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PROCEDURAL ANTECEDENTS OF BEHAVIORAL CONTRAST: A RE-EXAMINATION OF ERRORLESS LEARNING[1]

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Behavioral contrast reliably occurred in pigeons following errorless discrimination training, contrary to Terrace's (1963) observations. In the main experiment, a 60-sec green keylight, associated with a variable-interval 30-sec schedule of reinforcement alternated with a 60-sec period of extinction when the key was dark. Such aspects of the discrimination training procedure as: (1) the amount of prior nondifferential exposure to the positive stimulus before the discrimination was instituted, and (2) the rapidity with which the negative stimulus was introduced (whether progressively or abruptly) directly influenced the amount of behavioral contrast produced. This occurred independently of the number of errors made by a pigeon during acquisition of the discrimination. In a series of control experiments, substitution of a red keylight for the dark key during extinction resulted in greater behavioral contrast, while an increase to 3 min in the duration of the green keylight associated with reinforcement attenuated the behavioral contrast effect.

Key words: behavioral contrast, errorless discrimination, acquisition of discrimination, discrimination training, errors, extinction, key peck, pigeons

Behavioral contrast is often observed within the context of successive discrimination training. For one stimulus, S+, the consequences of responding remain constant throughout the experiment; the schedule of reinforcement associated with that stimulus never objectively changes. However, when S+ alternates with another stimulus, S−, which is associated with nonreinforcement (or reinforcement on a less-preferred schedule) for the same response, an increase in responding during S+ occurs relative to the baseline rate of responding during S+ (Reynolds, 1961). This response-rate increase is the defining characteristic of behavioral contrast.

Stemming from his early investigations of the acquisition of a discrimination (Terrace, 1963), Terrace (1972) formulated an influential theory to account for behavioral contrast as a byproduct of discrimination learning. The critical observation from which Terrace's theory evolved was that behavioral contrast occurred only when the discrimination training procedure produced a reduction during S− of the response that is reinforced during S+. Such responses during S− are commonly designated as errors. When the discrimination was acquired without such errors, no behavioral contrast was observed (Terrace, 1963). Terrace consequently concluded that behavioral contrast does not occur in cases where a discrimination is acquired without errors.

Considerable research challenges the validity of Terrace's conclusion. For example, Halliday and Boakes (1974), Reynolds (1961), Sadowsky (1973), Taus and Hearst (1970), and Vieth and Rilling (1972), investigated the effects of blackouts on behavioral contrast. Because the pigeon easily discriminates the blackout from the stimuli associated with reinforcement, the blackout serves as an S− that readily occasions errorless (or nearly errorless) performance. In each of these studies, the rate of responding during S+ increased above baseline rates when alternated with a blackout period, even though few responses were made during blackout periods.

Because Terrace's (1963) observation that behavioral contrast occurs only in subjects that learned the discrimination with errors

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is so fundamental to his theory of discrimination learning, and yet so discrepant from the results noted above, the present study intensively investigated the influence of Terrace's discrimination training procedures on the magnitude of behavioral contrast. Essentially, this experiment tested whether pigeons that acquire a discrimination errorlessly fail to show behavioral contrast, regardless of the procedure used to generate the errorless discrimination. This crucial test of Terrace's major premise has never been performed under conditions that approximate the context of his original investigation. For this reason, a systematic replication of Terrace's (1963) study (Experiment I) was attempted. If no compelling relationship between the occurrence of errors and the occurrence of behavioral contrast is demonstrated, then the alternative hypothesis must be entertained that the training procedure itself mitigates against both the occurrence of errors and the occurrence of behavioral contrast. This interpretation is plausible when one considers that Terrace's (1963) errorless group, which showed no behavioral contrast, was also the only group that experienced one particular training condition (Early-Progressive training).

Terrace (1963) considered two procedural variables in deriving his discrimination training methods: the time in the pigeon's experimental history at which discrimination training is instituted, and the rapidity with which S− is initially introduced. Clarifying the influence of these variables on the production of errors during S− and of behavioral contrast was the focus of the present procedural analysis.

Manipulation of the time at which discrimination training is introduced influenced the amount of nondifferential exposure to S+ each pigeon received before S− was introduced. Thus, for some pigeons, discrimination training followed a period of nondifferential baseline training on S+, with the time of introduction thus described as Late. For other pigeons, discrimination commenced from the first day of training, a condition labelled Early.

The introduction of S− was accomplished either abruptly or gradually across trials. The abrupt introduction of S−, termed the Constant procedure, involved presenting S− at full duration and intensity from the outset of discrimination training, differing from S+ only with respect to the relevant stimulus dimension: wavelength or color. This is in contrast to the Progressive procedure, which involved first presenting S− at reduced intensity for brief exposures and then gradually increasing intensity and exposure time with successive presentations of S−.

Each of the four procedures that resulted from crossing the Early *versus* Late time of initiation of discrimination training conditions with the Progressive *versus* Constant manner of S− introduction ultimately produced a discrimination. However, the quality of the discrimination obtained for groups differed considerably. Among these differences was the fact that the Early-Progressive group alone displayed errorless or nearly errorless performance, and at the same time it was the only group that did not exhibit behavioral contrast.

In order to partition the presumed effects due to training procedure from those due to responding or not responding to S−, it was necessary to establish more than one errorless group in the present study. The key to the design of this aspect of the experiment was evidence, cited previously, that the rate of pecking a dark key is very low when responding on an illuminated key is reinforced. Since the likelihood of significant responding to a dark key is low, the probability of producing another errorless group by Terrace's suggested criterion of 25 or fewer responses throughout the course of the experiment (Terrace, 1972) is greatly increased when a dark key is used as S−.

METHOD

Subjects

Forty adult female White Carneaux pigeons, with no experimental history, were maintained at 80 ±2% of free-feeding body weights and individually housed under conditions of constant illumination and free access to water and grit.

Apparatus

Two standard three-key operant chambers (LVE model 1519) were equipped with LVE model 1348 QL stimulus projectors. Only the right key, 5 cm to the right of center and 25 cm above the floor, operated; the other

keys were covered. A minimum effective force of 0.2 N was required to operate the response key, which was lighted either red or green or remained dark. The key-peck response occasionally resulted in the presentation, according to schedule, of a hopper of mixed grain as a reinforcer. Except during scheduled blackouts, the chambers were each illuminated by 2.25-W houselights. Extraneous sounds were partially masked by ventilating fans in each chamber. Electromechanical programming and recording equipment was contained in an adjacent room.

Design

The variables, time of introduction of S− (Early or Late), and rapidity of introduction of S− (Progressive or Constant), were manipulated in a 2 × 2 factorial design. Eight pigeons served in each of the four main treatment groups. Four other pigeons also served in each of the two control groups. For pigeons in each group, within-subjects comparisons were made possible by multiple alternations between baseline and discrimination training conditions.

Procedure

Because only those factors relating to the introduction of S− differed across the four main treatment groups, the conditions for baseline and discrimination training were identical for all birds. Consequently, the procedures for each training phase are described below without regard for the specific treatment group designation of each pigeon. The order of these training phases, however, reflects the Early *versus* Late group distinctions, with subjects from the Early groups beginning immediately with discrimination training while subjects from the Late groups established baseline levels of responding before discrimination training was instituted. The Progressive *versus* Constant group distinction determined the rapidity with which exposure to S− was initiated during the first discrimination phase. The basic procedure followed for each group is outlined in Table 1.

