

DISCRIMINATION LEARNING WITH AND WITHOUT "ERRORS"¹

H. S. TERRACE

COLUMBIA UNIVERSITY

Responses to S— ("errors") are not a necessary condition for the formation of an operant discrimination of color. Errors do not occur if discrimination training begins early in conditioning and if S+ and S— initially differ with respect to brightness, duration and wavelength. After training starts, S—'s duration and brightness is progressively increased until S+ and S— differ only with respect to wavelength. Errors do occur if training starts after much conditioning in the presence of S+ has occurred or if S+ and S— differ only with respect to wavelength throughout training. Performance following discrimination learning without errors lacks three characteristics that are found following learning with errors. Only those birds that learned the discrimination with errors showed (1) "emotional" responses in the presence of S—, (2) an increase in the rate (or a decrease in the latency) of its response to S+, and (3) occasional bursts of responses to S—.

The acquisition of an operant discrimination may be defined as the process whereby an organism comes to respond more frequently to a stimulus correlated with reinforcement (S+) than to a stimulus correlated with non-reinforcement (S—). In popular terminology, responses made to S+ are "correct responses" while responses to S— are "errors".

It has been repeatedly shown that, because an organism conditioned to respond to one stimulus will make that response to certain other stimuli, it is impossible to establish a discrimination by simply reinforcing responding to S+. Instead, some procedure must be used whereby S+ and S— are alternated. Since the probability of the response to S+ is initially high, the main function of a discrimination training procedure is to reduce the probability of the response to S—. Most training procedures accomplish this by extinguishing responding to S—. An unreinforced response to S— weakens the effectiveness of S— while only slightly reducing the effectiveness of S+. On the other hand, the reinforcement of a response to S+ increases the effectiveness of S+ and to a lesser extent the effectiveness of S—. Thus, the alternation of S+ and S— eventually

results in a high probability of a response to S+ and a low probability of a response to S—.

The general occurrence of responding to S—, during the establishment of a discrimination by most differential reinforcement procedures, seems to have led to the acceptance of responding to S— as a necessary condition for discrimination learning. As a result, both theoretical and empirical studies of discrimination learning have neglected the variables that affect the occurrence of responding to S—. Information regarding the control of responding to S— is a fundamental requirement of any account of discrimination learning and is necessary to define the scope of "conditioning-extinction" theories of discrimination learning (e.g., Spence, 1936; Hull, 1950; Keller and Schoenfeld, 1950, pp. 364-374; Kimble, 1961, pp. 118-120).

Most knowledge concerning the amount of responding to S— that occurs during the acquisition of a discrimination stems from the assumption that generalization and discrimination are quantitatively inverse processes. This assumption states that the degree to which an organism can discriminate between the stimulus it has been conditioned to respond to, and some new stimulus, can be determined by presenting both stimuli during extinction and comparing the number of responses made to each stimulus. For this reason the height of the ordinate on a generalization gradient at different points along a

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physical continuum has been used to estimate the difficulty of a discrimination. Generalization gradients have been constructed for many continua, *e.g.*, wave length of light (Guttman and Kalish, 1956), visual intensity (Brown, 1943; Blough, 1959), auditory frequency (Hovland, 1937 a; Jenkins, 1959), and auditory intensity (Hovland, 1937 b). Very little effort, however, has been made to validate the use of generalization gradients against some criterion of the difficulty of a discrimination as, for example, the number of responses to S- emitted, during acquisition, at different intervals between S+ and S-. Hanson (1959) has shown that a "discrimination" gradient may be steeper than a generalization gradient for the wave length of light; the amount of time needed to train a discrimination remained constant for differences between S+ and S- greater than 10 m μ ., while the height of the generalization gradient did not decline to an asymptotic level until the difference between S+ and S- exceeded 50m μ .. Related to the discrepancy between generalization and discrimination gradients is Guttman's (1956) observation that the differential limens for the wave length of light cannot be predicted from the generalization gradient of wave length. This suggests that the steepness of a generalization gradient is not entirely determined by the ease with which an organism can discriminate between stimuli from the gradient.

The results of the relatively few studies that have systematically dealt with the difficulty of a discrimination as a function of the physical difference between the S+ and S- are in qualitative agreement with the results of the more numerous generalization studies. Frick (1948) has shown that the amount of bar-pressing emitted in the presence of S- varies inversely with the intensity difference between S+ and S-. In a similar experiment, Raben (1949) demonstrated that the latency of a running response to S- increases with increasing differences in intensity between S+ and S-. Spiker (1956), using human subjects, obtained results similar to Hanson's in showing that the difficulty of a discrimination is inversely related to the difference in wave length between S+ and S-.

Related to the physical difference between S+ and S- is the procedural problem of whether an organism should receive all of its differential training at one value of S-, or

whether S- should be progressively changed from some point at the extreme of the continuum to the value of S- required by the discrimination. William James (1890, pp. 505-515), in a discussion of discrimination and psychophysics, was perhaps the first to recognize the value of slowly reducing the interval between two discriminative stimuli. James noted that much smaller two-point limens could be obtained if training began with a widely separated pair of points, after which the distance between the two points was progressively reduced. In this manner "smaller differences affect us as if they were large ones" (James; 1890, p. 515).

In his studies on conditioned salivation in the dog, Pavlov (1927, p. 117) noted that discriminations between stimuli whose difference is progressively reduced are learned faster than discriminations between stimuli that were presented at a constant difference. Schlosberg and Solomon (1943) reported that rats could learn a simultaneous discrimination between two narrowly separated grays, with *no* errors if the discriminative stimuli were gradually changed from a pair of white and black cards to the final pair of gray cards. Lawrence (1952), also using rats, showed that a simultaneous discrimination between two narrowly separated grays is learned with fewer errors when training begins with two widely separated grays and progressively shifts to the narrowly separated grays, than when only the narrowly separated grays are used during training.

Another variable that affects the difficulty of a discrimination is the amount and type of conditioning that precedes discrimination training. Skinner (1938, pp. 203-206) has demonstrated that a brightness discrimination can be acquired by rats with virtually no responses to S- if discrimination training begins immediately after the bar-pressing response has been conditioned. Other rats, which had received more reinforcements for responding to S+, on either continuous or intermittent schedules of reinforcement, made many more responses to S- in acquiring the same discrimination.

The results of the few generalization studies in which the amount of prior training, as well as the difference between the S+ (or CS) and the test stimuli, were used as independent variables are in agreement with Skinner's

findings. Hovland (1937 c) found that the magnitude of the generalized galvanic skin response increased with the number of reinforcements of the CR. Razran's (1949) summary of the pertinent data from Pavlov's laboratory suggested that the magnitude of the generalized conditioned salivary response increased with the number of times the CR had been reinforced. The strength of a generalized instrumental response (the running response in a Grice runway) has also been shown to increase with the number of times the response had been reinforced during conditioning (Margolious, 1955).

The preceding discussion suggests that the number of responses to S- emitted during the acquisition of a discrimination is a joint function of when and how S- is introduced. The two experiments described below assessed the effects of these variables on the acquisition of an operant discrimination of color by pigeons. "When" refers to the time in the experimental history of the organism at which discrimination training begins. Two values of this variable were studied. Either the S- was introduced early during the first conditioning session or after a number of weeks of training in the presence of the S+. These conditions will be referred to as "early" and "late" respectively. "How" refers to the manner in which S- is initially presented. Two methods of introducing S- were used. Either the S- was initially of the same brightness and duration as the S+ and differed only with respect to wave length, or, in addition to the wave length difference, S- initially had lower brightness and shorter duration values which were gradually increased until the brightness and duration of the S+ was reached. These two conditions will be referred to as "constant" and "progressive" respectively.

The four methods of introducing S- that result from permuting the when and how variables defined the basic independent variables of each experiment. These were early-progressive, early-constant, late-progressive and late-constant introduction of S-. The main dependent variables were the number of responses emitted to S- and the rate or latency of the response to S+ during and after the acquisition of the discrimination. Experiment I was concerned with the discrimination learning in which the reinforced response was a free operant; Experiment II

with discrimination learning in which the reinforced response could occur only during short discrete trials. Because of the similarity of the training procedures employed by each experiment, the procedure and the results of Experiments I and II will be described in parallel rather than in successive fashion.

METHOD

Apparatus and Subjects

An experimental chamber of the type described by Ferster and Skinner (1957, p. 14 ff.) was used. The subject's compartment was illuminated by a diffuse 12-watt house-light. A Gerbrands response key, $\frac{3}{4}$ inches in diameter, was mounted behind a $\frac{3}{4}$ in. hole in a metal panel that separated the subject's compartment from the compartment housing the stimulus and food presenting devices. A minimum force of about 15 gm was necessary to operate the key.

The stimulus-presenting device, adapted from an Industrial Electrical Engineering Corporation display unit, was mounted directly behind the key. This device transilluminated the key with either a red or a green light by a system consisting of a 6.3 volt, 2.2 watt bulb, a colored filter, a lens, and a ground glass screen. The intensities of the two lights were adjusted so that the lights appeared equally bright to the dark-adapted experimenter when observed in a darkened room.

Four inches beneath the key was a 2x2 in. opening in the panel through which a hopper filled with mixed grain could be made available. The reinforcement was a 4.0 sec period of access to the hopper of grain. During the 4.0 sec reinforcement cycle, the house and the stimulus lights were shut off and the grain hopper was illuminated by two 6-watt bulbs directly above it. White noise was continuously present in the chamber to mask extraneous sounds.

The subjects were 32 male White Carneaux and White King pigeons with no prior experimental history. Since no reliable differences in the experimental behavior of these two breeds had been observed in a pilot experiment, a bird's breed was not a consideration in assigning it to a particular experimental group. Each bird was maintained at 80% of its

ad libitum body weight for a period lasting from two weeks prior to the start of the experiment until the end of the experiment.

Experiment I. Free-operant Procedure

Data were obtained from 16 pigeons over a 10 month period of daily experimentation. Twelve pigeons were used in the main portion of the experiment. This group was subdivided into four experimental groups of three pigeons each. The remaining four subjects served in a control experiment.

Two experimental procedures were followed for each group. In the first, no discrimination was required. Responding was reinforced on a variable interval (VI) schedule of reinforcement with a mean interval of 1 min. During these sessions the key was always red (S+).

The second procedure was a two-component multiple (variable interval-extinction) schedule (VI EXT). During the first component, the key was red (S+) and responses were reinforced on a VI 1' schedule of reinforcement. The first component lasted for 3 min immediately after which the second component began. During the second component, the key was green (S-) and responding was never reinforced. The duration of the second component was, in part, controlled by the bird's behavior. If no responding to S- occurred, the second component lasted for 3 min. If responding to S- did occur, the next S+ component started 3 min after the last response to S-. This correction procedure was

used to minimize the possibility of accidental reinforcement of responding to S- by the subsequent presentation of the S+ component.

The order of occurrence of the S+ and the S+ - S- sessions depended on whether or not S- was introduced early or late. If S- was introduced early, the order was S+ - S-, S+ and S+ - S-; if S- was introduced late, the order was S+, S+ - S-, S+ and S+ - S-. The number of each type of session and its order of occurrence for the four experimental groups appear in the upper half of Table 1. Both the non-discrimination (S+) and discrimination (S+ - S-) sessions were terminated after 60 reinforcements had occurred.

The procedures described in the following section were used to train the red-green discrimination during the first S+ - S- series. In all cases, the second S+ - S- series began abruptly with no special training procedure.

Early progressive S- discrimination training: Discrimination training for the birds of the early-progressive group (#'s 114, 116, 155) began approximately 30 sec after the key peck had been conditioned and continued through the first three sessions. During these three sessions the S- was changed from a dark key of 5 sec duration, to a fully bright green key of 3 min duration. (The values given for the duration of the S- component assume that no responding to S- occurred.) The intensity of S- was controlled by a variable resistor in series with the green key-light. At 80 ohms, the key appeared dark inside a darkened room.

