish; Graf et al., 1964: pigeons) are most likely to report matching performance.

Bitterman's phyletic view predicts that pigeons will show matching with

no nonrandom response tendencies on visual probability tasks. Although the present study was designed to minimize sequential effects, and thus provide an experimental situation favorable to the Bitterman hypothesis, reliable sequential effects between successive trial responses were found. In particular, a group tendency to increase responding to the nonreinforced alternative after a nonreinforced choice trial was found. Although the group mean response levels during generalization approximated matching (23 out of 36 birds matched), significant overshooting and undershooting of π levels were also found. Although it could be argued that undershooting birds had not yet attained asymptote, overshooting birds clearly violate Bitterman's matching prediction for pigeons on visual probability tasks. Also, in the present experiment the asymmetrical π groups were assigned a greater proportion of reinforcement to one of the two response keys; thus, a spatial, left key/right key probability task and the explicit luminance task were simultaneously presented during training. According to the phyletic hypothesis, maximizing should occur on the spatial probability task, which would markedly shift response proportions toward the key assigned the greater number of reinforcements. The data showed that subjects' response bias conformed to a spatial matching prediction, not a maximizing one.

To explain animal probability learning, the attentional construct proposed by Sutherland and Mackintosh (1971) depends heavily upon the subject's adoption of nonrandom response strategies. (p. *) To observe such nonrandom response tendencies, explicit stimuli "irrelevant" to the probability learning task are introduced to act as potential controllers of responding. According to Sutherland

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and Mackintosh, when subjects attend to the probability task, they maximize; when subjects fail to attend to the probability task, they base their responding on the explicit irrelevant stimuli. For example, Sutherland and Mackintosh (p.411) report a tendency of subjects to favor a particular value of the irrelevant dimension, such as a position or color preference, when responding to the minority key.

It is difficult to determine the control exerted by "irrelevant" stimuli on a task where no explicit irrelevant stimuli are programmed. If probability learning is importantly controlled by such irrelevant stimuli, evidence for the Sutherland and Mackintosh position is entirely dependent upon the results of experiments that manipulate irrelevant stimuli.

In the present investigation, no irrelevant stimulus dimension was introduced. Moreover, it is difficult to conceive of any external stimuli that reliably controlled responding, except the independent variables of light intensity and key position. All subjects were alternated daily between two insulated experimental chambers which minimized the influence of extraneous variables on the subjects' behavior. Since matching does occur without explicit irrelevant stimuli, it would seem that control of responding by stimuli irrelevant to the probability task is not necessary for the development of probabilistic responding.

The error matching principle (Gibbon et al., 1974) provides a more flexible concept of probability learning than the aforementioned theories. Error matching behavior according to Gibbon et al. may be maintained by consistently selecting the response alternative with the momentarily lower error probability (p. *); however, these authors do not specify how the

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presence of such a strategy might be empirically confirmed. It is stated that error matching on discrete trial tasks requires choice and correction trials to be completely indiscriminable. To provide support for this statement, sequential data must show an overall matching proportion, i.e. $p = \pi$ and no additional systematic response tendencies. In the present study, all groups showed a strong systematic tendency to increase the proportionof unreinforced responses on rerun trials after an unreinforced choice trial. Careful visual inspection of individual birds who matched P values suggests a similar response tendency to increase the propotion of unreinforced responses across rerun trial sequences. This finding indicates that subjects who match respond somewhat differently to choice trials vs. rerun trials -- a violation of the error matching principle.

Gibbon et al. further suggest that nonreinforced trials may be important to matching because they reduce the magnitude of sequential dependencies which cause deviations from matching of error frequencies on the response alternatives. In the present experiment, the presence of scheduled nonreinforced trials did not reliably reduce sequential effects, which included reward following, and the tendency to increase the proportion of responses to the unreinforced alternative after nonreinforced choice trials. Moreover, the data suggest that scheduled nonreinforced trials may increase the magnitude of sequential effects (see p.).

