RESPONSE DIFFERENTIATION

AN EXPERIMENTAL ANALYSIS
OF
RESPONSE DIFFERENTIATION

By

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ABSTRACT

Four experiments were undertaken to identify properties of differential reinforcement relevant to response differentiation. Differential reinforcement was given for the length of "runs" of pigeons' key pecks, the length of a run being defined as the number of responses on a key preceding a spatially different terminal response.

In Experiment I, a criterion run-length was assigned each subject and each subject was reinforced only following emission of a run-length which exceeded its criterion. Criterion run-lengths of 5, 10 and 20 responses were assigned to different groups. Mean run-lengths (N) were related to criteria (n) by a power function: $N = 2.63\ n^{0.69}$. The fractional exponent of this function implies that the proportion of responses exceeding criterion was lower for higher criterion values. Because reinforced response values were confined to an extreme of the distribution, a lower proportion of reinforced response values indicated a greater difference between the distribution of values of the response emitted by a subject and the distribution of values reinforced. Since higher criterion values produced higher asymptotic mean run-lengths, the differential between emitted and reinforced run-lengths was also related to asymptotic run-length.

A similar relationship between mean run-length and the proportion of responses exceeding a criterion was obtained in Experiments II and III. These experiments used a differential reinforcement paradigm in which the

criterion was continuously adjusted for each subject so that a constant proportion of its distribution of run-lengths exceeded its criterion. In Experiment II, the proportion of the distribution exceeding the criterion was set at 15%, 30% or 45%, for different groups. However, only a random half of the run-lengths exceeding the criterion for animals in the 30% group, and one-third of those for the 45% group were actually reinforced, so that the overall probability of reinforcement was constant at 0.15 for all groups. Increases in the mean length of runs were obtained for all groups, with the 15% group exhibiting a more rapid change and a higher asymptotic mean run-length than the 30% group, which in turn exceeded the 45% group.

In Experiment III, pigeons were reinforced only for run-lengths in the most extreme 30% of their run-length distributions. One group received reinforcement for a random half of these run-lengths, while others received reinforcement for all of the run-lengths in this range. The relative extremeness of run-lengths selected for reinforcement was therefore constant (30%) while the overall probability of reinforcement was either 0.30 or 0.15. Increases in mean run-length were obtained, but no differences in the rate of change or asymptotic mean run-length were found between groups.

The results of Experiments II and III suggest that the relative extremeness of run-lengths selected for reinforcement, that is the differential between emitted and reinforced run-lengths, determines the rate and extent of changes in values of a response. The relationship between the relative extremeness of reinforced response values and the rate and extent of changes in emitted response values was further

demonstrated in Experiment IV. Reinforcement was provided for a fixed area of the distribution of run-lengths closest to a specified target value. For one group, the area of the distribution reinforced was 15%, while another group was reinforced for a random half of run-lengths in the closest 30% to the target. Reinforcement probability was thus held constant at 0.15. Mean run-lengths changed in the direction of the target at a rate dependent on the difference between the mean run-length and the target run-length. An asymptote was reached (rate of change = 0) when mean run-length approached the target value (differential = 0). The relationship between asymptotic mean run-length and target run-length was nearly linear for both 15% and 30% groups.

The results of this series of experiments were discussed in terms of a hypothetical differentiation process emphasizing the differential between the central tendencies of the distributions of emitted and reinforced response values, expressed in percentage units. When a differential exists, a change in the distribution of response values occurs in a direction which tends to reduce the differential, and at a rate proportional to the magnitude of the differential. When no differential exists, no change occurs. Since change in many dynamic response properties is resisted in a way which suggests an opponent process (e.g., Law of Least Effort), the asymptote reached after differential reinforcement represents an equilibrium between differential reinforcement and its opponent process. The increased effectiveness of differential reinforcement when relatively more extreme response values are reinforced would thus not only result in greater rates of change, but would also overcome the resistance of the opponent process to a greater extent,

shifting the equilibrium point to a higher value.

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INTRODUCTION

The experimental analysis of behaviour has generally concentrated on responses such as rats' lever presses and pigeons' key pecks. These responses occur with variations in such dynamic properties as force, duration and temporal spacing (interresponse time or IRT). Skinner (1938; Chapter 8) recognized that when selected values of a response property are reinforced differentially (with higher probability, greater immediacy, greater magnitude, etc.) the relative frequency of occurrence of these values may increase. A change in the relative frequency distribution of response values as a result of differential reinforcement is called response differentiation.