Table 1
Type, Sequence, and Number of Experimental Sessions in Experiments I and II

Type of session (In order of occurrence)	Experimental Group			
	Experiment I:			
	Early-Progressive S- Introduction	Early-Constant S- Introduction	Late-Progressive S- Introduction	Late-Constant S- Introduction
S+			21	21
S+ - S-	21	21	14	14
S+	14	14	7	7
S+ - S-	7	7	14	14
Experiment II:				
S+			14	14
S+ - S-	14	14	14	14
S+	14	14	7	7
S+ - S-	14	14	14	14

The changes in the duration and intensity of S- were made in three phases. During the first phase the key was dark and the duration of the S- component was gradually increased from 5 to 30 sec. During the second phase the duration of the S- component was set back to 5 sec, and the intensity of the green key-light was gradually increased until the green and the red key-lights were equally bright. During the final phase the green key-light was fully bright and the duration of the S- component was gradually increased from 5 sec to 3 min. Until the S- reached its full duration (3 min) and intensity values, responding in any S- component resulted in a repetition of the prevailing S- duration and intensity values during the following S- component.

During the first three sessions, the duration of the S+ component was increased from 30 sec to 3 min, and the schedule of reinforcement was changed from continuous (CRF) to VI 30" to VI 1'. Table 2 summarizes the

changes made in the duration of the S+ and the S- components, the S- intensity values, and the schedule of reinforcement in the S+ component during the first three S+ - S- sessions. The column in Table 2 headed "Range of number of S- components" refers to the slightly different programs for changing the duration and intensity of the S- that were followed for each bird receiving progressive S- training. The entries in this column state the range of instances in which the training program repeated a given set of S- intensity and duration values.

During the first session, the first 25 changes from the S+ to the S- component were made when the bird did not seem to the experimenter to be in a favorable position to strike the key, *e.g.*, when his head was partially turned away from the key. It was assumed that the position of the bird's head would influence the probability of a response to S-. After the 25th S- component, alternation between the

Table 2
S+ and S- Component Values for Progressive Discrimination Training (Exp. I)

S+ - S-		S+ Component (Early-Progressive Training Only)		S- Component				
Session	Duration (secs.)	Schedule	Duration (secs.)	Intensity (ohms)	Range of number of S- components (for which duration and intensity values were used)			
1	60-90	VI 30"	5	80	1-4			
			10	80	1-3			
			15	80	1-3			
			20	80	1-2			
			25	80	1-2			
			30	80	1-3			
			5	70	0-1			
			5	60	0-1			
			5	50	0-1			
			5	40	1			
			5	30	0-1			
			5	25	1			
			5	20	0-1			
			5	15	0-1			
			5	10	1			
			5	5	0-1			
			5	2.5	1			
			5	0	1-3			
			10	0	1-4			
			15	0	1-3			
			20	0	1-5			
			25	0	1-7			
			30	0	1-7			
			2	180	VI 1'	30-90	0	20-38
						90-180	0	12-22
3	180	VI 1'						

S+ and the S- components occurred independently of the birds' behavior.

Early-constant S- discrimination training: Discrimination training for the early-constant group of birds (#'s 150, 151, 152) also began early during the first experimental session. The duration and brightness of the S-, however, were initially at their maximum values, *i.e.*, 3 min and full brightness, respectively. Approximately 30 sec after the key-peck and had been conditioned, the schedule of reinforcement was changed from CRF to VI 30". Three minutes later the first S- component began and the S+-S- procedure went into effect. After the first session, responses in the S+ component were reinforced on a VI 1' schedule.

Late-progressive S- discrimination training: After 21 S+ sessions, discrimination training was started for the birds in the late-progressive group (#'s 147, 148, 149). The duration and intensity values of S- that were used during the first three sessions of discrimination training for this group are shown in Table 2 under the column headings describing the S- component. Throughout discrimination training the duration of the S+ component was 3 min, and the schedule of reinforcement during the S+ component was VI 1'. Until S- was of full brightness and full duration, the intensity and duration values of an S- component in which responding occurred were repeated during the following S- component. The experimenter did not attempt to wait for the birds of this group to partially turn their heads from the key before presenting the the initial S-'s because no instance of such behavior was observed during the S+ session preceding the first discrimination training session.

Late-constant S- discrimination training: Discrimination training was started for the birds of the late-constant group (#'s 131, 132, 154) after 21 S+ sessions. S- was initially fully bright and of 3 min duration.

Experiment II. Trial Procedure

Experiments I and II differed with respect to the probability of reinforcement for a response in the presence of S+ and the number of responses that could occur during each presentation of the discriminative stimuli. In Exp. II the probability of reinforcement for a response to S+ was always 1.0 rather than

some value between 0.0 and 1.0 as was the case in Exp. I. Furthermore, a single response terminated the presentation of each S+ or S-. The trial procedure used in Exp. II and the rationale for its use stems largely from Jenkins' (1961) study of discrimination learning in the pigeon.

Reinforcing each response to S+ allows for a more precise specification of induction (generalization) between responding to S+ and S-. Skinner (1938) and Morse (1955) have demonstrated that induction between S+ and S- increases with the amount and the intermittency of reinforcement for responding to S+. Thus, because of the intermittency of reinforcement in Exp. I, it is not possible to specify the number of responses to S- solely in terms of the values of the independent variable, *i.e.*, the number of responses that were reinforced prior to discrimination training and the initial physical difference between S+ and S-.

The procedure followed in Exp. II of reinforcing each response to S+ also helped to insure that all of the information regarding the probability of a reinforcement was provided by the discriminative stimuli. The short pauses in responding to S+ that followed many reinforcements in Exp. I (see Fig. 10) suggest that it was possible to discriminate that, after each reinforcement, the probability of another reinforcement was zero. Thus some information about the probability of reinforcement was transmitted by the occurrence of a reinforcement. This phenomenon has been more extensively studied by Reynolds and Catania (1961) who have systematically demonstrated that, on an arithmetic-mean VI schedule, the rate of responding following a reinforcement increases until a maximal asymptotic rate is reached.

METHOD

An experimental session consisted of a series of discrete, automatically programmed trials. A trial was defined as the period of time during which the key was transilluminated by either a red (S+) or a green (S-) light.

All trials were terminated by a response or by a failure to respond within 5 sec of the onset of the trial. Thus, only one response could occur during a trial. A response made during an S+ trial was immediately reinforced. Be-

tween trials the houselight remained on but the key was dark. The duration of the inter-trial interval was randomly selected from a series of intervals with a range of 5 to 30 sec and mean of 15 sec. Responding during the inter-trial interval delayed the onset of the next trial for 10 sec.

Leaving the houselight on between trials made the key available for a second type of response to S-. Turning the houselight off, however, was shown in a pilot experiment to result in highly erratic S+ latencies. Because the S+ latency was one of the dependent variables and because it had also previously been noted that a pigeon will rarely peck at a dark key, the houselight was left on between trials.

As in Exp. I, two experimental procedures were followed. The first consisted of S+ trials only. The second consisted of an equal number of S+ and S- trials, alternating in random succession. A constraint on the randomization was imposed by a correction procedure whereby S+ trials, during which no response occurred, and S- trials, during which a response did occur, were repeated as the next trial. Both the S+ and S+-S- sessions were terminated after 60 reinforcements.

Data were collected from an experimental group of 12 pigeons and a control group of four pigeons over a period of 11 months of daily experimentation. The lower portion of Table 1 summarizes the number of sessions using each type of procedure and their order of occurrence for each experimental group. As in Exp. I, the four groups differed with respect to the training procedure used during the first series of S+-S- sessions. The procedure used during the second series of S+-S- sessions was identical for each group.

Early-progressive S- introduction: Discrimination training began for the birds in the early-progressive group (#'s 118, 119, 120) during the first session after 20 reinforcements for responding to S+ had occurred. S- was introduced in two phases. During phase I, the duration of S- was 0.5 sec and its brightness was increased from zero to full brightness. During the second phase, S- was maintained at full brightness and its duration was increased from 0.5 sec to 5 sec. The changes in the brightness and the duration of S- were all made during the first session. The experimenter withheld the initial 10 presentations

of S- until the bird did not seem in a favorable position to strike the key. After the 10th S- trial all S- trials were automatically programmed. The intensity and duration values of S- for trials in which responding occurred were repeated on the next trial until S- was fully bright and of 5 sec duration. Table 3 summarizes the changes in S- intensity and duration made during the first session. The duration and intensity values of S+ were never varied.

Table 3
S- Duration and Intensity Values for Progressive
Discrimination Training (Exp. II)

Duration (secs)	Intensity (ohms)	Range of number of S- components (for which S- duration and inten- sity values were used)
0.5	80	3
0.5	50	3
0.5	40	3
0.5	30	3
0.5	20	3-8
0.5	25	3-5
0.5	20	3
0.5	15	3
0.5	10	3
0.5	5	3
0.5	2.5	3-5
0.5	0	3
1	0	4
2.5	0	4-6
2	0	4-6
3	0	4-8
4	0	4-6
5	0	4-6

Early-constant S- introduction: Discrimination training for the early-constant group of birds (#'s 139, 144, 145) began early during the first experimental session with an S- that was fully bright and of 5 sec duration. The first S- trial occurred after 20 S+ trials had occurred.

Late-progressive S- introduction: For the late-progressive group of birds (#'s 140, 142, 146) discrimination training began after 14 S+ sessions. Table 3 describes the changes in S- intensity and duration that were made during the first discrimination session. Changes in the brightness or duration of S- were made only if no responding to S- occurred during the previous S- trial. All S- trials were started independently of the birds' behavior.

Late-constant S- introduction: Discrimination training began for the birds of the late-

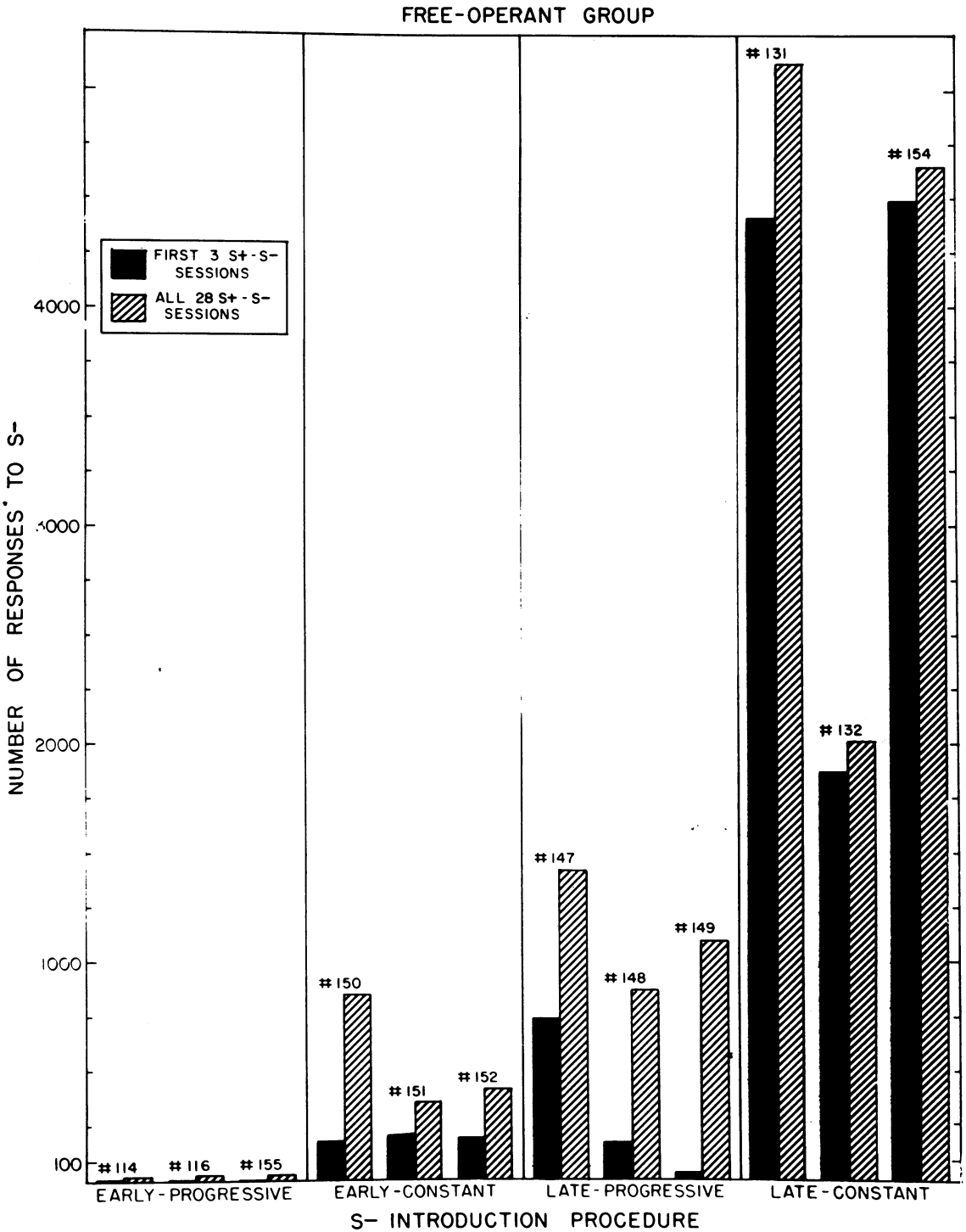


Fig. 1. The number of responses to S- made by each bird during the first three, and during all 28 S+ - S- sessions of Exp. I.

constant group (#'s 127, 128, 141) after 14 S+ sessions. S- was initially fully bright and of 5 sec duration.