Baseline training phases. During all baseline sessions, only one stimulus component was available. The response key was green (S+) for 60-sec periods, during which time a variable-interval (VI) 30-sec schedule of reinforcement was in effect. Each 3-sec reinforcement presentation was arranged according to the formula described by Catania and Reynolds (1968) for deriving constant-probability VI schedules. During reinforcement, the key-light changed from green to red. Successive presentations of S+ were separated by 3-sec blackouts, during which time the key- and houselights were turned off. Daily baseline sessions terminated after 25 presentations of S+.

Discrimination training phases. The principal distinction between baseline and discrimination training phases consisted in the

Table 1

Summary of Training Procedures for Experimental Groups

Phase	*Experimental Groups*			
	Early-Progressive	*Early-Constant*	*Late-Progressive*	*Late-Constant*
I	Progressive introduction of S− / DISCRIMINATION Training	Constant introduction of S− / DISCRIMINATION Training	BASELINE Training	BASELINE Training
II	BASELINE Training	BASELINE Training	Progressive introduction of S− / DISCRIMINATION Training	Constant introduction of S− / DISCRIMINATION Training
III	DISCRIMINATION Training	DISCRIMINATION Training	BASELINE Training	BASELINE Training
IV	BASELINE Training	BASELINE Training	DISCRIMINATION Training	DISCRIMINATION Training
V	DISCRIMINATION Training	DISCRIMINATION Training	BASELINE Training	BASELINE Training

interpolation of a stimulus correlated with extinction (S−) between successive presentations of S+ during discrimination training. Sixty-second presentations of a dark key (S−) alternated on a pseudorandom schedule with 60-sec presentations of the green key S+, separated by 3-sec blackouts. No stimulus was presented more than twice in succession.

A multiple schedule of reinforcement was in effect during the discrimination training phases, with S+ associated with a VI 30-sec schedule (as it was during baseline training) and S− associated with extinction. Responses during S− had no scheduled consequences. Daily discrimination training sessions terminated after 25 presentations each of S+ and S− components, making a total of 50 stimulus presentations.

Introduction of S−. Immediately after the key-peck response was established and 25 consecutive responses were reinforced, the training conditions appropriate to each group were instituted. Both Early groups (Early-Progressive and Early-Constant) were placed in the discrimination phase with the next experimental session. The Late groups (Late-Progressive and Late-Constant) established baseline levels of responding to S+ before the discrimination phase was initiated.

The Progressive procedure for introducing S− preceded the first discrimination phase for the appropriately designated groups (Early-Progressive and Late-Progressive) according to the procedure outlined in Table 2. All discrimination-phase contingencies were in effect throughout the Progressive introduction of S−, but the dark key was gradually faded in by increasing the duration of its exposure. No special procedure was necessary for the Constant groups because they were exposed to S− at full duration from the first session of discrimination training.

Control groups. Discrimination training for both control groups followed the basic Early-Progressive procedure. The training procedure followed with the Red S− control group

Table 2

Summary of the Five-Day Progressive Procedure for Introducing S−

	Day 1		*Day 2*		*Day 3*		*Day 4*		*Day 5*	
S− *Trial*	*S−* *Duration*	*S−* *Intensity*[a]	*S−* *Duration*	*S−* *Intensity*	*S−* *Duration*	*S−* *Intensity*	*S−* *Duration*	*S−* *Intensity*	*S−* *Duration*	*S−* *Intensity*
1	2	5000	2	2000	2	1000	2	600	3	300
2					3		4		6	
3					4		6		9	
4			↓		↓		↓		↓	
5			3		5		8		12	
6					6		10		15	
7			↓		↓		↓		↓	
8			4	↓	7	↓	12	↓	18	↓
9				1400	8	850	14	500	21	200
10			↓		9		16		24	
11	↓		5		10		18		27	
12	3				11		20		30	
13			↓		12		22		33	
14			6	↓	13	↓	24	↓	36	↓
15				1200	14	700	26	400	39	100
16		↓	↓		15		28		42	
17		2000	7		16		30		45	
18					↓		↓		↓	
19			↓		17		32		48	
20	↓		8	↓	18	↓	34	↓	51	↓
21	4			1000		600	↓	300	↓	0
22			↓		19		36		54	
23			9		20		38		57	
24					21		40		60	
25	↓	↓	↓	↓	22	↓	42	↓	60	↓

NOTE: S− duration is reported in seconds, S− intensity in ohms resistance.

[a]S− intensity manipulations were performed only for the Red S− Control Group. For all other groups, S− was a dark key.

differed from that applied to the Early-Progressive group in the main experiment only in the respect that during S− the key was red rather than dark. The red S− was introduced according to the schedule described in Table 2. The intensity of S− was controlled by placing a resistor in series with the 24-V, type 757, red stimulus light. The intensity values listed in Table 2 are in units of ohms resistance. The Three-Minute S+ control group was exposed to stimulus components identical to those used in the main experiment in all respects except S+ duration. Total S+ time was held constant at 25 min, but each successive presentation lasted 188 sec. Eight presentations of S+ alternated with eight 60-sec presentations of the dark key as S−.

Phase termination. The decision to terminate each baseline and discrimination training phase was based on a comparison of each pigeon's behavior with a stability criterion: a new phase could be initiated after at least 10 days of exposure to a given phase, but then only if the standard deviation of the rate of key pecking for five consecutive experimental sessions was less than two responses per minute. Any bird whose responding failed to stabilize within 35 sessions on any phase was dropped from the study. Only one pigeon (from the Early-Constant group) failed to exhibit stable performance by the thirty-fifth day of the first discrimination training phase and consequently was replaced.

For each group, a total of four changes in training phase occurred, yielding a BABAB configuration for Early groups, which began on the discrimination phase (B) and were then shifted to baseline training (A), then back to discrimination training, *etc.*, and an ABABA configuration for the Late groups, which began with the baseline phase (A), were then introduced to the discrimination training phase (B), and then shifted back to baseline, *etc.* The Red S− and Three-Minute S+ control groups experienced only two training phase changes.

RESULTS

Chief among the results were the observations that the number of errors emitted during S− and the amount of behavioral contrast were independently influenced by the time at which S− was introduced, and to a lesser degree by the rapidity with which S− was introduced. No systematic relationship was found between the occurrence or nonoccurrence of responding during S− and the production of behavioral contrast. The greatest influence of the Progressive or Constant S− introduction procedure was on the distribution of responses during S−.

Responses during S+. Figure 1 illustrates the rate of responding to S+ exhibited by two individual subjects randomly selected from each training group across training phases. Because the number of training sessions differed between subjects, due to the imposition of the stability criterion, only the first and last five training sessions are represented for each training phase. Baseline sessions are captioned on each figure as "S+ ONLY"; discrimination sessions are captioned as "S+|S−". For ease of reference, discrimination phases are also indexed. The first five sessions of S+|S−1 presented for the Late-Progressive group are the five discrimination sessions that immediately follow the progressive introduction of S−. The numbers in parentheses indicate the number of errors made by that pigeon during each discrimination training phase.

It is important to recognize that the conditions associated with S+ are never physically changed. Any changes in S+ response rate are instead due to the effect of S− alternating with S+ during discrimination training. An increase in S+ response rate at transitions from baseline to discrimination training denotes behavioral contrast, as does a decrease in response rate at transitions from discrimination training to baseline conditions. In all subsequent discussions, the magnitude of behavioral contrast observed was measured by comparing the mean S+ response rate for the final five sessions of one training phase with the mean S+ response rate for the first five sessions of the subsequent training phase.