Shimp (1966) accounted for probability learning and probabilistic discrimination with the "momentary maximizing" principle which states that subjects will respond to the operandum that momentarily has the higher probability of reinforcement. Momentary reinforcement probability is determined by the π assignment and the probability that reinforcement will

be available (p. *). On a discrete trial probability task without scheduled nonreinforced trials, a nonreinforced response to one key will be a perfect predictor of scheduled reinforcement on the other key (assuming the animal "knows" the difference between choice trial errors and rerun trial errors). Scheduled nonreinforced trials will alter the momentary maximizing sequences because a nonreinforced response to one key will not perfectly predict the availability of reinforcement on the other key. The ambiguous consequences of nonreinforcement imply only an increased likelihood that reinforcement will be available on the other key. A momentary maximizing strategy will be maintained under probabilistic conditions with scheduled nonreinforced trials; however, it will yield overall matching on discrete trial tasks, instead of the near maximizing behavior that would be expected without scheduled nonreinforced trials.

As noted previously (p.), Shimp's (1966) evidence for matching on probabilistic tasks with scheduled nonreinforced trials vs. overshooting on probabilistic tasks without scheduled nonreinforced trials is based upon four experiments which did not separate the effects of extended training and scheduled nonreinforced trials on asymptotic response proportions. Also, the evidence for momentary maximizing sequences on discrete trial probabilistic tasks is based entirely upon experiments using short intertrial intervals (1.5 seconds). Without scheduled nonreinforced trials, immediate alternation to the reinforced alternative after a nonreinforced choice is predicted by the momentary maximizing principle, and is confirmed by experiments using short intertrial intervals. Under conditions similar to the experiments of Shimp (1966), the present study used longer intertrial intervals (10 seconds)

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but did not find the "lose shifting" strategies reported by Shimp. In fact, subjects increased their proportion of errors as the number of rerun trials increased, a reversal of the "lose shifting" strategy. Since the choice trial (first trial) proportions for Shimp (1966), the present experiment, and similar pilot studies by Friedberg all show that response proportions based on first trials correspond closely in terms of response levels attained as a function of number of acquisition trials, it appears that the momentary maximizing concept is unnecessary to explain asymptotic behavior. The subject does not have to favor the key with the momentarily higher reinforcement probability in order to produce overall matching when nonreinforced trials are scheduled, or to produce overshooting of π levels when nonreinforced trials are not scheduled. Indeed, the subject can increase its proportion of errors (i.e. favor the key with the momentarily lower reinforcement probability) on rerun trials and yet show first trial matching. The crucial learning event on probabilistic tasks would then seem to be the collection of the assigned ratio of reinforcements, and not the number of acquisition trials required to collect reinforcement, the particular sequence of nonreinforced responses, or the length of the intertrial interval.

Shimp (1966, 1973, 1975) has further suggested that diverse nonmatching response strategies combine to produce overall "matching" behavior, or departures from matching, under probabilistic schedules. Empirical response strategies uncovered by Shimp include a within session progression from matching to maximizing (Shimp, 1970; 1973, experiment I) and reward following (Shimp, 1966, experiment I).

Although nonrandom response tendencies were exhibited by all groups in the present experiment, visual inspection of individual data from several

subjects revealed no apparent nonrandom tendencies, other than the maintenance of a particular P value. Considering this observation, it would seem that the importance of component nonmatching response tendencies remains to be demonstrated.

The influence of systematic response tendencies on probabilistic responding was further evaluated by Hale and Shimp (1975). These researchers conducted a probabilistic discrimination study with 11 temporal stimuli, 6 assigned levels of 0/.10, .20, .30, .40, .50, while the remaining stimuli were assigned complementary probabilities of .60, .70, .80, .90 and 1.0. "Overall choice probability averaged over the 11 local reinforcement contingencies approximately equaled the overall reinforcement probability of .50 (p.). In other words, when the 11 response proportions associated with the ten reinforcement ratios were collapsed across the temporal discriminative stimuli, birds responded with a 50/50 split to the left key/right key positional task. (Response proportions to each of the temporal stimuli tended to overshoot π levels.) On this basis, Hale and Shimp asserted that only a molecular analysis of the data would reveal the component response strategies that yielded overshooting to the individual stimuli, but approximated matching when averaged together.