RESULTS

In both Exp. I and II, the manner in which S- was introduced had a systematic effect on the number of responses to S- that were emitted during the acquisition of the discrimination, and on the amount and the pattern of responding to S- that occurred during subsequent discrimination performance. The occurrence of responses to S-, in turn, affected the rate and the latency of responding to S+.

Responses to S-: The black bars in Figs. 1 and 2 show the number of responses to S- emitted by each bird during the first three S+ - S- (acquisition) sessions. The birds in both early-progressive groups acquired the discrimination with virtually no responses to S-

In Exp. I (Fig. 1) the range of responses to S- of the early-progressive group was 5 to 9. The birds of the late-constant group made the most errors during the first three discrimination sessions. Their range of errors was 1922 to 4153. Between these extremes fell the early-constant and the late-progressive groups. The range of errors of the former group was 191 to 210; the range of the latter was 31 to 760.²

In Exp. II, (Fig. 2. Note that Figs. 1 and 2 use differently scaled ordinates) the birds of the early-progressive group made the fewest responses to S-. Their range was 2 to 8. The largest number of responses to S- was made by the birds of the late-constant group. Their range was 175 to 228. Between these extremes fell the birds of the early-constant group (range: 9 to 23) and the late-progressive group (range: 4 to 20).

In both Exp. I and II, the bird of the early-progressive groups and those of the other three experimental groups differed markedly with respect to the number of responses to S- they emitted after the first three (acquisition) S+ - S- sessions. These differences can be seen

by comparing the heights of the black and the hatched bars in Figs. 1 and 2. The hatched bars show the number of responses to S- emitted during all S+ - S- sessions. In Exp. I (Fig. 1) the range of responses to S- that occurred after the first three S+ - S- sessions for the early-progressive group was 21 to 32. The range for the early-constant, the late-progressive, and the late-constant groups were 111 to 524, 545 to 825, and 121 to 562, respectively.

In Exp. II, (Fig. 2) the birds of the late-constant group made the largest number of post-acquisition responses to S-. They were followed, in order, by the early-constant and the late-progressive groups. None of the birds in the early-progressive groups made any responses to S- after the first S+ - S- session.

The occurrence of responding to S- throughout discrimination training generally followed either a monotonically decreasing or an irregular cyclic pattern. These patterns can be seen in Figs. 3 and 4, which show the number of responses to S- emitted by the birds of each group, from Exp. I and II, during the first 10 discrimination (S+ - S-) sessions. It is important to note the differently scaled ordinates used within Figs. 3 and 4.

In both experiments the responses to S- of the birds in the early-progressive and the late-constant groups (except bird #128 of late-constant group, Fig. 4) followed the monotonically decreasing pattern. Responding was most frequent during the initial discrimination sessions. During subsequent discrimination sessions, however, responding to S- declined to a stable low level.

The number of responses to S- emitted by the birds of the early-constant and late-progressive groups varied irregularly with the amount of discrimination training. Initially, responses to S- occurred infrequently. At later stages of training, however, bursts of responses to S- occurred which were in turn quickly followed by a decline to the initially low rates of responding.

Another difference between the performance of the early-progressive and the other experimental groups of both experiments was observed at the start of the second series of S+ - S- sessions. In both experiments, the early-progressive birds went through the transition from the S+ to the S+ - S- procedure with no responses to S-. However, all of the birds in the other groups emitted at

²Most of the results of this experiment were shown to be statistically significant by the appropriate non-parametric test at at least the .05 level, and in many cases beyond the .001 level. The results that were not significantly different are described in the text as not different. Sufficient data appear in the figures for the reader to make a statistical test in those cases in which the statistical significance of a result is in doubt.

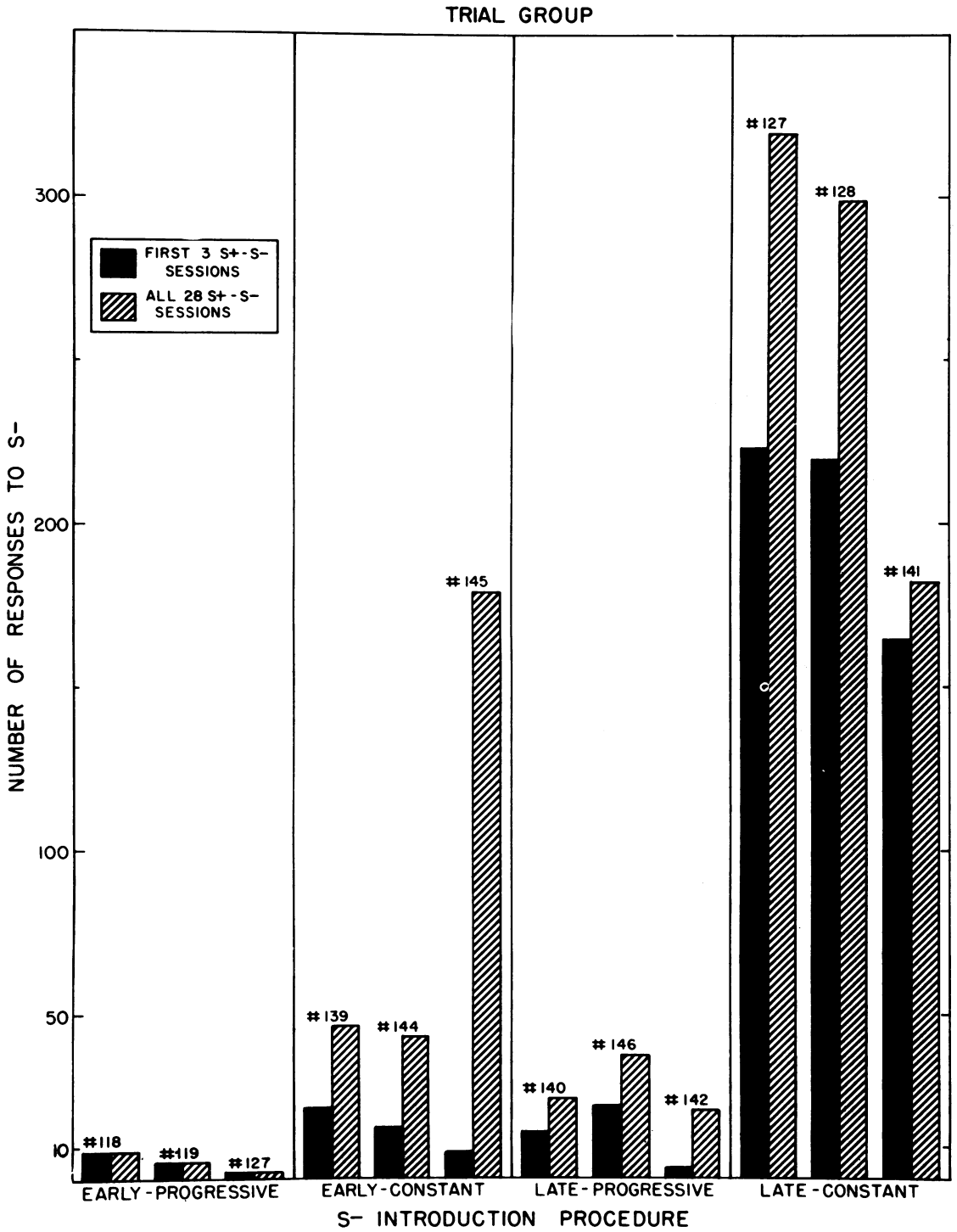


Fig. 2. The number of responses to S- made by each bird during the first three and during all 28 S+-S- sessions of Exp. II.

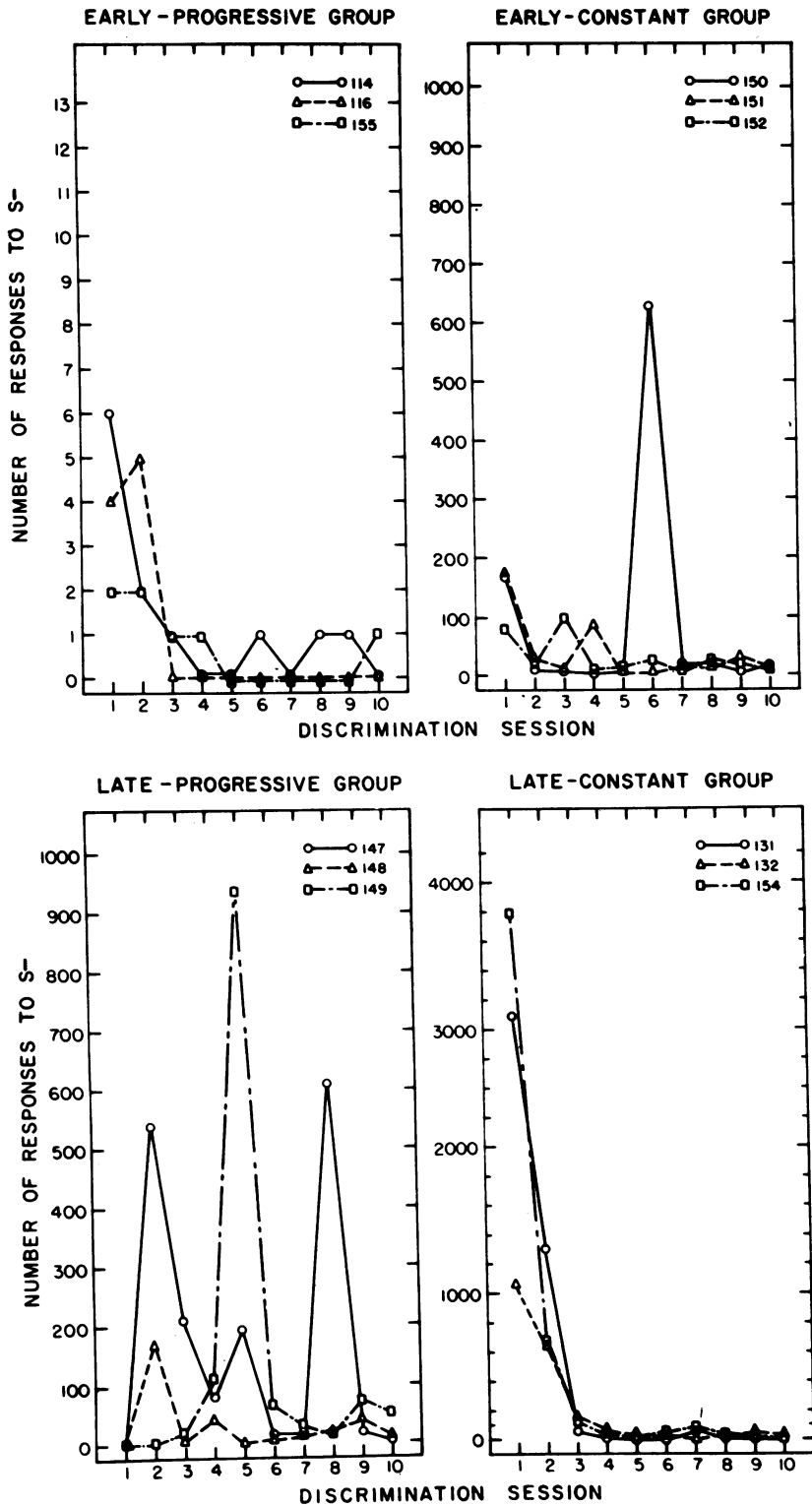


Fig. 3. The number of responses to S- made by each of the three birds of the four experimental groups during the first 10 discrimination (S+ - S-) sessions of Exp. I. Note that three differently scaled ordinates were used.