Behavioral contrast was displayed in all groups, although there were differences in the magnitude of the effect, as well as in the reliability and permanence of the change in S+ response rate. Behavioral contrast during each training phase was said to occur in individual subjects only if the mean S+ response rate during the first five days of each training phase was greater than one standard deviation from the mean response rate of the preceding five days. In the Early-Progressive group, five pi-

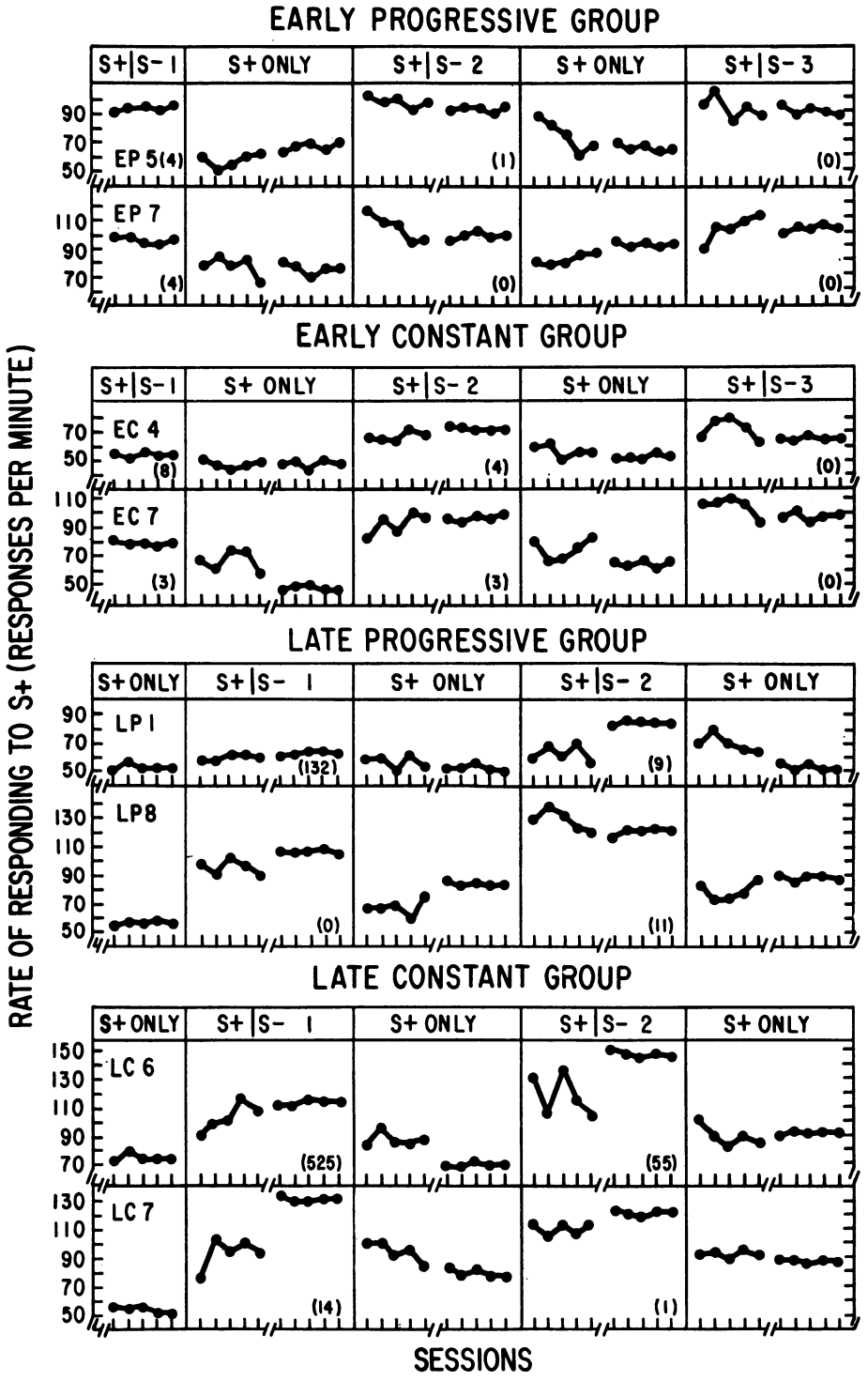

Fig. 1. Rate of responding to S+ for two randomly selected pigeons from each of the principal training groups. Only the first and last five sessions of each phase are presented. During discrimination training, labelled "S+ S−", S+ (green key) alternated with S− (dark key). During baseline training sessions, labelled "S+ ONLY", S+ alternated with itself in the absence of S−. The numbers in parentheses refer to the number of responses during S− (errors) produced during that phase of discrimination training.

geons clearly showed contrast throughout the experiment. Of the three remaining Early-Progressive pigeons, one showed behavioral contrast at the first phase change, but thereafter the effect dissipated. Contrast was evident to a small degree in another pigeon early in the experiment, and only erratically in the last.

All subjects of the Early-Constant group displayed contrast in all phases of the experiment, with the exception of one that showed response-rate changes at the start of each new training phase, but these were not maintained for more than one or two sessions. Each subject of the Late-Progressive group and of the Late-Constant group manifested behavioral contrast across all training phases. In some cases, the magnitude of the effect was notably small—as, for example, in the records of three Late-Progressive and one Late-Constant pigeon—but the effect was nonetheless evident. Although the data are not presented in Figure 1, contrast was evident in all except one pigeon of the Late-Progressive group from the first day of S− fade-in. The amount of contrast exhibited on each succeeding session increased in direct proportion to the total duration of S−.

The mean daily rates of responding to S+ for each group are reproduced in Figure 2. This figure underscores the observation that behavioral contrast occurred in all groups. In addition, it demonstrates that the groups did not appreciably differ in baseline rate of responding to S+. For each group, response rates for the initial baseline phase averaged between 50 and 57 responses per minute. Thereafter, the baseline of the Early-Progressive, Late-Progressive, and Late-Constant groups shifted upward to a level approximately 10 responses per minute higher than the initial baseline, at which point they remained. An interesting order effect can also be seen in Figure 2. To a significant degree ($t = 1.99$, $df = 126$, $p < 0.05$) more behavioral contrast was seen overall on transitions from baseline to discrimination training than on transitions from discrimination to baseline training.

Figure 3 presents the group means and ranges of behavioral contrast expressed in terms of the change in response rate at each phase change and overall. This figure reveals a trend for Late groups to exceed Early groups in the magnitude of behavioral contrast produced. While time of S− introduction appears to be the more powerful variable, if this variable is held constant, the Constant manner for introducing S− produces more behavioral contrast than does Progressive S− introduction.

An analysis of variance conducted to investigate these trends indicated that time of S− introduction significantly influenced the magnitude of the contrast effect, with Late S− introduction resulting in greater changes in S+ response rate ($F = 5.06$; df = 1; $p < 0.05$). Individual comparisons of group means from the first phase change (S+|S− 1 → S+ ONLY) and overall by Dunn's Multiple Comparison Procedure (Kirk, 1968, p. 79) disclosed no significant differences at the first phase change. Overall, Early-Progressive and Early-Constant groups differed significantly from the Late-Constant group (EP *versus* LC: d = 12.57; df = 16,28; $p < 0.05$. EC *versus* LC: d = 10.54; df = 16,28; $p < 0.05$), displaying less behavioral contrast than did the Late-Constant group. The difference between the means of the Late-Progressive and Late-Constant groups approached significance. The overall difference between Early and Late groups was significant ($p < 0.05$); the difference between Progressive and Constant groups was very nearly so ($p < 0.10$).