Skinner demonstrated response differentiation by differentially reinforcing the force of a rat's lever presses. At first each press was reinforced and its force measured to determine the normal range of variation. A criterion was then specified in the upper part of this range, and only presses with forces greater than this criterion value were reinforced. Differential reinforcement of presses with force values exceeding the criterion was found to increase their relative frequency of occurrence.

Notterman and Mintz (1962) differentially reinforced lever presses with force values within one of two ranges, each associated with a different exteroceptive stimulus. With one rat, for example, presses with a force of 5 to 10 grams were reinforced when the houselight was on. When the houselight was off, only forces in the 15-20 gram range were

reinforced. Following differential reinforcement, the modal force value typically fell within the 5-10 gram range when the houselight was on. When the houselight was off, however, modal force was slightly below the 15-20 gram range. A higher criterion for reinforcement thus produced a higher response value, but there was a tendency for response values to be less than the criterion at the higher value.

Catania (1970) differentiated the latency of pigeons' key pecks by reinforcing only pecks with latencies that exceeded some minimum value. Criterion latencies of from 0.6 to 48.0 seconds were set for each subject in descending and ascending sequences. Catania also reported a tendency for mean response values to be less than the criterion at higher criterion values. When mean latencies (T) were plotted against reinforcement criteria (t) in logarithmic coordinates, the points could be fit with a straight line describing a power function with parameters $T = 1.6\ t^{0.8}$. The fractional exponent of this power function reflects the progressive decline of mean latency relative to the reinforcement criterion. Catania noted that a number of other investigators with human and animal subjects have reported a similar relationship between the experimenter's criterion for reinforcement and the subject's production of temporally spaced responses. The relationship, he stated,

> . . . is not linear; it is a power function. The deviation from matching of the temporal spacing of responses to the temporal parameters of the schedule, therefore, is not a failure of temporal control. Rather, it is a fundamental characteristic of the control of temporal spacing of responses by the temporal properties of the reinforcing environment. (p. 30)

Catania's results have been systematically replicated in a differentiation experiment by Platt, Kuch and Bitgood (1973) using rats'

lever press durations. When press durations of 0.4, 0.8, 1.6, 3.2 and 6.4 seconds were required for reinforcement, Platt, et. al. found that the relationship between median press duration and reinforcement criterion was a power function with parameters $T = 1.32\ t^{0.92}$. The fractional exponent of the function again indicates the progressive decline of median press duration relative to criterion duration.

The examples of response differentiation discussed thus far have involved situations in which a fixed criterion is established within the normal range of variation of some dynamic property of responding. However, the range of response values which may be differentially reinforced can be greatly extended by a modification of this basic design in which a criterion is systematically shifted in successive approximations to a desired response value. The shaping of values of a response by successive approximations was described by Skinner (1938):

> When a single property such as intensity is the basis of the differentiation, the process may be represented in the following way. Originally the responses occur with their intensities distributed (say, normally) about a low value. Reinforcement of members in the upper part of the range shifts the mean upward, and with it the whole curve. Responses in the upper part of this new range may then be reinforced, and so on (p. 339)

Using this procedure, Skinner was able to increase lever press force for one rat to a value of over one-half of the rat's body weight. In another example, Skinner described the consequences of a too rapid advance in the reinforcement criterion. Having established a mean force of 40 grams, the criterion was raised to 60 grams. Too few responses met this new criterion, however, and extinction occurred. When the criterion was returned to 40 grams, responding was reinstated.

Another passage from Skinner's report suggests a dimension for

quantifying the degree of differential reinforcement.

> If a value is chosen for differential reinforcement that is likely to occur, say, once in ten times without differentiation, responses possessing that value begin to occur more frequently (say, once in two times) with what is apparently an instantaneous change. (p. 314)

When the criterion was set to a value which was exceeded by a relatively small proportion of responses (like 10%), response values changed rapidly enough for the change to appear instantaneous. When a larger proportion (like 50%) exceeded the criterion, no further change was noted. The rate of change of values of a response property thus appeared to be related to the proportion of the distribution of values exceeding the criterion.

While Skinner's observations suggest that the proportion of response-values exceeding a reinforcement criterion may be an important determinant of behaviour change, the experiment did not control or even systematically measure this proportion. In a series of experiments by Lane (1964; Lane, Kopp, Sheppard, Anderson & Carlson, 1967) investigating the shaping of human vocal duration, an attempt was made to specify such a measure of differential reinforcement.