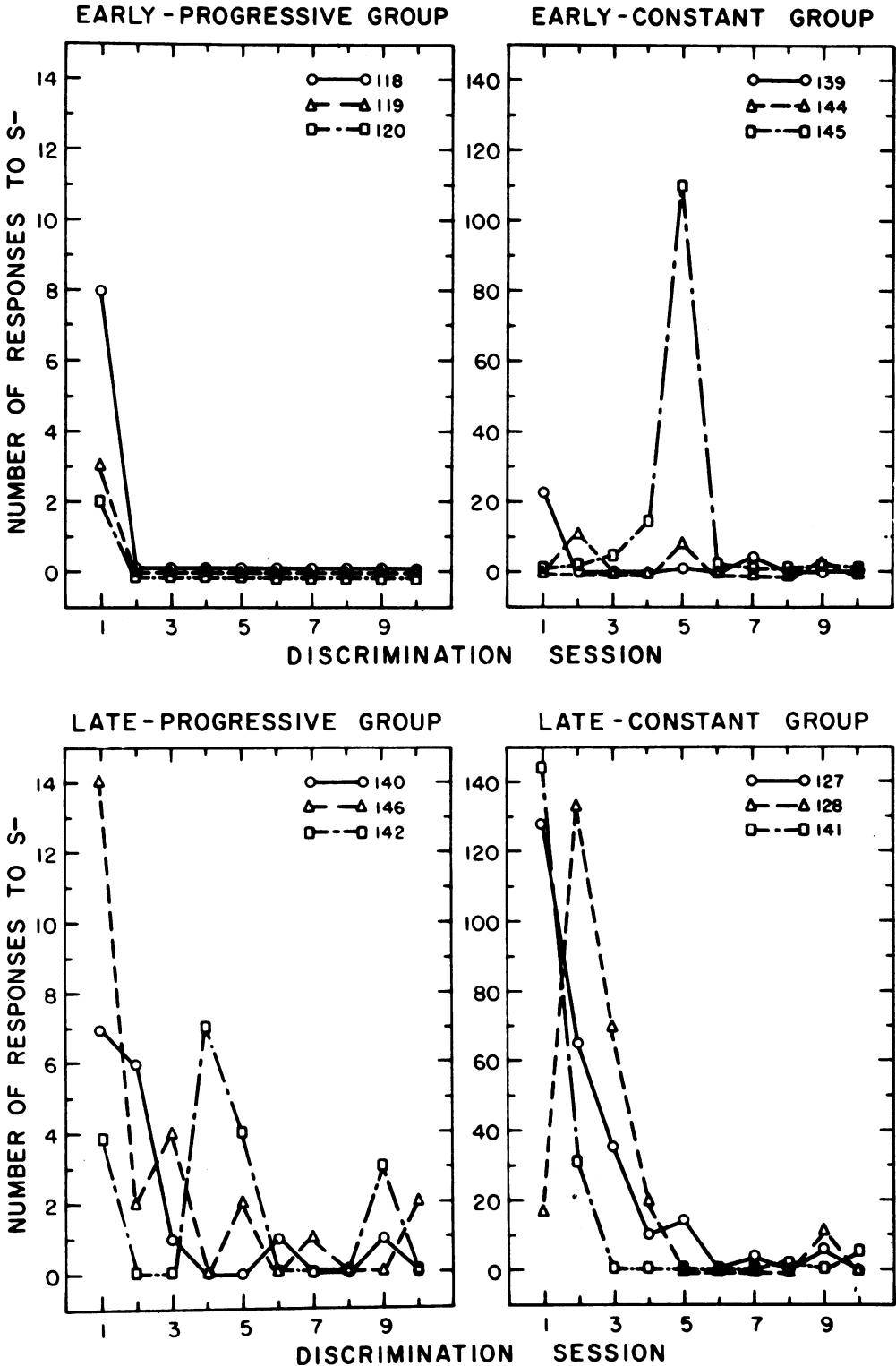


Fig. 4. The number of responses to S— made by each bird during each of the first 10 discrimination sessions of Exp. II. Note that the ordinates of the left and right-hand panels differ by a factor of 10.

least one burst of responses to S- during the first session of the second S+ - S- series.

Some casual observations of the non-key-pecking behavior in the presence of S- suggested further differences between the early-progressive and the other three groups of both experiments. When S- appeared, birds of the early-progressive group lowered themselves away from the key and stood quietly facing the key until the next S+ appeared. The behavior of the birds of the other groups, however, was much more agitated. When the S- component began, these birds would usually flap their wings, stamp on the floor of the chamber, and orient themselves away from the key. Occasionally, this behavior would be interrupted by sporadic key-pecking responses to S-.

Responses to S+: In Exp. I, at least 22 responses occurred during each S+ component of the first three S+ - S- sessions and at least 21 responses occurred during each S+ component during the subsequent S+ - S- sessions. In Exp. II, the probability of a response to S+, for each bird, was always 1.0 following the first S+ - S- session. The *rate* (Exp. I) and the *latency* (Exp. II) of responding to S+, however, were systematically affected by the onset of responding to S-. Two interactions between the S+ and the S- rates and latencies of responding will be discussed. The first is the effect of initial responding to S- on the rate or the latency of responding to S+ during the S+ - S- sessions. The second is the effect of responding to S- on the rate or latency of responding in subsequent S+ sessions.

The two different sequences of the S+ - S- and S+ sessions (cf. Table 1) prevent direct comparisons of the two types of interaction among all four experimental groups. Considering rate, for example, an increase in the rate of responding to S+, by the two early S- introduction groups, may not be exclusively attributed to discrimination training because the rate of responding to S+ normally increases during early training until some asymptotic level is reached. However, the effect of responding to S- on the rate of responding to S+ can be directly studied in the case of the two late S- introduction groups because, after 21 S+ sessions, the rate of responding had reached its asymptotic value and any change in the rate of responding to S+

can be attributed to the effects of discrimination training. It is also possible to directly study the second type of interaction (the effect of responding to S- on the rate of responding in the S+ sessions following the first series of S+ - S- sessions) because the rate of responding to S+, at the end of the first series of S+ - S- sessions, had reached stable asymptotic values. The same reasoning would apply to the latency interactions observed in Exp. II.

In Exp. I, the occurrence of many responses to S- was consistently accompanied by an immediate increase in the rate of responding to S+. On the other hand, when little responding to S- occurred there was no increase in the rate of responding to S+. Thus, the effect of acquiring a discrimination, on the rate of responding to S+, depended upon the amount of responding to S-. The increased rate of responding did not decline after responding to S- had declined to a stable low rate. Instead the higher rate continued throughout the remaining S+ - S- sessions. Conversely, during the S+ sessions that followed the first series of S+ - S- sessions, the rate of responding decreased if much responding to S- had previously occurred. This decrease in the rate of responding usually occurred in the first session following the S+ - S- sessions. If little responding to S- occurred during the previous S+ - S- sessions there was no rate decrease during subsequent S+ sessions.

The S+ and S- rates of responding for each bird are shown in Fig. 5. The top two panels show the rate of responding to S+ of the birds in the two early S- introduction groups during the last five S+ - S- sessions of the first S+ - S- series, the 14 subsequent S+ sessions and the first five of the second series of S+ - S- sessions. The rate of responding to S+ of the birds in the early-progressive group was not affected by any of the changes in procedure. These birds acquired the discrimination with virtually no responses to S-. The rate of responding of two out of three birds of the early-constant group (#'s 151, 152) dropped during the first S+ session. The rate of responding to S+ of all three birds, however, increased at the start of the second series of S+ - S- sessions. It is interesting to note that the rate of responding to S+ during the last five S+ - S- sessions of all three birds of the early-constant group is approximately

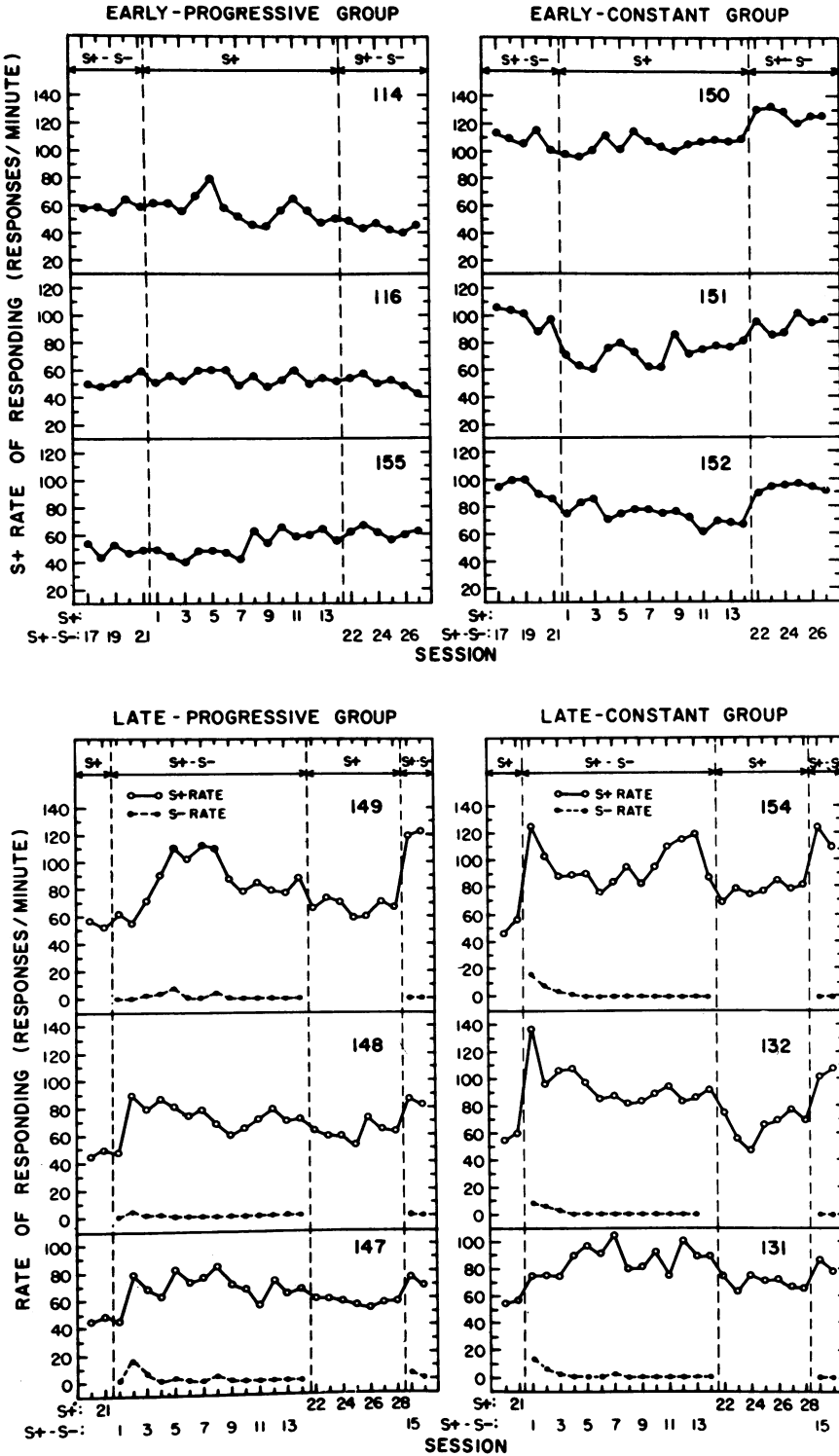


Fig. 5. The S+ rate of responding for each bird during the successive changes between S+ and S+ - S- sessions during Exp. I. The top two panels show the S+ rate of responding for each bird of the early-progressive and the early-constant groups. The bottom two panels show the S+ rate of responding (open circles) and the S- rate of responding (filled circles) for each bird of the late-progressive and the late-constant groups.

twice that of the birds of the early-progressive group during the same period. The birds of the early-constant group made many errors during the acquisition of the discrimination. Thus, even though an initial baseline rate of responding to S+ could not be obtained for the birds of the two early S+ introduction groups, it was shown that the rate of responding to S+ is higher following the acquisition of a discrimination with many errors, than following the acquisition of a discrimination with few errors.