Responses during S−. The dependent variable described as errors refers to the number of responses directed toward the response key during the dark-key S− component. Of interest in the present study was the total number of such responses and their distribution as a function of the discrimination training procedure followed.

Responses during scheduled blackouts were not treated as errors, even though they were responses directed toward a dark key. Responding during blackouts appeared to be the result of a spill-over of activity from an immediately preceding S+ component. Such responding ceased quickly after the onset of the blackout. No responding was noted during blackouts that followed S− components.

The distribution of responses during S− displayed by each subject is presented in Figure 4. The subjects in each group are ordered according to the total number of errors they emitted throughout the experiment, from the least to the most. Note that the data are plotted across the cumulative percentage of sessions in each of the two discrimination

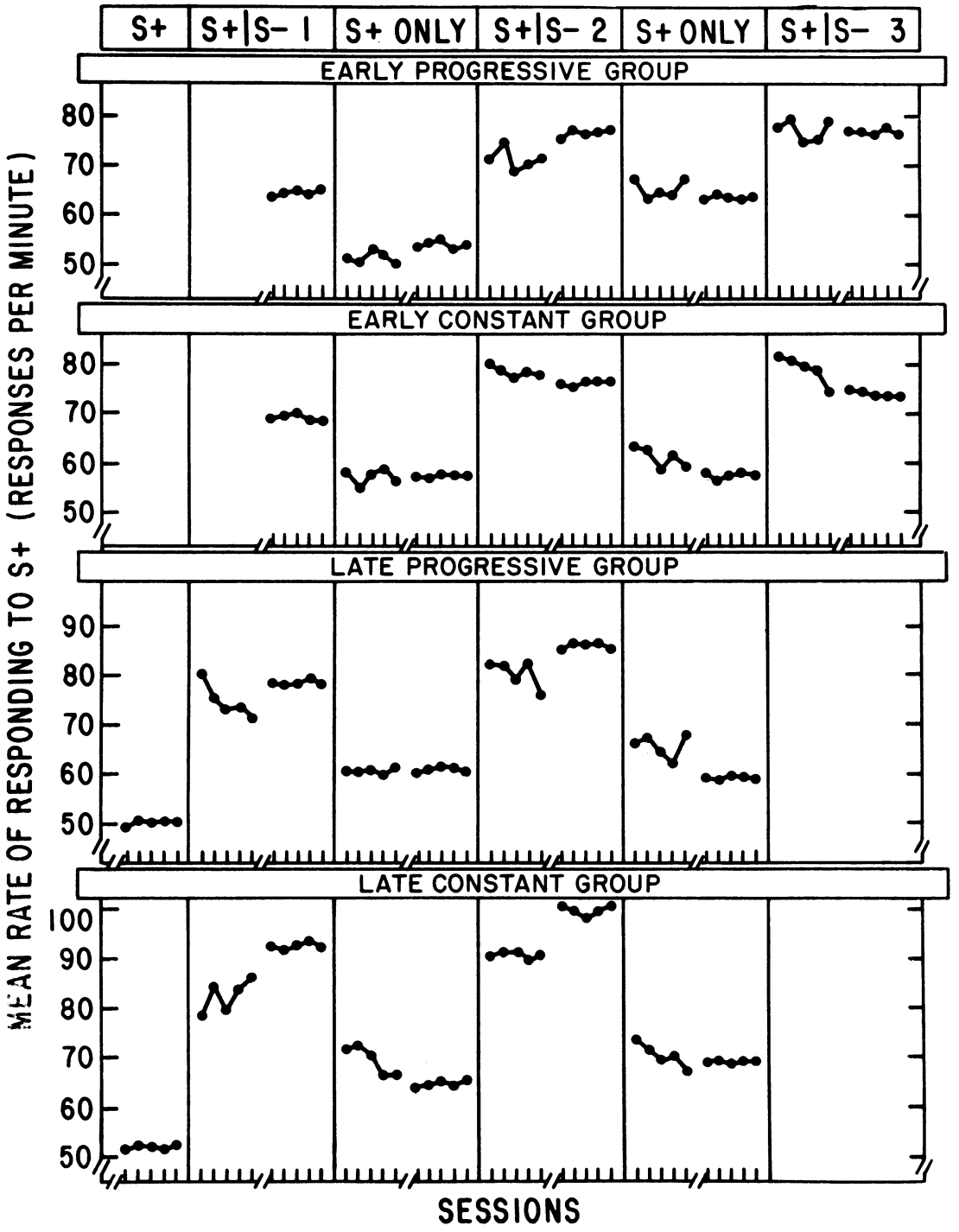

Fig. 2. Mean rate of responding to S+ for the Early-Progressive, Early-Constant, Late-Progressive, and Late-Constant training groups. Because the Early introduction of S− precluded an initial phase of baseline training, the data for the Early groups are displaced to the right to place them in phase with the data of the Late groups. All comparisons of the magnitude of behavioral contrast are based upon this configuration of the data.

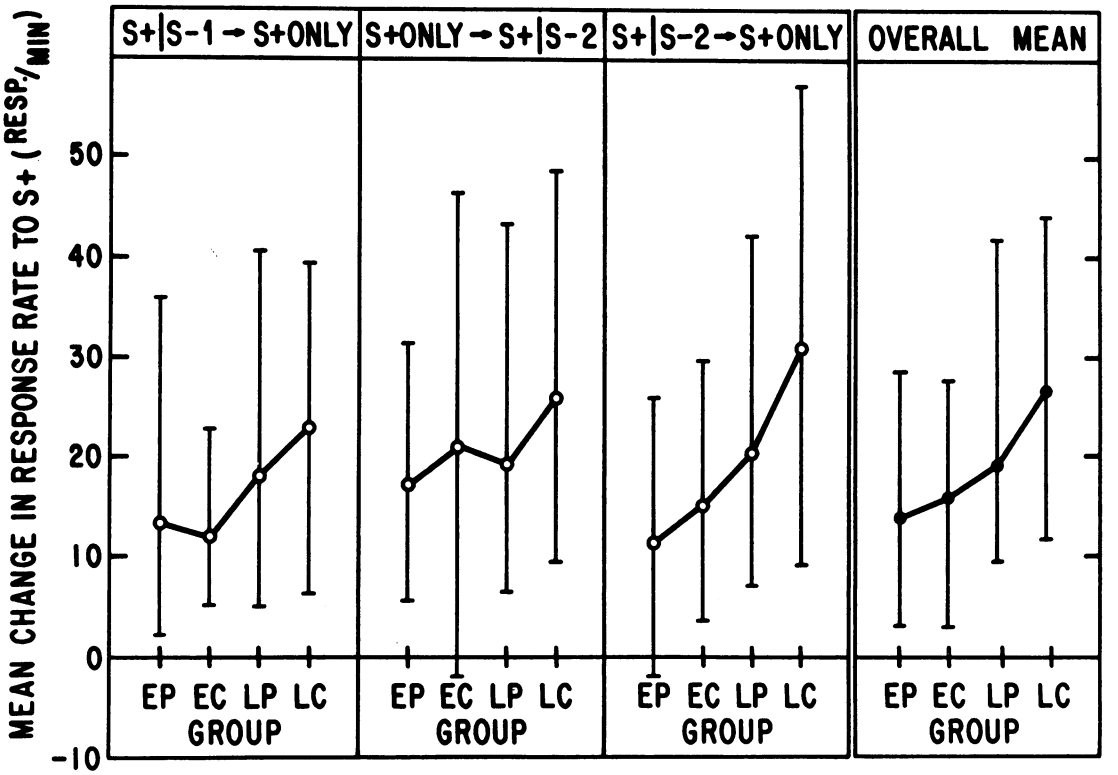

Fig. 3. Mean change in response rate to S+ (behavioral contrast) for the Early-Progressive (EP), Early-Constant (EC), Late-Progressive (LP), and Late-Constant (LC) training groups at each change of training conditions. Each panel represents a comparison of mean S+ response rates in the last five days of one training phase with the first five days of the subsequent phase. Positive values denote behavioral contrast, while negative values denote induction. The group means are represented by the circles, with the range of response-rate changes indicated by the bars.

phases. This transformation was necessary to standardize the disparate number of training sessions given each pigeon. One can determine the amount of discrimination training each pigeon received by simply counting the data points.