Such an analysis appears, upon closer inspection, to be trivial. By ignoring the temporal discriminations and, in effect, focussing on the overall left/right positional task, it is not at all surprising that matching would result. The eleven temporal probability tasks were symmetrically counterbalanced (five tasks with $\pi < .50$, and five with $\pi > .50$) such that any result other than spatial matching would be unexpected.

The Hale and Shimp experiment scheduled 11 probability tasks within a probabilistic discrimination, instead of the usual two probability tasks, each

associated with a single discriminative stimulus. The eleven schedules produced eleven different response levels. Shimp's original view assumed that different response strategies determined overall response levels under a single π assignment. The finding that different behaviors are produced by different levels, which is essentially what was reported by Hale and Shimp, provides no evidence for within session response strategies.

Major Findings and Implications

The variability of asymptotic response proportions including reliable undershooting, matching and overshooting of π levels. Asymptotic behavior, if described with the more stable P-difference measure (p.), rather than P value, revealed that about two-thirds of the subjects reliably undershot assigned π-differences, while the remaining one-third matched assigned -differences during discrimination training. Theories of choice behavior that predict a specific response level on probabilistic tasks, such as matching, will fail to describe the wide variability of asymptotic response proportions generated in the present parametric study.

It is instructive to assess the results of the present study in light of the design variables, discussed in the introduction, that are most likely to produce behavioral variation on discrete trial probabilistic tasks. These factors are (1) the type of procedure employed, (2) the length of the intertrial interval, (3) the number of acquisition trials, and (4) discrimination difficulty.

Considering factors (1) and (2), correction rerun procedures with long intertrial intervals are most likely to yield undershooting of π levels

(Melers, 1966; Revusky, 1961). The results of the present study provide further empirical support for this view.[10] Concerning the number of acquisition trials (factor 3), the evidence indicates that as the number of acquisition trials is increased under correction rerun conditions, matching and overshooting of $\frac{11}{11}$ levels become more likely. In the present parametric study, nearly all subjects showed matching or undershooting after 2400 trials. In the unpublished study previously noted (Friedberg, 1975), two pigeons matched and two pigeons overshot levels after 4000 trials. Another unpublished study by the present author found reliable overshooting in four pigeons after 10,000 trials on a probabilistic discrimination task under conditions similar to the present experiment. Finally, Shimp (1966; experiment 1) reported overshooting of $\frac{11}{11}$ levels in five out of six pigeons after 16,000 trials on a probabilistic choice task. Considering these findings, it may be concluded that response proportions on probabilistic discrimination tasks gradually increase from undershooting to matching and overshooting as the number of acquisition trials are increased. The question of how many trials are needed to produce the "true" asymptote may be less important than a thorough description of the independent variables that determine response levels at different stages of acquisition.

Discrimination difficulty (factor 4) has been shown to influence response levels on probabilistic discrimination tasks. Friedberg & Brenner (unpublished) used a ½ log unit light intensity discrimination in a probabilistic choice experiment under conditions similar to the above studies. After

10. However, comparisons of discrete trial probability data in pigeons (Shimp, 1966 and the present experiment p.) suggest that inter-trial intervals may not be related to speed of acquisition or first trial asymptotic response proportions.

7000 trials under reinforcement ratios of 65:35/35:65 and 75:25/25:75 in two independent groups, all subjects showed reliable undershooting of assignments. This finding may be compared to the matching and overshooting proportions attained under a one log unit light intensity discrimination after only 4000 trials in the Friedberg, 1975 study. Thus, a more difficult discrimination yielded reduced discrimination accuracy and undershooting of π values. On the other hand, an immediate reliable increase in P-difference and P value was achieved by the introduction of a wider stimulus intensity range (1 log unit to 2½ log units) for generalization testing in the present study and in the Friedberg, 1975 study.