The two bottom panels of Fig. 5 show the rate of responding to S+ (open circles) of the birds in the two late S- introduction groups during the last two sessions of the first S+ series, the first S+ - S- series, the second S+ series, and the first two sessions of the second S+ - S- series. To indicate the occurrence of responding to S- the two bottom panels of Fig. 5 also show the rate of responding (filled circles) to S- during the S+ - S- sessions. It should be remembered that, because the correction procedure allowed additional time to respond to S- after a response to S- occurred, the ratio of S+ and S- rates of responding is not directly proportional to the ratio of the amounts of responding to S+ and to S-.

The rate of responding to S+ of the birds of the late-progressive group increased in those sessions in which responses to S- first occurred. For birds 147 and 148 the increase occurred during the second session. The rate of responding of all three late-progressive birds declined during the first session of the second S+ series. During the second S+ series the rate of responding did not decline to the rate of the first S+ series. However, the increase in the S+ rate that occurred at the start of the second S+ - S- series restored the S+ rate to the value that prevailed during the first S+ - S- series.

In Exp. II, the initial occurrence of responding to S- was generally followed by a decrease in the latency of responding to S+. The shortened latency of responding to S+ persisted after responding to S- had stopped, or had reached a stable low level. The latency of responding increased to its pre-discrimination level at the start of the subsequent S+ series, and later decreased again at the start of the second S+ - S- series. If few responses to S- occurred during the formation of the

discrimination, the latency of responding to S+ was unaffected by any changes in procedure.

The mean latency of responding of each bird during the successive series of S+ and S+ - S- sessions is shown in Fig. 6. The top two panels of Fig. 6 show the mean latency of responding to S+ of the birds of the two early S- introduction groups during the last six sessions of the first series of S+ - S- sessions, all 14 subsequent S+ sessions, and the first five of the second series of S+ - S- sessions. All three of the early-progressive birds responded with approximately the same latency during each procedure. The latencies of responding to S+ of two out of the three birds of the early-constant group (#'s 139 and 145) increased at the beginning of the first S+ series and decreased at the start of the second S+ - S- series. The S+ latency of responding of Bird 144 was unaffected by either change in procedure.

The bottom two panels of Fig. 6 show the mean S+ (circles) and S- (triangles) latency of responding of the birds of the two late S- introduction groups during the last two sessions of the first S+ series, the first S+ - S- series, the second S+ series, and the first three sessions of the second S+ - S- series. S- trials during which no responses occurred were excluded from the computation of the mean S- latencies of the S+ - S- sessions. The S+ latency of Birds 140 and 146 (late-progressive group) became shorter at the start of discrimination training. After three S+ - S- sessions, however, the S+ latency of Bird 146 returned to its former value. At the start of the second S+ series, the latencies of Birds 140 and 146 increased but their latencies did not decline during the second S+ - S- series. The S+ latency of Bird 142 (late-progressive group) was unaffected by any of the changes in procedure.

The S+ latencies of all three of the birds of the late-constant group decreased during the first discrimination session, increased at the start of the second S+ series, and again decreased during the second S+ - S- series. The S- latency was initially only slightly longer than the S+ latency but gradually increased during successive discrimination sessions.

The decrease in the mean S+ latency (during the acquisition of a discrimination in

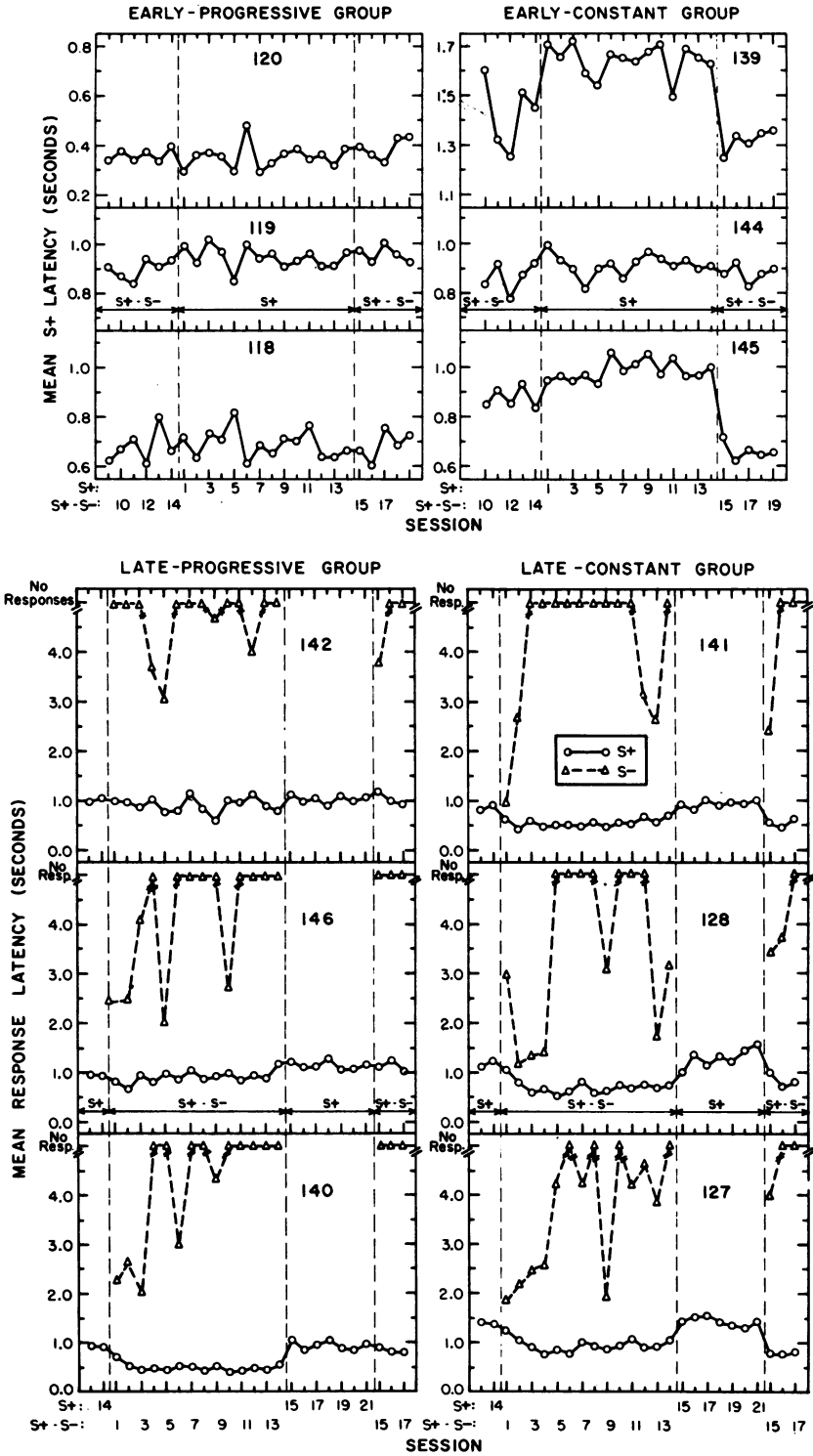


Fig. 6. The average latency of responding to $S+$ of each bird during the successive series of $S+$ and $S+ - S-$ sessions of Exp. II. The two top panels show the $S+$ latency of responding of each bird of the early-progressive and the early-constant groups. The bottom two panels show the $S+$ latency of responding (circles) and the $S-$ latency of responding of the late-progressive and late-constant groups.

which responding to S- occurred) resulted from both a decrease in the frequency of long latency responses and an increase in the frequency of short latency responses. Fig. 7 shows the latency distribution from two S+ and S- sessions of Bird 141 of the late-constant group. The S+ and S- latency distributions appear in the left and right-hand columns respectively. The positively skewed distribution in the top left panel is for the last S+ session prior to discrimination training. During the first S+-S- session, a large portion of the positive tail disappeared and the frequency of the short-latency responses increased. During the second S+-S- session the positive tail disappeared completely. During the first S+ session of the second S+ series (15th S+ session) the frequency of short-latency responses diminished sharply and the long positive tail reappeared.

Except for the relatively high frequency of long-latency responses, the S- latency distribution for the first S+-S- session (Fig. 7, right panels) closely resembled a positively skewed distribution from an S+ session. This resemblance, however, is only a superficial

one as the short-latency responses to S- occurred early during the session while the longer latency responses appeared toward the end of the session.

Intertrial responses: The number of responses to S- that occurred during the acquisition of the discrimination systematically affected the frequency of intertrial responses (ITR's) in Exp. II. Fig. 8 shows the number of ITR's that were made by each bird during all the S+ and S+-S- sessions. For the two late S- introduction groups the total frequency of ITR's during the S+ sessions has been broken down into those which occurred before (black bars) and after (large-dotted bars) discrimination training began. ITR's that occurred during S+-S- sessions have been broken down into the number following S+ trials (hatched bars) and the number following S- trials (lighter bars).

The birds of the early-progressive group responded between trials equally often during the S+ and S+-S- sessions. During the S+-S- sessions, ITR's following S+ and S- trials also occurred equally often. This group of birds made fewer ITR's during both the

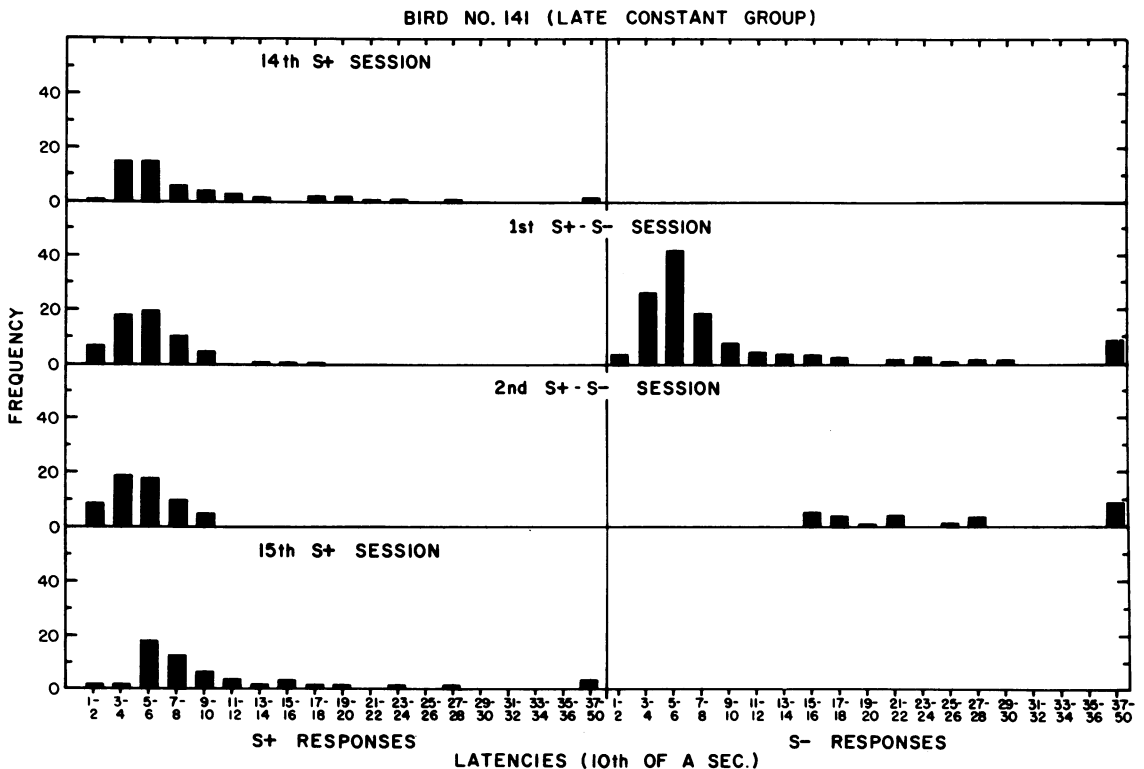


Fig. 7. Frequency distributions of S+ and S- latencies of bird 141 of Exp. II.