This figure clearly indicates the effectiveness of the Early introduction of S− in reducing the number of errors during discrimination training. The influence of Progressive or Constant S− introduction is more subtle and requires finer analysis. Since the S− introduction procedures for the Progressive and Constant groups differed only during the first five days of discrimination training, the occurrence of responding to S− during this five-day period was compared with that of the subsequent five days. There is a problem with such a comparison though: while the total number of exposures to S− was equal for all groups, the total time of such exposure was not. Constant groups experienced 7500 sec of S−; Progressive groups experienced only 2111 sec of S− during the same number of sessions. Consequently, two separate analyses were conducted, transforming the error data in slightly different ways—as either the mean rate of occurence of errors or as the absolute number of errors produced.

Regardless of the statistical treatment of the error data, the Early *versus* Late group comparisons by Mann-Whitney U tests revealed that Late groups displayed more responding to S− during the first five days of discrimination training. (Total errors: $U = 63.5$; $p < 0.01$. Error rate: $U = 83$; $p < 0.05$). The only other significant difference between groups resulted from the analysis of the absolute number of errors produced during the first five days of discrimination training. Individual group comparisons showed significant differences between the Early-Progressive and Late-

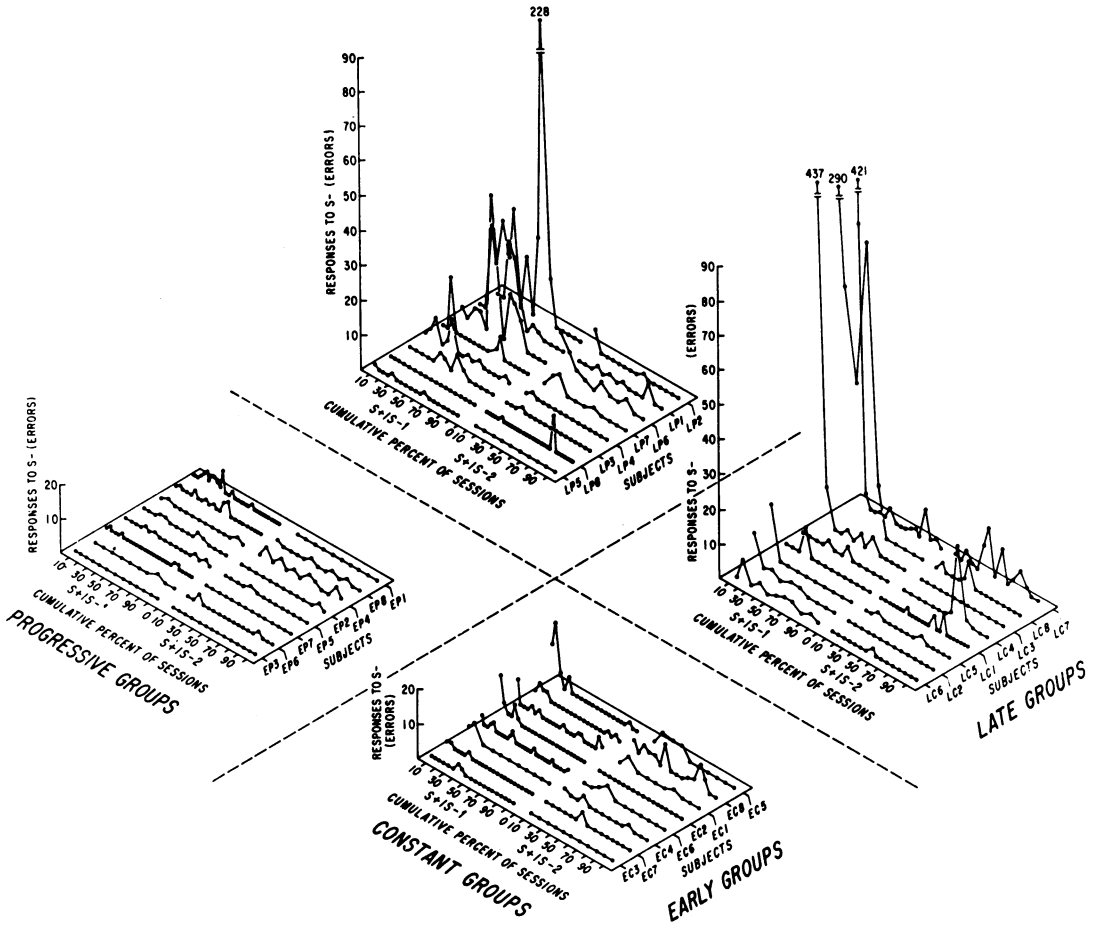

Fig. 4. Occurrence of responses during S− (errors) during S+|S− 1 and S+|S− 2 for individual pigeons. The data are plotted across the cumulative percentage of sessions. The pigeons are ordered according to the total number of errors made by each during discrimination training, with those producing the fewest errors at the front of each block.

Constant groups. (Total errors: $U = 1.5$; $p < 0.001$. Error rate: $U = 24$; $p > 0.05$). The Early-Progressive group emitted fewer responses to S− than did the Early-Constant group. (Total errors: $U = 8.5$; $p = 0.006$. Error rate: $U = 23$; $p > 0.05$). The Progressive groups made significantly fewer errors during the first five days of discrimination training than did the Constant groups. The *rate* of occurrence of errors, however, did not differ between the groups. (Total errors: $U = 64.5$; $p < 0.01$. Error rate: $U = 123$; $p > 0.05$). The importance of this discrepancy, which relates to the method of transforming the error data, is noted later in the discussion. Analysis of the occurrence of errors during the second five days of discrimination training revealed no significant differences between the groups.

The upper panels of Figure 5 represent the total number of errors made by each pigeon during the first discrimination phase (S+|S− 1) and throughout the experiment (S+|S− 1 and S+|S− 2). Because the Early groups experienced three discrimination training phases while the Late groups experienced only two, the first two discrimination phases alone are included for purposes of statistical analysis. The data in Figure 5 are ordered according to the number of errors made during the first discrimination phase (S+|S− 1). Group means are indicated by horizontal arrows.

For the first phase of discrimination training (S+|S− 1), the Early-Progressive group averaged 6.5 errors, ranging from 0 to 24. The Late-Constant group produced the largest number of errors, averaging 191.8 and rang-

ing from 5 to 525. Falling between these two extremes were the Early-Constant group, with a mean of 15.0 errors and a range of 3 to 38, and the Late-Progressive group with a mean of 76.5 and a range of 0 to 132. Applying a criterion suggested by Terrace (1972) that subjects making 25 or fewer responses to S− be considered errorless, there were thus eight errorless subjects in the Early-Progressive group, seven in the Early-Constant group, five in the Late-Progressive, and five in the Late-Constant group during the first discrimination phase.