Response latencies: The monotonically nondecreasing trend in latencies as the percentage of scheduled nonreinforced trials increased from 0-90%: Sequential effects: sequential dependencies showing an increase in the proportion of unreinforced responses as the number of successive rerun trials increased. In the NR groups, the increase in group mean latencies as the percentage of unreinforced trials increased from 0-90% appears to be related to the magnitude of sequential effects.

The difference in latencies among the NR groups showed the following pattern: relatively short mean response latencies for groups D(0) and G(30) of 860 and 770 msec, respectively, and relatively long group mean response latencies for groups H(50), I(70) and J(90) of 1020, 1050 and 1115 msec, respectively (figure 18). Sequential dependencies between successive rerun trials follow a similar pattern: a reliably decreasing success (reinforcement) rate on successive rerun trials, present in all groups, and NR, which is greatly accelerated in the NR groups H(50), I(70) and J(90) (Table 14).

Another distinction between the sequential effects found in $\overline{\Pi}$ and NR groups is also evident. Only one of the six $\overline{\Pi}$ groups showed reliable reward following, while three of the four NR groups showed significant reward following.

On the basis of the differences in sequential effects and response latencies described above between $\overline{\Pi}$ and NR conditions, it is suggested that the interpolation of nonreinforced trials on probabilistic discrimination tasks may be responsible for a response strategy that is different from that used by subjects on probabilistic discrimination tasks without interpolation of nonreinforced trials. The assumption that nonreinforced trials do not alter asymptotic response proportions (identity operator model, p.) is not challenged by my data. However, the sequential dependencies and response latencies that are uniquely associated with probabilistic choice tasks with interpolated unreinforced trials may represent inherent properties of a response strategy that govern each choice response, and ultimately yields the observed P level. Further analysis, in a later report, of the asymptotic data for the NR groups will explore this possibility. The nonsignificant differences in P value between $\overline{\Pi}$ and NR groups show only that the dependent measure of P value is not sensitive to the manipulation of reinforcement ratios, not that important behavioral differences do no exist between $\overline{\Pi}$ and NR conditions.

The sequential effects observed in the present study call into question twoassumptions made by the present author. First of all, the assumption that sequential effects can be minimized by incorporation of relatively long inter-trial intervals and addition of scheduled nonreinforced trials would seem to

be invalidated. In fact, nonreinforced trials seem to be associated with an increased magnitude of sequential effects. Secondly, the sequential dependencies found between successive rerun trials do not support the concept of optimal strategy, defined in the introduction as minimizing the number of trials per reinforcement.

How is the animal's response strategy affected by a nonreinforced response on the preceding trial? A possible mechanism to explain the reversal of the usual "lose shifting" strategy on correction rerun trials can be constructed from signal detection theory (p.). An unreinforced response may alter the subject's decision criterion, which determines the response alternative chosen. This decision criterion is expressed as the ratio of the likelihood that a given event was due to S2 (bright stimulus) relative to S1 (dim stimulus). Assuming that presentation of an S2 under a given π ratio yields an unreinforced response, the subject may then shift his criterion on the next S2 rerun trial so that it is less likely that the stimulus will be classified as an S2. Thus, it will be more likely that the stimulus will be classified and responded to as an S1.

Responding as if the bright stimulus were an S1 will reduce the proportion of reinforced responses (successes) for each rerun trial. Each subsequent unreinforced rerun trial will tend to move the criterion so as to increase the likelihood that the stimulus will be classified incorrectly, and result in an increased proportion of nonreinforced responses. The increased tendency over nonreinforced rerun trials to classify the stimulus incorrectly, and respond according to this incorrect classification, will lead to the development of a "reverse" discrimination on rerun trials. Stated differently, the tendency to classify an S1 as an S2, and Vice versa, will cause subjects

to respond to one discriminative stimulus as if it were the other stimulus. At the end of the rerun sequence, the reinforcement delivered for a correct response will then cause the subject to resume the correct stimulus discrimination.