S+ and S+ - S- sessions than did the birds of any other group.

The ITR's made during the S+ - S- sessions by the birds of the other three groups occurred mainly after S- trials. Bird 145 of the early-constant group and the three birds of the late-constant group made the most ITR's during the S+ - S- sessions. These four birds also made the most responses to S- during the S+ - S- sessions. Almost all of the post S- trial ITR's occurred very shortly after the end of the trial, occasionally in bursts. The post S+ trial ITR's, on the other hand, were uniformly distributed throughout the intertrial intervals.

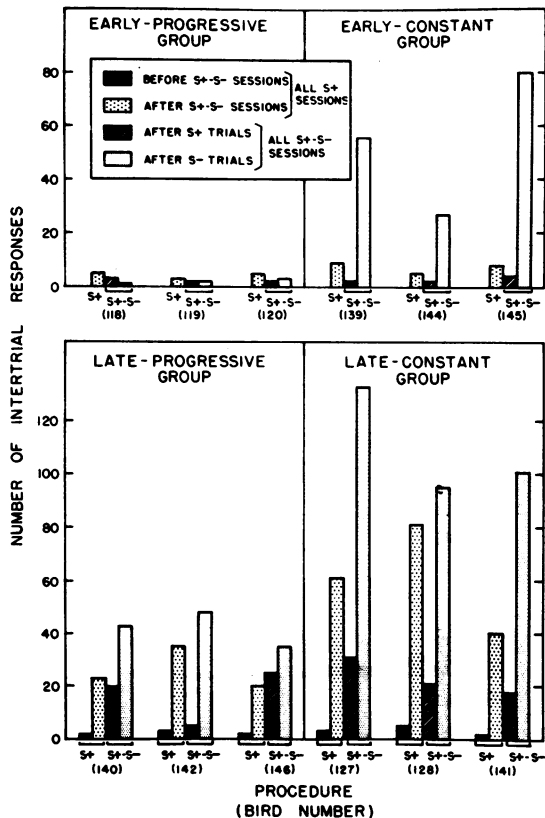


Fig. 8. The number of intertrial responses made by each bird during the S+ and S+ - S- sessions of Exp. II.

Almost all of the ITR's made during S+ sessions by the birds of the two late S- introduction groups, occurred during the S+ sessions following the first S+ - S- series. The fact that there were only seven S+ sessions in the second S+ series, as compared with 14 in

the first S+ series, makes this difference even more significant as there was more opportunity to make an ITR during the very first S+ series.

Cumulative Records: The cumulative records shown in Figs. 9 and 10 illustrate the acquisition of the discrimination, the accuracy of discrimination performance, and the changes in the S+ rate of responding of one bird from the early progressive and the late constant groups. These two groups were selected because they represent the extremes of the range of responses emitted to S-. The features of the records described below are typical of all birds in each group. In these figures the recording pen has been displaced downward for the duration of the S- component. The occurrence of reinforcements is indicated by short vertical lines below the cumulative curve.

Acquisition of the discrimination: Cumulative records I, II, and III in Fig. 9 show the first three S+ - S- sessions of Bird No. 114 of the early-progressive group. Dots have been placed over all of the S- components of the first S+ - S- session to distinguish the initially long magazine cycles from the short S- components. The pen displacements in record I that do not have dots over them indicate the occurrence of reinforcement. At *a*, in record I, Bird 114 was placed in the experimental box for the first time with the food magazine in its raised position. After magazine training, shaping of the key-pecking response began. At *b* the first key peck to S+ occurred. The cluster of deflections labeled *c* represents the reinforcements that followed each of the first five responses. Following the last reinforcement of this cluster, the schedule of reinforcement was changed from CRF to VI 30". The first phase of the early-progressive S- introduction, during which the duration of the dark key was increased from 5 to 30 sec, occurred between S- components *d* and *f*. The second phase, during which the duration of the S- component was 5 sec and the brightness of the S- was increased to that of the S+, began at *g* and ended at *j*; the final phase, during which the duration of the fully-bright S- was increased from 5 sec, to 3 min, occurred between S- components *k* and the third S+ - S- session. No responding to S- occurred until the second S- component, *e*, during which Bird 114 made two responses to

S-. Four other responses to S- were made during the first session which occurred in the S- components labeled *h* and *i*.

Responding to S- during the second and third sessions is indicated by arrows under the S- components in which they occurred. These

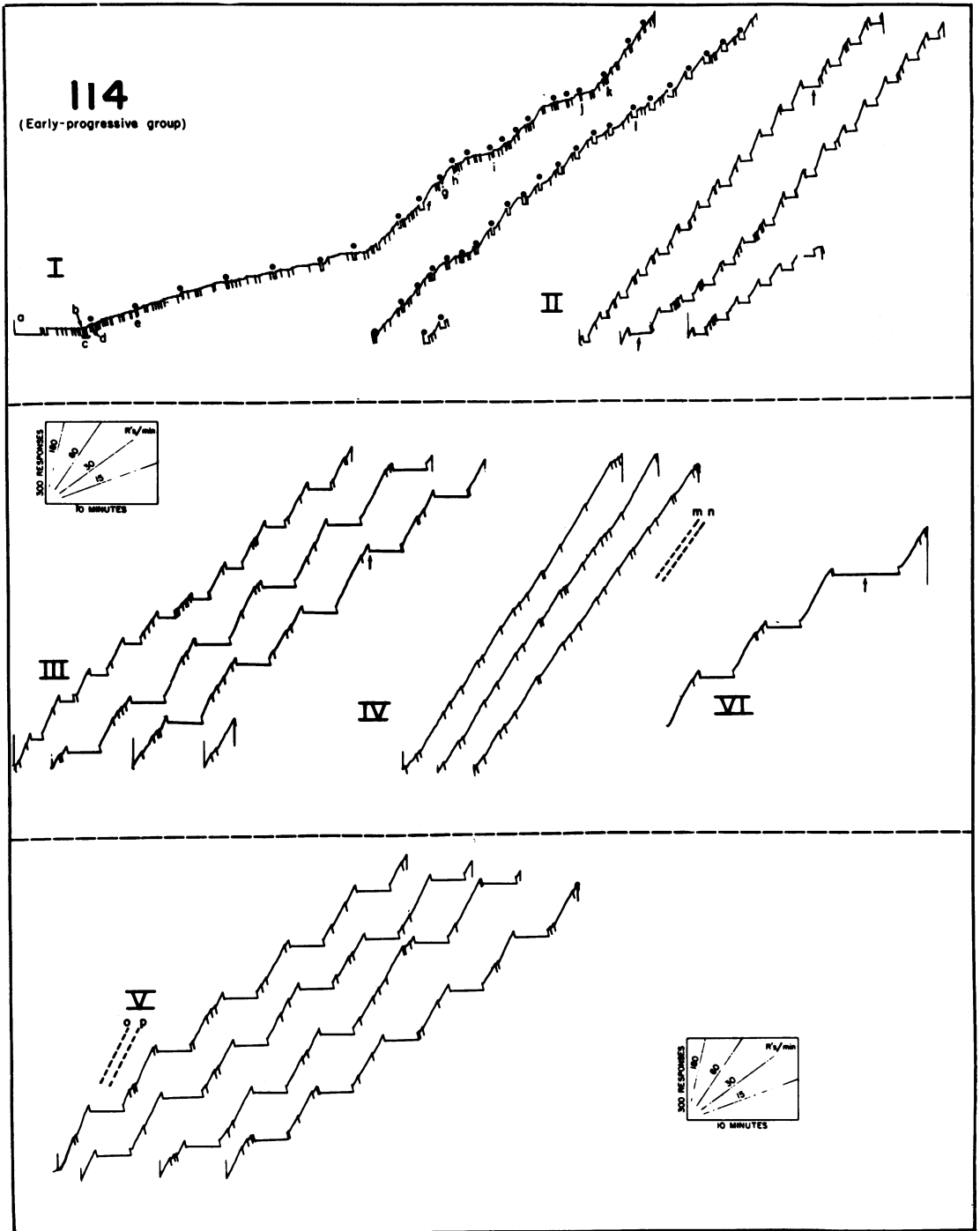


Fig. 9. Cumulative records of responding of bird 114 (early-progressive group) during the first three S+ - S- sessions (records I-III) a portion of the 24th S+ - S- session (record VI), the first S+ session (record IV), and the 22nd S+ - S- session (record V).

responses are typical of the two general types of responses to S- that the birds of the early-progressive group made during subsequent S+ - S- sessions. Two examples of the first type are shown in record II. Both responses to S- occurred just prior to the time at which the S- component could have ended had no responses occurred. Another example of this type of response to S- is shown by the arrow in record VI which shows a portion of the 24th S+ - S- session. The arrow in record III points to an example of the second type of response to S-. These responses came immediately after S- components began, just after the key-light changed from red to green.

The first discrimination session of Bird 154 of the late-constant group is shown in record II of Fig. 10. Responding to S- started immediately after the first S- component began (a). The rate of responding to S- was initially low but within 3 min it equalled the rate of responding of the previous S+ component and of the previous S+ session (Fig. 5, record I). Responding to S- persisted for approximately an hour, alternating between the S+ and a near zero rate. This pattern of responding to S- also occurred in the second S- component. Shortly after the start of the S- component, the S- rate of responding equalled the S+

rate of responding of the previous (second) S+ component, even though the rate of responding in the second S+ component had increased from about one to three responses a second. By the end of the first S+ - S- session, the S- rate of responding had declined to a near zero rate. With the exception of a burst of responding that occurred during the second S- component of the second S+ - S- session (not shown), a low rate of S- responding was maintained throughout the remaining S+ - S- sessions.

Accuracy of discrimination performance: During the first session of the second S+ - S- series, Bird No. 154 emitted three bursts of responding to S- (Fig. 10, record V). This bird had made many responses to S- during the first S+ - S- series. Bird 114, which had hardly responded to S- during the first S+ - S- series, did not respond to S- during the second S+ - S- (Fig. 9, record V).