Overall (see upper-right panels of Figure 5 labelled S+|S− 1 and S+|S− 2), the Early-Progressive group produced a mean of 9.1 total errors (range: 0 to 24), the Early-Constant

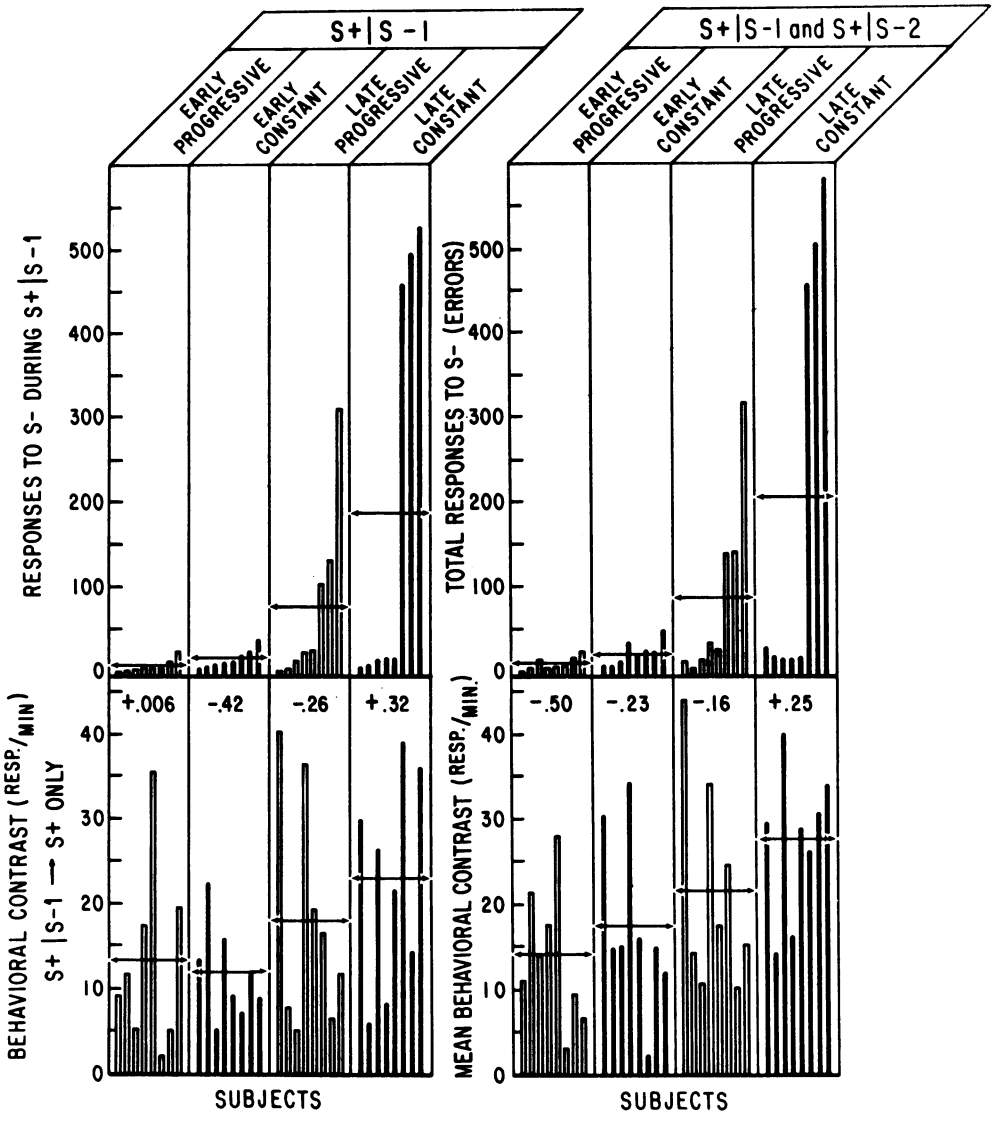

Fig. 5. Relationships between responding during S− (errors) and the magnitude of behavioral contrast produced. The bars within each panel are ordered with respect to the total number of errors produced during S+ S−1 (the first discrimination phase). Arrows within each panel mark the group mean for that measure. The left half of this figure depicts the relationship between the number of errors made during S+|S− 1 and the amount of behavioral contrast observed for each pigeon. The right half of the figure presents the relationship between the total number of errors occurring during the first two phases of discrimination training and the mean behavioral contrast produced overall. Spearman rank-order correlation coefficients for each group are indicated by the numbers appearing just below the error data.

group averaged 21.9 errors (range: 6 to 39), the Late-Progressive group averaged 85.5 errors (range: 3 to 317), and the Late-Constant group averaged 204.4 errors (range: 15 to 580). At the completion of the experiment, all eight birds of the Early-Progressive group were still errorless, as were six of the Early-Constant group, three of the Late-Progressive group, and four of the Late-Constant group.

Considerable caution must be exercised, however, when interpreting differences between group means, since the assumption of homogeneity of variance, necessary for parametric statistical analyses, is invalid ($F_{max} = 1028.8$, $df = 4/7$, $p < 0.01$). In view of this, group differences were assessed by Mann-Whitney U tests, which are summarized in Table 3. In all comparisons, the Early-Progressive group made significantly fewer errors than did the other groups. The Early-Constant, Late-Progressive, and Late-Constant groups did not significantly differ from each other. The time at which the discrimination was introduced significantly influenced the number of responses to S−: fewer errors were observed when S− was introduced Early. Such differences were evident during the first discrimination phase, as well as overall. The Progressive manner of introducing S− also significantly influenced the total amount of responding to S−, resulting in fewer errors than did the Constant procedure. However, this difference was not observed during the first discrimination training phase (S+|S− 1): the total number of errors made during the entire initial phase of discrimination training was not significantly affected by the rapidity of S− introduction.

Table 3

Summary of Mann-Whitney U Tests

COMPARISON	Value of U	p
Errors during first discrimination phase (S+|S− 1):		
EP vs EC	14.5	$p < 0.037$
EP vs LP	14.0	$p < 0.032$
EP vs LC	7.5	$p < 0.004$
EC vs LP	20.5	n.s.
EC vs LC	21.5	n.s.
LP vs LC	27.0	n.s.
EARLY vs LATE	63.5	$p < 0.010$
PROG. vs. CONS.	92.5	n.s.
Total errors (S+|S− 1 and S+|S− 2):		
EP vs EC	12.5	$p < 0.022$
EP vs LP	12.5	$p < 0.022$
EP vs LC	6.0	$p < 0.002$
EC vs LP	23.0	n.s.
EC vs LC	20.5	n.s.
LP vs LC	24.0	n.s.
EARLY vs LATE	62.0	$p < 0.010$
PROG. vs CONS.	83.0	$p < 0.050$

Relationships between S+ and S− responding. Figure 5 also details the relationship between the amount of responding during S−, or errors, and the magnitude of the change in response rate to S+, or behavioral contrast, for each subject. The left panels relate the number of errors during the first discrimination training phase (S+|S− 1) with the amount of behavioral contrast exhibited during the phase. The right panels relate the total number of errors made throughout the experiment with the mean behavioral contrast produced by each pigeon. Subjects within each group are ordered with respect to the total number of errors emitted during the first discrimination training phase.