In Lane's procedure, reinforcement was presented in the form of pennies for durations of the vowel /u/ which exceeded some criterion duration. The significance of the procedure was in the rule for selecting a criterion on the basis of the subject's current distribution of duration values. In one experiment (Lane, 1964), subjects were first allowed to make 20 responses under continuous reinforcement. The mean and average deviation of the obtained response durations were then determined, and a new criterion set at a value equal to the mean plus one average deviation. Differential reinforcement was then carried out under

this criterion until 10 successive responses exceeded the criterion and were reinforced. The mean and average deviation of these 10 reinforced responses were then summed to form the new criterion, and the cycle repeated for up to 9 phases. In another variant of this procedure, the new criterion was computed from the mean of the 10 consecutive reinforced responses plus some increment of the mean (0.05, 0.10, 0.15 or 0.20). The extent of the increase of the criterion in each case was expressed as a "shaping index" calculated from the difference between the criterion duration for reinforcement and the mean duration in units of the standard deviation of the current duration distribution.

Lane, *et*. *al*. (1967) systematically varied values of the shaping index in an effort to determine "In quantitative terms, and taking vocal duration as a case in point . . . how many standard deviations (σ) away from the mean (M) of current responding should the criterion (C) be set for effective and efficient shaping." (p. 9) Values of the shaping index of 0.5, 1.0, 1.5, 2.0 and 3.0 were tested. Assuming a normal distribution of duration values about M, these values of the shaping index would correspond to proportions of 31%, 16%, 7%, 2% and 0.5% of the distribution exceeding the criterion for reinforcement. Results of this study indicated that the number of subjects who underwent extinction increased as the shaping index increased from 0.5 to 2.0. Although Lane was aware of the question of differential rates of behavioural change among subjects who did not undergo extinction, no data on this point were presented.

Despite the significance of Lane's research in attempting to specify general relationships between behaviour and reinforcement criteria which influence behavioural change, his procedure suffers from a number of

limitations. To begin with, the measurement and control of these relationships was limited to the beginning of each phase and varied in an uncontrolled manner thereafter until reaching a steady state at a point where the proportion of responses exceeding the criterion approached 100%. Furthermore, the parametric computations used to specify the reinforcement criterion as a function of the distribution of duration values are questionable unless the distributions of response values are normal, or at least of invariant form.

A different approach to the problem of controlling relationships between behaviour and reinforcement criteria during shaping by successive approximations was reported by Eckerman and Redd (1970). The response dimension utilized in this study was the length of runs of responses emitted by pigeons in a two-key counting procedure, where reinforcement was made available for a response on one key following a run of at least a criterion number of responses on the other key. The experiment was concerned with shaping longer run-lengths by adjusting the reinforcement criterion according to a pair of rules specifying relationships between the criterion and the subject's performance. A step-up rule determined the number of reinforcements received by a subject at a particular criterion before the criterion was incremented. A step-back rule established the length of time without reinforcement before the criterion was decremented. When this "titration" was carried out with any pair of step-up and step-back rules, the subject's run-length would increase to an asymptote which was interpreted as an index of the relative effectiveness of differentiation with this pair of values. Eckerman and Redd found that asymptotic run-lengths increased as the step-back interval was raised

from 30 seconds to about 5 minutes. Further increases in the step-back interval were ineffective in producing further changes in run-length. No consistent effects were found for variation in the step-up rule.

The identification and control of selected relationships between behaviour and differential reinforcement criteria attempted by Lane and by Eckerman and Redd represent significant advances in the analysis of response differentiation. However, the rules described in these examples specify conditions for transition between a succession of steady states, each associated with a fixed criterion value, rather than a more continuous response-by-response treatment of behavioural change. Weiss (1970) has noted that similar limitations characterize the experimental analysis of behaviour as a whole.

> Until recently, operant investigators were content simply to demonstrate lawful relationships in behavior and to show how you could control behavior by choosing appropriate reinforcement contingencies. But now, more than ten years after Ferster and Skinner (1957), there has been a distinct shift in focus. Experimenters are less willing merely to display correlations between events. Their present concerns are more with the fine grain of behavior; with moment-to-moment variations and what they signify; with the detailed analysis of interresponse times; with the precise control of how discriminations develop; with more precise specifications of the dimensions of reinforcement and of response; and so on. (p. 279)

Weiss went on to proclaim such a shift in focus as characteristic of a maturing science, and noted that the task was made "immeasurably easier" by the advent of the computer.