APPENDIX

TABLE A

Chi Square for Homogeneity of Asymptotic P values within Groups

Group	Stimulus		df	Group	Stimulus		df
A	1	478.21***	5	D	1	144.23***	5
	2	545.95***	5		2	138.21***	5
B	1	869.49***	5	E	1	419.68***	5
	2	385.89***	5		2	106.19***	5
C	1	37.36***	5	F	1	124.22***	5
	2	139.33***	5		2	36.88***	5

TABLE B

Analyses of variance for the Effect of changing π level in the presence of one discriminative stimulus on asymptotic P levels in the presence of the other discriminative stimulus under constant

1. π constant = .60

Source	SS	df	MS	F
Between	233.562	2	116.781	2.069
Within	846.735	15	56.449	
Total	1080.296	17		

2. π constant = .75

Source	SS	df	MS	F
Between	120.960	2	60.480	0.914
Within	992.239	15	66.149	
Total	1113.119	17		

3. π constant = 1.0

Source	SS	df	MS	F
Between	29.017	2	14.508	1.170
Within	185.927	15	12.395	
Total	214.944	17		

***$p < .001$

APPENDIX

TABLE C

Analysis of Variance on the Effect of Training Stimulus Intensity on Asymptotic Response Proportions

L = luminance, S1 & S2
D = 1 constant & 2 varying
S = 2 constant & 1 varying
R = subjects

Source		SS	df	MS	F
L		124.244	1	124.244	2.052
LD		2959.238	2	1479.619	24.436***
LS		2102.285	2	1051.143	17.360***
LSD		162.094	4	40.524	0.669
LR(DS)	error	1089.900	18	60.550	
S		2664.229	2	1332.115	40.721***
D		3699.007	2	1849.503	56.636***
SD		10.686	4	2.672	0.082
R(SD)	error	588.842	18	32.713	

TABLE D

Analysis of Variance on the Effect of Π-difference and Stimulus value Assignment on Response Bias

Source	SS	df	MS	F
Π-difference	195.265	5	39.053	1.072
Stimulus value	1428.210	1	1428.210	39.186***
Π-difference X Stimulus value	1181.113	5	236.223	6.481***
Error	874.726	24	36.447	

*** $p < .001$

TABLE E

t values for Expected vs. Observed Response Bias

Group	Stimulus	t	df	Group	Greater Stimulus	t	df
A		-1.93	2	D	1	-1.91	2
		-1.18	2		2	1.48	2
B		-1.72	2	E	1	1.69	2
		-0.61	2		2	-1.68	2
C		0.45	2	F	1	0.96	2
		0.22	2		2	-1.37	2

TABLE F

Analysis of Variance on the Effect of π -difference and stimulus π value assignment on ln LR

Source	SS	df	MS	F
π -difference	8.554	5	1.771	2.670*
Stimulus π value	7.229	1	7.229	11.392**
π -difference X Stimulus π value	20.777	5	4.155	6.486***
Error	15.377	24	0.641	

TABLE G

Analysis of Variance for Replication Effects on Asymptotes During Training

R = replication, 1 & 2
L = π level
W = subjects

Source		SS	df	MS	F
R		50.624	1	50.624	1.256
LR		460.341	5	92.068	2.284
W(LR)	error	967.398	24	40.308	
L		18654.750	5	3730.950	40.524***
LR	error	460.341	5	92.068	

TABLE H

Analysis of Variance on the Effect of π -difference on P-difference

Source	SS	df	MS	F
Between	18709.150	5	3741.883	68.94***
Within	1510.830	30	50.360	
Total	20219.98	35		

***p < .001

TABLE I

Analysis of Variance of Replication Effects on Asymptotic P-differences in Generalization

R = replication, 1 & 2
L = π level
W = subjects

Source		SS	df	MS	F
R		.156E-01	1	.156-01	0.0005
LR		375.828	5	75.166	2.458
W(LR)	error	733.76	24	30.574	
L		21946.57	5	4389.31	58.395***
LR	error	375.828	5	75.166	

TABLE J

Analysis of Variance for the Effect of π -difference on P-difference in Generalization

Source	SS	df	MS	F
Between	21965.28	5	4393.06	118.720***
Within	1110.09	30	37.000	
Total	23075.37	35		

*p < .05
**p < .01
***p < .001

TABLE K

Analysis of Variance on P-difference (P8 - P1) in Generalization vs. Asymptotic P-difference (P6 - P3) in training