A direct relationship between errors and behavioral contrast within groups would be represented by a series of bars that reflect the symmetry of the error data. Clearly, such was not the case with the present data. Pigeons that produced the fewest errors in each group were as likely to show the greatest amount of contrast as were those that produced the greatest number of errors. Spearman rank-order correlation coefficients between the number of errors and the amount of behavioral contrast are indicated in Figure 5 for each group. For the relationship to be considered significant ($df = 6$), the absolute value of r had to exceed 0.70. None of the groups showed a significant correlation between number of errors produced and the magnitude of behavioral contrast.

Control groups. The rates of responding to S+ for the Red S− group and the Three-Minute S+ group are recorded in Figures 6 and 7, respectively. All four pigeons of the Red S− group showed behavioral contrast at each change of training phase. Three of the four birds were errorless at the end of the first phase of discrimination training (mean errors = 19.25; range = 2 to 60). Only one bird was errorless at the completion of the experiment (mean total errors = 164.25; range = 2 to 445).

Behavioral contrast was very slight, if present at all, in the Three-Minute S+ group. All pigeons in this group were errorless through-

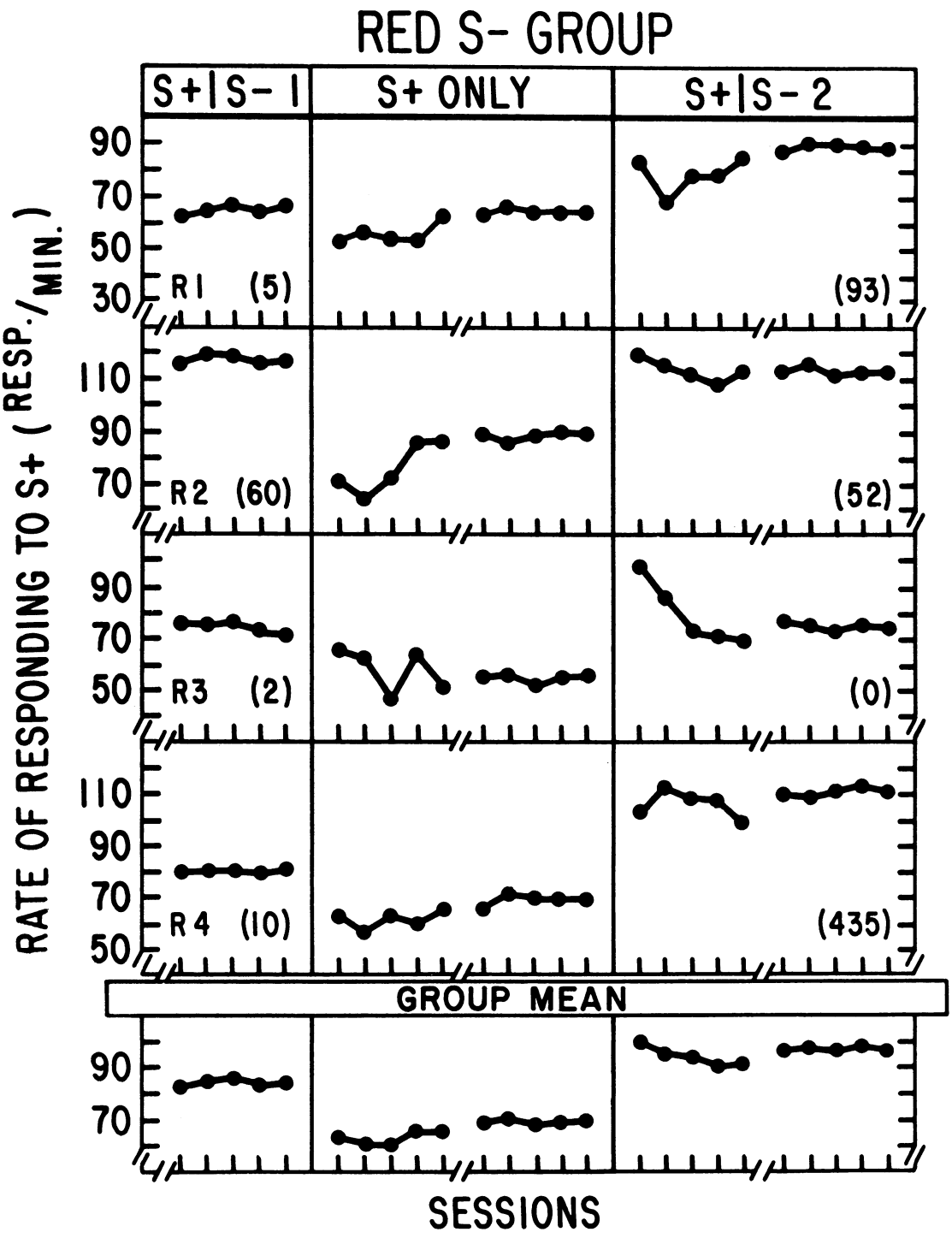

Fig. 6. Rate of responding to S+ for the Red S− control group. Individual data and group means are presented. During discrimination training, labelled "S+|S−", S+ (green key) alternated with S− (red key). During baseline training sessions, labelled "S+ ONLY", S+ alternated with itself in the absence of S−. The numbers in parentheses refer to the number of responses during S− (errors) produced during that phase of discrimination training.