S+ rate interactions: Examples of the development, within a single experimental session, of the two types of S+ rate interactions are shown in Fig. 10. The S+ rate of responding increased markedly following the initial occurrence of responding to S-. Following the extensive occurrence of responding to S- during the intervening S- component, the S+

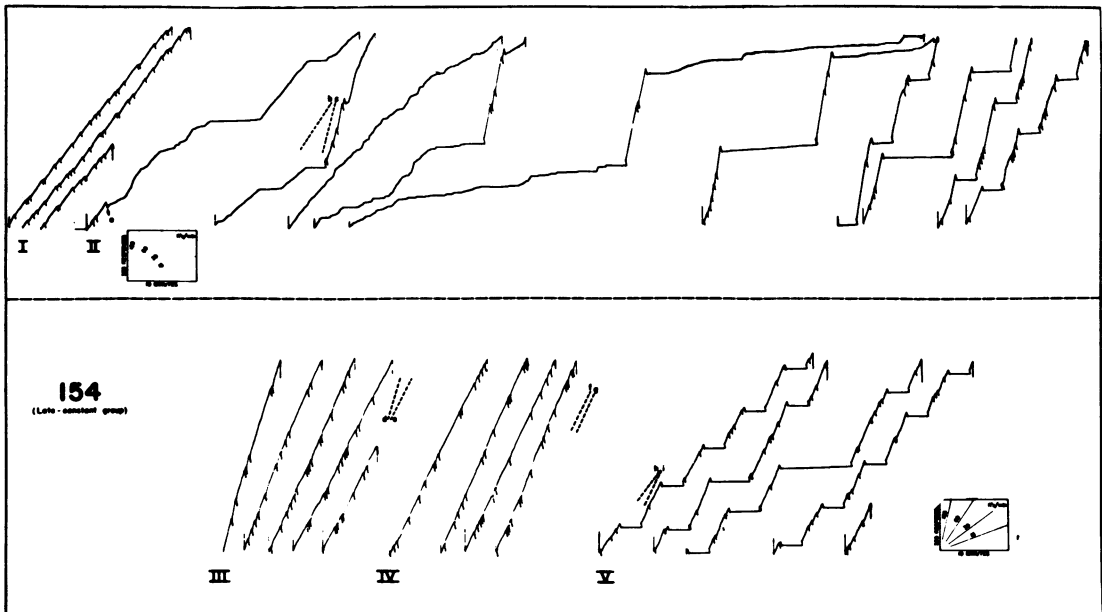


Fig. 10. Cumulative records of responding of bird 154 (late-constant group) during the 21st S+ session (record I), the first S+ - S- session (record II), the 22nd and 29th S+ sessions (records III and IV), and the 15th S+ - S- session (record V).

rate of responding increased from 60 (slope of line *b*) to 180 (slope of line *c* response per min.) This rate of responding prevailed throughout the first series of S+ - S- sessions and during the first portion of the first S+ session that followed (slope of line *d*). By the end of this S+ session, however, the rate of responding had declined to 90 responses per min (slope of line *e*). During the remaining S+ sessions the rate of responding ranged between 60 and 90 responses per min. The rate of responding within each S+ session, however, was fairly constant. Record IV of Fig. 10 shows the last (seventh) of the second series of S+ sessions. The slopes of line *f* and *g* (the rates of responding at the beginning and the end of this session, respectively) are essentially identical. The first of the second series of S+ - S- sessions is shown in record V. The S+ rate of responding during the first component, which was 60 responses per min, is represented by the slope of line *h*. After the intervening S- component the rate of responding in the second S+ component increased to 110 responses per min, even though no responding to S- occurred during the intervening S- component. The increased S+ rate of responding represented by the slope of line *i* prevailed throughout the remaining S+ - S- sessions.

An example of a failure to obtain either type of change in the S+ rate of responding is shown in Fig. 9 (Bird 114). The rates of responding during the final S+ session of the first S+ - S- series (slope of line *m*) and during the beginning (slope of line *n*) and the end (slope of line *o*) of the first S+ series were all the same. During the first of the second series of S+ - S- sessions (record V) there was no difference between the rate of responding during the first (slope of line *o*) and the second (slope of line *p*) S+ components.

Control Experiment

Two control experiments involving eight additional birds were performed to determine whether or not the results obtained from the main experiments were artifacts of three features of their procedures. The first type of artifact would be a reduction in the probability of a response to S- during the beginning of the first early-progressive session. This may have resulted from the experimenter's presentation of S- when the bird's head was

partially turned away from, or not near, the key. Another type of artifact could have resulted from the correction procedure. In Exp. I, responding in the S- component lengthens the duration of the S- component. Thus any extra time spent in the S- component increases the opportunity for responses to S- to occur. Similarly, in Exp. II, each response to S- results in the repetition of that trial and an increased opportunity to respond to S-. The third type of artifact could stem from a preference of red over green. Reid (1958) reported such a preference in a study of discrimination-reversal in the pigeon.

METHOD

The control experiment differed from the main experiment as follows. S- was introduced independently of each bird's behavior. The discriminative stimuli were reversed so that S+ was a green key-light and S- was a red key-light. The correction procedure was not used. In free-operant procedure, all S- components were 3 min long. In trial procedure, S+ and S- trials alternated randomly, independently of what happened on a given trial.

In the free-operant control a progressive S- was introduced early in the first session, independently of the birds' behavior (Birds 184 and 186). The procedure for introducing S- was the same as for the early-progressive group of Exp. I. Late-constant discrimination training for two other birds (#'s 189, 194) began after 21 S+ sessions. The S- was initially fully bright and of 3 min duration. This portion of the control experiment was terminated after 28 S+ - S- sessions.

The remaining four birds served as controls for Exp. II. For two birds (#'s 156 and 157) discrimination training, with a progressive S- began early during the first session. The procedure outlined above for the early-progressive S- introduction of Exp. II was followed. For the remaining two birds (#'s 158 and 159) discrimination training began after 14 S+ sessions. The S- was initially fully bright and of 5 sec duration. This portion of the control experiment was terminated after 21 S+ - S- sessions.

RESULTS

The data obtained from the control experiments show that the results of the main

experiment could not be attributed to special shaping by the experimenter, to the correction procedure, or to a color preference.

Figure 11 shows the number of responses to S- emitted by the free-operant control group during the first three (black bars) and during all 28 (hatched bars) of the S+ - S- sessions. The early-progressive control group made virtually no responses to S- during the first three (acquisition) and subsequent S+ - S- sessions. The two birds of the late-constant control group, however, made 1434 and 1763 responses to S-, respectively, during the acquisition sessions. This range of responses to S- during acquisition is lower than the range of 1922-4153 responses to S- made by the late-constant group of the main experiment during the first three S+ - S- sessions. It should be remembered, however, that the late-constant group of the main experiment reached a stable low rate of responding by the third S+ - S- session (c.f. Fig. 3). However, the

birds of the control group took 16 S+ - S- sessions to reach a low asymptotic level of responding to S-. Very little responding to S- occurred after the 17th S+ - S- session.

The range of the total number of responses to S- (2224-5396) made during all of the S+ - S- sessions fell completely within the range of responses to S- made by the late-constant group of the main experiment. Thus, while the decline of responding to S- was more abrupt under the correction procedure, the total amounts of responding to S- under the correction and the non-correction procedures were the same.

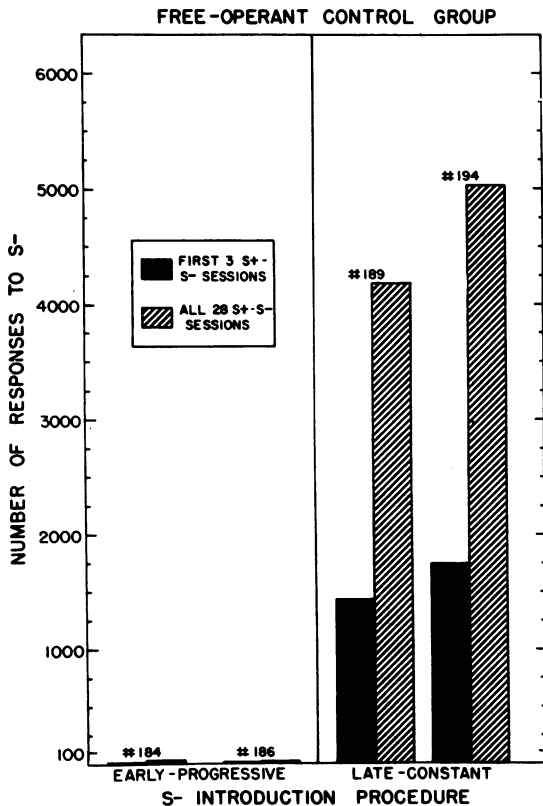


Fig. 11. The number of responses to S- made during the first three and during all 28 S+ - S- sessions by the birds of the free-operant control group.

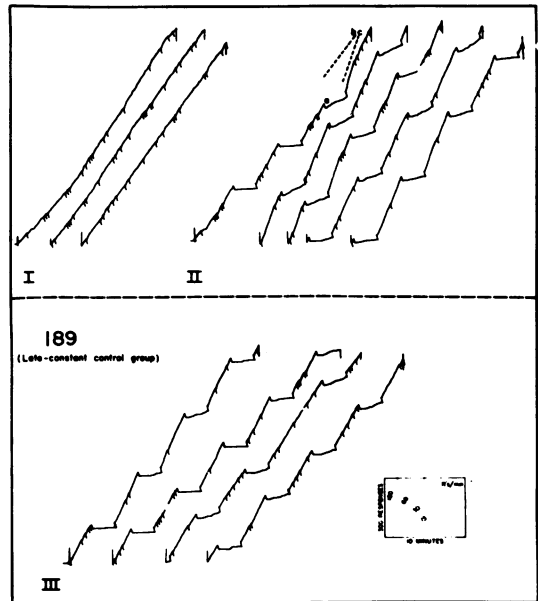


Fig. 12. Cumulative records of responding of Bird 189 during the 21st S+ session (record I), and the first and the third S+ - S- sessions (records II and III).

Another difference between the responding to S- that occurred during the main and control experiments was observed in the distribution of responses to S- within each S- component. By the end of the first session the rate of responding in the S- component had accelerated until a maximum rate was reached just prior to the onset of the next S+ component. This "scallop" effect during the S- component was fully developed by the third S+ - S- session (record III, Fig. 12) and is similar to the scalloping in the S- component reported by Morse (1955) in a multiple fixed ratio-extinction schedule.

The S+ rate of responding of Birds 184 and 186 remained at approximately 60 responses per min after the third S+ - S- session. The S+ rate of responding of Birds 194 and 189, however, increased during the first S+ - S- session after relatively little responding to S- had occurred, from approximately 60 to 90 responses per min. As in the main experiment, the increase in the S+ rate was maintained after responding to S- had declined to a low stable rate.

The amount of responding to S- of the trial procedure control birds during the first and during all of the S+ - S- sessions is shown by the black and the hatched bars of Fig. 13. Bird 157 of the early-progressive control group acquired the discrimination without a single response to S- and made no response to S- during any of the remaining sessions. The two birds of the late-constant control group made fewer responses to S- during the first three S- sessions than did the birds of the late-constant group of the main experiment. However, the total number of responses to S- made by the late-constant control group during all 28 S+ - S- sessions fell within the range made by the late-constant group of the main experiment.

As in the main experiment, the occurrence of responding to S- during the acquisition of the discrimination was accompanied by an immediate shortening of the S+ latency of responding.

The birds of the late-constant control group (#'s 158, 159) made 142 and 126 ITR's respectively during the 28 S+ - S- sessions. During their 28 S+ - S- sessions Birds 156 and 157 of the early-progressive control group made four and zero ITR's respectively. The number of ITR's following S+ and S- trials were not recorded separately during the control experiment.

DISCUSSION

Both experiments provided clear evidence that an operant discrimination can be acquired with few or no responses to S-, and that the number of responses to S- that do occur during the formation of a discrimination depends upon the manner in which S- is introduced. It was also shown that discriminations acquired with zero, or a near zero number of responses to S-, can be clearly

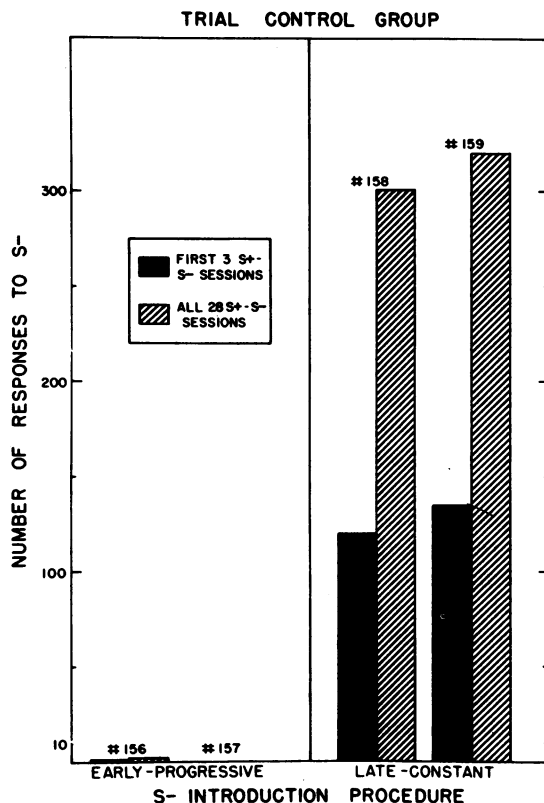


Fig. 13. The number of responses to S- made by the trial control group during the first three and during all 21 S+ - S- sessions.

distinguished from discriminations acquired with large amounts of responding to S- by criteria other than the number of acquisition responses to S-. These criteria are the accuracy of post-acquisition discrimination performance, the rate or latency of the responses to S+, and the pattern of non-key-pecking behavior that occurs in the presence of S-.