G = generalization & training P-difference
P = π -difference
S = stimulus
R = subjects

Source		SS	df	MS	F
G		1201.636	1	1201.636	69.990***
PG		121.258	5	24.252	1.413
GS		142.696	1	142.696	8.312**
PGS		132.409	5	26.482	1.542
RG(PS)	error	412.047	24	17.169	
P		48826.430	5	8765.285	103.943***
S		15.681	1	15.681	0.186
PS		243.370	5	48.674	0.577
R(PS)	error	2023.867	24	84.328	

TABLE L

Analysis of Variance on P-difference (P3 - P6) in Generalization vs. Asymptotic P-difference (P3 - P6) in Training

G = generalization & training P-differences
P = π -difference
S = stimulus
R = subjects

Source		SS	df	MS	F
G		380.281	1	380.281	12.878**
PG		188.032	5	37.606	1.274
GS		87.407	1	87.407	2.960
PGS		56.936	5	11.387	0.386
RG(PS)	error	708.715	24	29.530	
P		42833.300	5	8566.66	120.077***
S		42.983	1	42.983	0.602
PS		271.329	5	54.266	0.761
R(PS)	error	1712.230	24	71.343	

**p < .01
***p < .001

TABLE M

Analyses of Variance for the Effect of Changing π Level in the Presence of One Discriminative Stimulus on Asymptotic P Level under Constant π in the Presence of the Pther Discriminative Stimulus

1. π constant = .60

Source	SS	df	MS	F
Between	116.429	2	58.215	0.717
Within	1218.369	15	81.225	
Total	1334.798	17		

2. π constant = .75

Source	SS	df	MS	F
Between	244.674	2	122.337	1.186
Within	1547.398	15	103.160	
Total	1792.072	17		

3. π constant = 1.0

Source	SS	df	MS	F
Between	95.29	2	47.65	3.402
Within	210.07	15	14.00	
Total	305.36	17		

TABLE N

Analysis of Variance on the Effect of Stimulus Intensity on Generalization Response Proportions

L = luminance, $\overline{S1 - S4}$ & $\overline{S5 - S8}$
D = π 1 constant, π 2 varying
S = π 2 constant, π 1 varying
R = subjects

Source		SS	df	MS	F
L		198.297	1	198.297	0.783
LD		38.472	2	19.236	0.076
LS		32.465	2	16.232	0.064
LDS		380.858	4	95.214	0.376
LR(DS)	error	4556.938	18	253.163	
S		1814.895	2	907.448	7.232**
D		303.601	2	151.801	1.210
SD		1693.953	4	423.488	3.375*
R(SD)	error	2258.707	18	125.484	

*$p < .05$
**$p < .01$

TABLE O

Analysis of Variance on the Effect of π -difference and Stimulus Assignment on Response Bias

Source	SS	df	MS	F
π -difference	310.317	5	62.063	0.797
Stimulus $\times$ π value	1183.933	1	1183.933	15.204***
π -difference X stimulus π value	870.484	5	161.497	2.074
Error	1868.985	24	77.874	

TABLE P

t Values for Expected vs. Observed Response Bias in Generalization

Group	Stimulus	t	df	Group	Greater Stimulus	t	df
A		-1.27	2	D	1	-0.89	2
		-0.86	2		2	1.79	2
B		-0.53	2	E	1	2.29	2
		0.17	2		2	-0.93	2
C		0.13	2	F	1	1.71	2
		0.56	2		2	-1.11	2

***$p < .001$

symmetrical groups, i.e. $\pi 2 = \pi 1$, otherwise each subgroup is counterbalanced in the same way as the asymmetrical groups

TABLE Q

Analysis of Variance on the Effect of Stimulus Intensity on Response Latencies During Training

L = Probabilistic Group
S = Stimulus Intensity (bright or dim)
W = subjects

Source		SS	df	MS	F
L		1,324,894	5	264,978.8	1.738
W(L)	error	4,590,547	30	153,018.2	
S		288.1	1	288.1	1
SL		17091.7	5	3418.2	1
SW(L)	error	11,621,309	30	387,376.9	