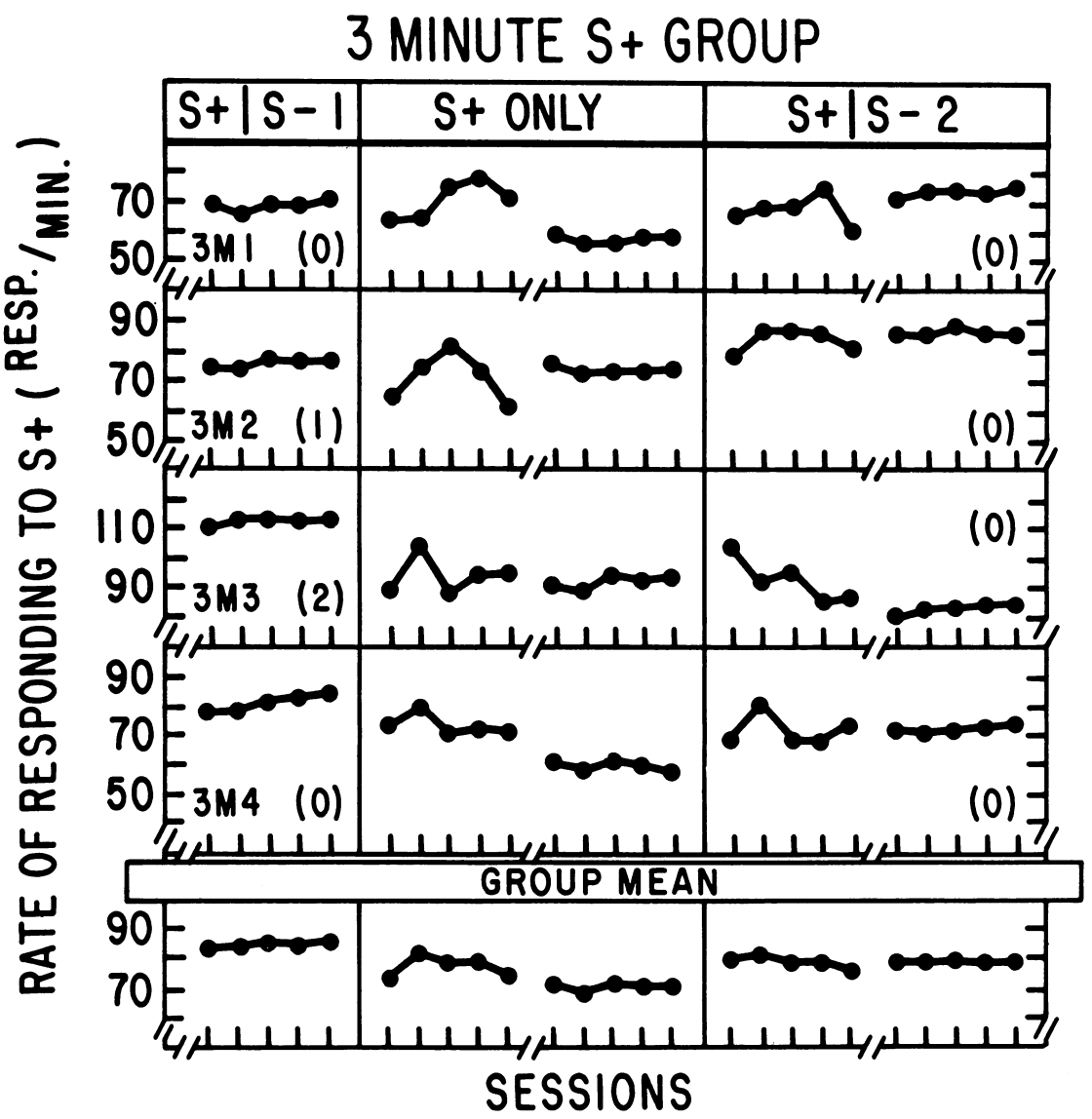

Fig. 7. Rate of responding to S+ for the Three-Minute S+ control group. Individual data and group means are presented. The numbers in parentheses refer to the number of responses during S− (errors) produced during that phase of discrimination training.

out the experiment (mean total errors = 0.75; range = 0 to 2). Neither group showed a significant correlation between the number of errors emitted and the magnitude of behavioral contrast.

Comparisons were made between the two control groups and the Early-Progressive group of the main study. These calculations are based on comparisons of the mean response rate for the first five days of one training phase with the mean response rate for the final five days of the preceding training phase. In terms of the mean overall behavioral contrast produced, the Three-Minute S+ group displayed the least contrast, averaging a rate change of 7.8 responses per minute. The greatest amount of behavioral contrast, on the order of 23.2 responses per minute, was produced by the Red S− group. The data from the Early-Progressive group for a comparable period of training fell midway between the data for the two control groups: the mean behavioral contrast for the Early-Progressive group was 15.3 responses per minute across the

first two changes in training phase. The difference between the Red S− group and the Three-Minute S+ group was significant (Mann-Whitney U = 0, $p = 0.014$). Each of the control groups differed from the main Early-Progressive group to a degree that nearly approached significance (Early-Progressive *versus* Red S−: U = 7, $p = 0.077$; Early-Progressive *versus* Three-Minute S+: U = 8, $p = 0.107$).

DISCUSSION

The present study showed that the occurrence of errors is not necessary for the production of behavioral contrast. In addition, the magnitude of behavioral contrast exhibited no systematic relationship with the number of errors produced while pigeons learned a discrimination. This demonstration suggests that one need not posit separate laws to account for errorless learning as a special case of discrimination learning. The present results indicate that procedural variables that affect the acquisition of the discrimination have long-term influences on subsequent discrimination performance. Early initiation of differential training facilitates learning the discrimination quickly and with relatively few errors. Additionally, it appears to reduce the magnitude of behavioral contrast throughout the experiment from the level that would otherwise occur if a Late procedure were applied. Progressive introduction of S− likewise results in fewer errors during discrimination training, as well as a reduction in the amount of behavioral contrast.

In this experiment, the first five days of discrimination training had a substantial influence upon whether or not a subject acquired the discrimination without errors. Although the rate of responding to S− did not differ between Progressive and Constant groups, the absolute number of errors produced during the first five days was significantly greater for the Constant groups. This indicates that the Progressive introduction procedure effectively reduced the tendency to respond to S− by simply restricting the opportunity for responding early in the pigeon's experimental history when the tendency to respond to S− was greatest. Once the crucial first sessions were completed, responding to S− was similar across all training groups.

One surprising result was the number of pigeons in the three discrimination training groups other than Early-Progressive that were also errorless: six in the Early-Constant group, three in the Late-Progressive group, and four in the Late-Constant group at the end of the experiment. This can perhaps be attributed to the use of a dark key as S−. It may be that the difference between a dark key S− and a green key S+ is so great that the acquisition of the discrimination is a simple task. The fact that the Progressive or Constant introduction of S− was a less powerful manipulation than the Early *versus* Late introduction of S− is consistent with this argument, since the gradual introduction of S− would be unnecessary in easy discrimination.

From the results of the two control groups, the fact that Terrace (1963) failed to observe behavioral contrast appears to be due in part to the use of stimulus components of 3-min duration. The effect of the illuminated key S− was to increase the magnitude of behavioral contrast observed. In the present experiment, this amounted to a two-fold increase in behavioral contrast.

It must be noted that the Progressive procedure for introducing the illuminated S− was less effective than Terrace's: errors occurred to a substantially greater degree, especially during the second discrimination training phase where no special S− introduction procedures were applied. Although the Red S− subjects acquired the discrimination less accurately than did Terrace's, there was no indication of a systematic relationship between the occurrence of errors and the occurrence of behavioral contrast. The three Red S− pigeons that were errorless at the end of the first discrimination phase showed behavioral contrast at the subsequent phase change. In addition, the one Red S− pigeon that was errorless at the completion of the experiment showed behavioral contrast throughout the experiment.

Determinants of Behavioral Contrast

As the results of the present experiment demonstrate, the following variables are related to the occurrence of behavioral contrast.

(1) The amount of prior nondifferential exposure to S+ before discrimination is introduced directly influences the amount of behavioral contrast produced. Of the two levels

manipulated, introduction of the discrimination immediately after the key-peck response was acquired reduced the level of behavioral contrast throughout the experiment. Sensitivity to this variable is probably restricted to large differences in the range of prior exposure, as no significant correlation was found within groups between the number of training sessions and the magnitude of behavioral contrast produced.

(2) The procedure by which initial introduction of S− is accomplished, whether Progressively or Constantly, affects the occurrence of behavioral contrast. If a Progressive procedure is followed, less contrast results throughout discrimination training than if a Constant procedure, where S− is abruptly introduced, is used.

(3) The duration of the stimulus components, within a currently ill-defined range of variation, acts directly upon the magnitude of the behavioral contrast effect. In general, the longer the duration of S− (Taus and Hearst, 1970; Wilton and Clements, 1971) and the shorter the duration of S+, the greater the amount of behavioral contrast. Extension of S+ exposure to 3 min in the present study virtually eliminated behavioral contrast following the Early-Progressive introduction of S−.

(4) The physical characteristics of the stimuli selected as S+ and S− contribute to the production of behavioral contrast. In this experiment, the similarity between the stimuli, in terms of saturation and/or wavelength, directly influenced the amount of behavioral contrast that resulted: the more similar the stimuli, the greater the behavioral contrast. A similar observation was reported by Hearst (1969). When the postintradimensional discrimination training gradients were compared with the corresponding excitatory gradients, behavioral contrast was observed in the region of S+. The magnitude of the elevation of the postdiscrimination gradient in the vicinity of S+ was directly influenced by the proximity of S+ and S− and on the line-tilt dimension.

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