It is important to note that Bird 157 of the early-progressive control group of Exp II, which *never* responded to S- during all of the S+ - S- sessions, could not be distinguished from any of the other early-progressive birds that acquired the discrimination with a near-zero number of responses to S- with respect to both the S+ latency and non-key-pecking behavior in the presence of S-. Bird 157 was the last early-progressive subject of the two experiments that was trained and probably benefited from refinements in the program for progressively introducing S-. In a later experiment (Terrace, 1962) it was shown that the program used to train Bird

157 of the present experiment resulted in the acquisition and maintenance of a discrimination with *no* responding to S- in 12 out of 12 possible instances. For these reasons, discriminations acquired with zero, or a near zero number of responses to S-, will both be referred to as discriminations acquired without any responses to S-.

Characteristics of Discrimination Acquired with and without Responding to S-

Accuracy of discrimination performance: The accuracy of discrimination performance was best for the birds that acquired the discrimination without responding to S-. In Exp. II, the discrimination performance of the birds in the experimental and the control early-progressive groups was perfect. S- was never responded to after the first session. The performance of the early-progressive experimental and control groups of Exp. I was marred by only occasional single responses to S- which were always widely spaced in time. However, the birds of the remaining groups in both experiments frequently made bursts of responses to S- during the post-acquisition sessions. In Exp. II, the bursts of responding to S- were usually accompanied by intertrial responses. On the other hand, the absence of responding to S- was always correlated with the absence of intertrial responding. These differences suggest that one of the effects of large amounts of responding to S- during the acquisition of a discrimination is the development of permanently faulty discrimination performance.

Rate and latency of responding to S+: When the discrimination was acquired with few errors, the rate of responding to S+ in Exp. I and the latency of responding to S+ in Exp. II were unaffected by the acquisition of the discrimination. For the remaining birds, however, the S+ response rate increased and the S+ response latency shortened after the initial occurrence of responding to S-. Reynolds (1961) described similar instances of increases in the S+ rates of responding and decreases in the S+ latency of responding which occur during the formation of a discrimination and named these changes "behavioral contrast."

The data from the present study, especially the close correlation between the occurrence of responding to S- and the increase in the S+

rate of responding, suggest that behavioral contrast results from the occurrence of unreinforced responding to S-, rather than the acquisition of a discrimination *per se*. This conclusion supports Jenkins' (1961) interpretation of the shortening of the S+ latency during the formation of a discrimination. Jenkins noted that, since the S- latency is initially longer than the S+ latency of responding, the probability of reinforcement becomes more favorable for responses of a short latency. This contingency is actually a spurious one as the apparatus does not selectively reinforce short-latency responses. The selective reinforcement of short-latency responses is entirely due to the relative values of the latencies of responding on S+ and S- trials. In the present experiment, the discriminations acquired without responding to S- could not give rise to the selective reinforcement of relatively higher S- rates or to relatively shorter S+ latencies as no "reference" S- rate or latency was available. In the discriminations acquired with responding to S-, a "reference" rate or latency was provided in each case by the relatively lower S- rates or the relatively longer S- latencies.

Reynolds (1961) has suggested an alternative explanation of contrast during the formation of a discrimination: "A change in the relative frequency of reinforcement associated with one of several successive stimuli changes the rate of responding during that stimulus; an increase in relative frequency produces an increase in the rate of responding." (Reynolds, 1961, p. 70.) Thus, Reynolds' specification of contrast does not consider whether or not responses to S- occurred. Instead, it considers only changes in reinforcement density. In the present study the reinforcement density was halved during the discrimination sessions, yet the S+ rate or latency was affected only in those instances in which responding to S- occurred. In their present form, these results cannot directly test the generality of Reynolds' account of contrast because, during the S+ sessions, only one discriminative stimulus was presented. Thus, a comparison of the relative reinforcement densities in the S+ and the S+ - S- sessions is not possible. Subsequent data (Terrace, 1962), however, indicate that a change in the relative reinforcement density will not result in a change in the rate of responding to S+ if the discrimination was

acquired without responding to S⁻. Thus, a necessary condition for contrast seems to be responding to S⁻.

Behavior in the presence of S⁻: Only those birds that made many responses to S⁻ during the acquisition of the discrimination displayed a fright reaction or turned their heads away from the key following the onset of an S⁻. This suggests that, as a result of the process of S⁻ extinction, S⁻ acquires aversive properties.

The aversive properties of S⁻ have been studied in a number of different types of experiments. The maintenance of avoidance behavior by the delay of the occurrence of an S⁻ was demonstrated by Morse and Herrnstein (1956). Brethower (personal communication) has shown that a pigeon will work for time-outs from the extinction component of a multiple variable-interval-extinction (MULT VI EXT) schedule of reinforcement. Herrnstein (1955) demonstrated conditioned suppression in the presence of a stimulus that precedes S⁻. In this experiment the Estes-Skinner warning stimulus procedure was superimposed on a MULT VI EXT schedule of reinforcement. (A warning stimulus appeared in the VI component *t* sec before the onset of the EXT component.) Under certain conditions, Herrnstein found that positively reinforced behavior was suppressed in the presence of the warning stimulus. In similar experiments, Ferster (1957, 1958) demonstrated that positively reinforced behavior can be suppressed in the presence of a warning stimulus where responding to S⁺ results in the appearance of an S⁻. Finally, Hanson (1961) and Pierrel and Sherman (1962) have demonstrated that the peak of a generalization gradient obtained after discrimination training is displaced away from S⁺, in a direction that is also away from S⁻.

The absence of any examples, among these earlier experiments, of discriminations acquired without responding to S⁻ prevents us from determining to what extent the extinction of responses to S⁻ contributed to the aversiveness of S⁻. The results of the present study, however, suggest that when no responses to S⁻ occur, S⁻ could act as a neutral stimulus and that unreinforced behavior in the presence of S⁻ is necessary for S⁻ to function as an aversive stimulus.

The aversive properties of S⁻ may also contribute to the maintenance of the permanent

contrast effects observed in both experiments. In Exp. I, for example, the rate of responding to S⁺ often increased following the first S⁻ component of the second S⁺-S⁻ series, even though no responding occurred during the S⁻ component (*e.g.*, Fig. 10, record V). Similarly, the S⁺ rate increase was maintained during the first S⁺-S⁻ series even though responding to S⁻ had declined to a near zero level. On the other hand, no increase in the S⁺ rate of responding was obtained for any of the birds that acquired the discrimination without responding to S⁻. This interpretation suggests that the aversiveness of S⁻, resulting from extinction that occurred in its presence, is maintained long after the extinction of responding to S⁻ is complete.

Relationships between the Manner of Introducing S⁻ and Subsequent Responding to S⁻

In accounting for the different amounts of responding to S⁻ following each of the four modes of introducing S⁻ it is important to distinguish between responses to S⁻ emitted during the early, and during the later portions of discrimination training. In both Exp. I and II, classical generalization theory would predict the relative amounts of initial responding to S⁻ of each group. The early-progressive S⁻ introduction procedure would result in the least amount of generalization. Fewer than a dozen responses to S⁺ were reinforced before discrimination training began, and S⁺ and S⁻ differed with respect to both brightness and duration as well as with respect to wave length. At the other extreme, a maximal amount of generalization should result from the late-constant S⁻ introduction procedure because the S⁺ response had a long history of reinforcement and S⁺ and S⁻ differed only with respect to wave length. The early-constant and the late-progressive S⁻ introduction procedures afforded intermediate amounts of generalization between S⁺ and S⁻. The early-constant procedure started discrimination training with two closely spaced stimuli on a relatively low gradient. The late-progressive procedure started discrimination with two, more widely spaced stimuli on a relatively high gradient.

Discrimination performance following the initial S⁺-S⁻ sessions cannot be predicted from the known properties of generalization

gradients. After the first (Exp. II) or the third (Exp. I) discrimination sessions, the physical difference between S+ and S- was the same for each experimental group. Furthermore, each of the two early and two late S- introduction procedures ultimately provided the same number of reinforcements for responding to S+. From this information one would, for example, predict that the early-progressive groups would start emitting responses to S- after a certain number of responses to S+ were reinforced, or after the S+ - S- difference had been reduced to a certain value. The absence of responding to S- as training progressed suggests that certain features of the early-progressive S- introduction procedure produced a permanent "short-circuiting" of the S- extinction process. This is also true, to a lesser extent, of the early-constant and the late-progressive groups, as they made fewer responses to S- than did the late-constant groups. These data and the results of other discrimination experiments (*e.g.*, Lawrence, 1952) also suggest a "short-circuiting" of the extinction process. This short-circuiting may be attributed to one or both of the following factors: the absence of intermittent reinforcement resulting from responding to S-, and the superstitious conditioning of not responding to S-.

Intermittent reinforcement generated by responding to S-: Discrimination performance was poorest for birds that made many responses to S- in acquiring the discrimination. The poor performance may, in part, be attributed to early intermittent reinforcement resulting from responding to S-, which had the effect of retarding the subsequent elimination of responding to S-. Occasional bursts of responding to S- may in turn generate a further intermittent effect which could, under appropriate conditions, result in permanently faulty performance. This interpretation is supported by the results of an experiment of Jenkins (1961). Jenkins showed that pigeons that had received intermittent reinforcement, generated by responding to S- during the acquisition of a discrimination, showed the same resistance to extinction, of the response to S+, as did pigeons that received the same schedule of intermittent reinforcement in the presence of only one stimulus. However, the resistance to extinction of a group of pigeons continuously reinforced in the presence of one

stimulus, was lower than the resistance to extinction of the pigeons of both of the first two groups.

Superstitious conditioning of not responding to S-: At the start of the progressive S- training procedure, S- was a short presentation of a dark key. The initial response to this stimulus, of every pigeon of the progressive S- introduction groups, was jerking the head away from the key. Approximately 5 sec later, the S+ appeared. This sequence of events may have established a spurious contingency between moving the head away from the key and the rapid subsequent restoration of the S+. By strengthening a response that is incompatible with a response to S-, this contingency could have been an effective factor in the reduction of responding to S-. It is important to note in this connection that the initially short duration seems more important than the initial dimness of the progressive S- for the establishment of this contingency. None of the birds of the early-constant group of Exp. I responded to the first S- (a fully bright key of 3 min duration) for at least 30 sec. This suggests that a gradual lengthening of even a fully bright S- may have been effective in establishing the superstitious withdrawal of the head away from the key.

Implications for theories of discrimination learning: The demonstration of the acquisition and the maintenance of a discrimination without responding to S- necessitates a revision of a number of currently accepted accounts of discrimination learning. It is widely agreed that the extinction of responding to S- is a necessary condition for the formation of a discrimination. This point of view was perhaps most succinctly stated by Keller and Schoenfeld: "Extinction is the hallmark of discrimination" (1950, p. 119). Spence's (1936) and Hull's (1950) quantitative accounts of discrimination learning are based upon the interactions between excitatory and inhibitory gradients that result from conditioning in the presence of S+ and extinction in the presence of S- respectively. Without the concept of an inhibitory gradient it is difficult, if not impossible, for a conditioning-extinction theory to account for discrimination learning without errors. Discrimination learning without errors would thus be excluded from the domain of conditioning-extinction theories as no inhibitory gradient could occur in this case.

As suggested earlier, other factors such as the intermittent reinforcement of faulty discrimination performance and the superstitious conditioning of not responding to S-, may prove to be important in accounting for discrimination learning without errors. An additional factor worth exploring is the possible influence of visual learning-sets that may have been acquired, prior to the experiment, in the natural environment of a bird.

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