TABLE R

Chi Square for Sequential Effects Across Trial Rerun Sequences within Groups

Group		df	Group		df
A	150.33***	18	C	280.65***	18
D	163.51***	18	G (30)	189.86***	18
B	135.26***	18	H (50)	732.42***	21
F	283.66***	18	I (70)	444.31***	18
E	371.33***	18	J (90)	307.84***	18

***p < .001

REFERENCES

Atkinson, R. C. & Estes, W. K. Stimulus sampling theory. In R. D. Luce, R. R. Bush & E. Galanter (Eds.). Handbook of Mathematical Psychology, Vol. 2, New York: Wiley, 1963: pp. 121-268.

Behrend, E. R. & Bitterman, M. E. Probability-matching in the fish. American Journal of Psychology, 1961, 74, 542-551.

Behrend, E. R. & Bitterman, M. E. Probability-matching in the goldfish. Psychonomic Science, 1966, 6, 327-328.

Bitterman, M. E. Toward a comparative psychology of learning. American Psychologist, 1960, 15, 704-712.

Bitterman, M. E. Phyletic differences in learning. American Psychologist, 1965, 20, 396-410.

Bitterman, M. E., Wodinsky, J. & Candland, D. K. Some comparative psychology. American Journal of Psychology, 1958, 71, 94-110.

Bullock, D. H. & Bitterman, M. E. Probability matching in the pigeon. American Journal of Psychology, 1962, 75, 634-639.

Bush, R. R. & Mosteller, F. Stochastic Models for Learning. New York: Wiley, 1955.

Calfee, R. C. Choice behavior during long-term probabilistic reinforcement schedules. Journal of Comparative & Physiological Psychology. 1968, 65, 232-237.

Chase, S. & Heinemann, E. G. Choices based on redundant information: an analysis of two-dimensional stimulus control. Journal of Experimental Psychology, 1972, 92, 161-175.

Cole, M., Belensky, G. L., Boucher, R. C. Fernandez, R. N. & Myers, D. L. Probability learning to escape from shock. Psychonomic Science, 1965, 3, 127-128.

Estes, W. K. The statistical approach to learning theory. In S. Koch (Ed), Psychology: A Study of Science. Vol. 2. New York: McGraw-Hill, 1959, pp. 359-379.

Fisher, R. A. & Yates., F. Statistical Tables for Biological, Agricultural, and Medical Research (3rd.) Oliver-Boyd, 1948.

Friedberg, F. Postdiscrimination generalization gradients for probabilistic choice tasks. Unpublished.

Friedberg, F. Brenner, N. ROC curves for probabilistic discrimination. Unpublished.

Gibbon, J. Berryman, R. & Thompson, R. L. Contingency spaces and measures in classical and instrumental conditioning. Journal of the Experimental Analysis of Behavior, 1974, 21, 585-605.

Gonzalex, R. C., Roberts, W. A. & Bitterman, M.E. Learning in adult rats with extensive cortical lesions made in infancy. American Journal of Psychology, 1964, 77, 547-562.

Graf, V., Bullock, D.H. & Bitterman, M.E. Further experiments on probability matching in the pigeon, Journal of the Experimental Analysis of Behavior, 1964, 1, 151-157.

Hanson, H. M. Effects of discrimination training on stimulus generalization. Journal of Experimental Psychology, 1959, 74, 315-321.

Hale, J. M. & Shimp, C. P. Molecular contingencies: Reinforcement probability. Journal of Experimental Psychology, 1975, 74, 315-321.

Heinemann, E. G., Avin, E., Sullivan, M. A. & Chase, S. Analysis of stimulus generalization with a psychophysical method. Journal of Experimental Psychology, 1969, 80, 215-224.

Heinemann, E. G. & Chase, S. Conditional stimulus control. Journal of Experimental Psychology, 1970a, 84, 187-197.

Heinemann, E. G., Chase, S. & Mandell, C. Discriminative control of attention. Science, 1968, 160, 553-554.

Mackintosh, N. J. Comparative psychology of serial reversal and probability learning: Rats, birds, and fish. In R. Gilbert & N.S. Sutherland (Eds.), Animal Discrimination Learning, London: Academic Press, 1969. pp. 137-167.

Mackintosh, N. J. Attention and probability learning. In D. I. Mostofsky (Ed.), Attention: Contemporary Theory and Analysis. New York: Appleton-Century-Crofts, 1970, pp. 173-191.

Mackintosh, N. J. Psychology of Animal Learning. London: Academic Press, 1974.

Mackintosh, N. J., Lord, J. & Little, L. Visual and spatial probability learning in pigeons and goldfish. Psychonomic Science, 1971, 24, 221-222.

Mandell, C. C. Choice, time allocation and response rate during generalization testing. Unpublished doctoral dissertation, Columbia University, 1973.

Melera, R. P. Probability learning in the T-maze as a function of proportion of reinforcement. Psychonomic Science, 1966, 5, 331-332.

Nevin, J. A., Olson, L., Mandell, C. Yarensky, P. Differential reinforcement and signal detection. Journal of the Experimental Analysis of Behavior, 1975, 24, 355-367.

North, A. J. & MacDonald, R. D. Discrimination learning as a function of the probability of reinforcement. Journal of Comparative and Physiological Psychology, 1959, 52, 342-344.

Parducci, A. & Polt, J. Correction vs. noncorrection with changing reinforcement schedules. Journal of Comparative and Physiological Psychology, 1958, 51, 492-495.

Pierrel, R. & Sherman, J. G. Generalization of auditory intensity following discrimination training. Journal of the Experimental Analysis of Behavior, 1960, 3, 313-332.

Revusky, S. Nonreinforced trial procedure for probability learning. Science, 1961, 134, 328-329.

Roberts, W. A. Learning and motivation in the immature rat. American Journal of Psychology, 1966, 79, 3-23.

Shimp, C. P. Probabilistically reinforced choice behavior in pigeons. Journal of the Experimental Analysis of Behavior, 1966, 9, 443-455.

Shimp, C. P. Optimal Behavior in free-operant experiments. Psychological Review, 1969, 76, 97-112.

Shimp, C. P. A within session effect after prolonged training in probability learning by rats. Psychonomic Science, 1970, 18, 152.

Shimp, C. P. Probabilistic discrimination in the pigeon. Journal of Experimental Psychology, 1973, 97, 292-304.

Skinner, B.F. Are learning theories necessary? Journal of Experimental Psychology, 1950, 50, 60-67.

Stubbs, A. The discrimination of stimulus duration by pigeons. Journal of the Experimental Analysis of Behavior, 1968, 11, 223-228.

Sutherland, N. S. & Mackintosh, N. J. Mechanisms of Animal Discrimination Learning, New York: Academic Press, 1971.

Tanner, W. P., Jr. & Birdsall, T. G. Definitions of d' and as psychophysical measures. In J. A. Swets (Ed.), Signal Detection and Recognition in Human Observers: Contemporary Readings. New York: Wiley, 1964.

Uhl, C. N. Two-choice probability learning in the rat as a function of incentive, probability of reinforcement, and training procedure. Journal of Experimental Psychology, 1963, 66, 443-449.

Weinstock, S., North, A. J., Brody, A. L., & LoGuidice, J. Probability learning in a T-maze with noncorrection. Journal of Comparative and Physiological Psychology, 1965, 60, 76-81.

Weitzman, K. A. Positional matching in rats and fish. Journal of Comparative and Physiological Psychology, 1967, 63, 54-59.

Williams, B. A. Probability learning as a function of momentary reinforcement probability. Journal of the Experimental Analysis of Behavior., 1972, 17, 363-368.

Winer, B. J. Statistical Principles in Experimental Design. New York: McGraw-Hill, 1962.

Witte, R. S. A stimulus-trace hypothesis for statistical learning theory. Journal of Experimental Psychology. 1959, 57, 273-282.

Wright, R. L. D. Motivational effects in probability learning. Psychonomic Science, 1967, 7, 329-330.