> Among the questions which become amenable to solutions are those that originate in transition states - the "unstable" periods following a change to a new schedule of reinforcement or the introduction of

> a new schedule parameter. Given the power to undertake the microanalysis which computer technology makes possible, we do not have to concentrate as heavily on steady-state behavior as we have in the past. We can make an attempt to account for the shifting base lines of transition states and to search out phenomena which may explain many features of the relatively stable behavior which finally evolves. (p. 281)

Alleman and Platt (1973) have reported one example of such a microanalysis concerning the differentiation of pigeons' key peck interresponse times (IRTs). Their approach began with the development of a paradigm for controlling the proportion of the distribution of IRTs reinforced. This was accomplished by maintaining a continuously updated list or memory of the m most recent IRTs, and reinforcing those IRTs more extreme than a fixed number of the IRTs in memory. To the extent that the last m IRTs represent a random, independent sample of the current distribution of IRTs, it can be shown that the expected proportion of the distribution exceeding all m IRTs in memory is $1/(m+1)$ (Smith, 1953). Reinforcing only those IRTs more extreme than the m values in memory will therefore result in reinforcement for a constant proportion of the distribution of IRTs: $1/(m+1)$. More generally, any desired proportion of reinforced responses can be maintained according to the expression $1-(k/(m+1))$, where k is the number of response values in the sample of size m which must be exceeded for reinforcement. Since this procedure reinforces response values exceeding a certain percentile point in the current distribution of response values, it is referred to as Percentile Reinforcement. Alleman and Platt found that differential reinforcement of the most extreme 5% or 10% of the distribution of IRTs increased the modal IRT to a relatively high value. Reinforcement

for the most extreme 25% or 50% of emitted IRTs produced little or no change in the IRT distribution.

Alleman and Platt's (1973) results represent a quantitative confirmation of Skinner's (1938) observation that differential reinforcement of response values "in the upper part of the range" of the response distribution (in particular to values occurring "once in ten times") increases the central tendency of the response distribution. When the most extreme 50% of IRTs was reinforced ("once in two times"), no change in IRT distributions was observed. The proportion of the distribution of response values exceeding the reinforcement criterion thus determined whether differentiation occurred.

With the demonstration of a relationship between the proportion of the IRT distribution reinforced and the occurrence of differentiation, the emphasis of Alleman and Platt's approach shifted to a microanalysis of more fundamental aspects of this relationship. In particular, they recognized that differential reinforcement may affect the overall probability of reinforcement per response. Changes in reinforcement probability are also thought to produce changes in response rate which may be confused with IRT differentiation (Norman, 1966; Reynolds & McLeod, 1970).

Since reinforcement probability was confounded with the proportion of the IRT distribution exceeding the criterion in their original experiment, Alleman and Platt modified the procedure to allow these variables to be independently manipulated. An additional experiment was performed in which the proportion of the distribution exceeding the criterion was varied as before, while the probability of reinforcement

was held constant by reinforcing a fraction of the IRTs which exceeded the criterion. In one group pigeons were reinforced for all IRTs in the most extreme 5% of the IRT distribution. In another group reinforcement was presented for a random 0.5 of IRTs in the most extreme 10% of the distribution. In other groups reinforcement was provided for 0.2 of the most extreme 25%, and 0.1 of the most extreme 50%. The probability of reinforcement for each group was thus equated at 0.05. Mean IRTs were found to be essentially identical to the comparable groups in the original experiment, showing that IRT differentiation was independent of reinforcement probability.

A final point should be emphasized in discussing the Percentile Reinforcement paradigm. Unlike Lane's parametric shaping index and the step-up and step-back rules of Eckerman and Redd, the measure of differential reinforcement represented by the proportion of the distribution of response values exceeding a criterion can be applied to any dimension of behaviour. The relationship between the proportion of the distribution exceeding the criterion and response differentiation might thus have some generality. Alleman and Platt concluded that:

> . . . percentile schedules offer a unique opportunity for abstracting general laws of behavior shaping from highly controlled laboratory situations. The present experiments suggested at least one such law of shaping which is rather surprising. The suggested law is that effectiveness of shaping is related to the relative degree (in a percentile sense) of differential reinforcement, _independent_ of the . . . probability of reinforcement. (p. 71; emphasis in original)

Alleman and Platt (1973) found that asymptotic mean response value was a function of the proportion of response values exceeding a reinforcement criterion. Differential reinforcement of response values

in the most extreme 5% or 10% of the distribution differentiated IRTs, while no effect was obtained when less extreme values (25% or 50%) were reinforced. Because the relative extremeness of reinforced values implies a greater differential between the values of emitted and reinforced responses, Alleman and Platt's results showed that a greater differential generated higher asymptotic response values. A similar relationship was observed in experiments in which response values were required to exceed a fixed criterion for reinforcement. In these experiments (e.g. Notterman & Mintz, 1962; Catania, 1970; Platt, Kuch & Bitgood, 1973) higher criterion values produced mean response values which were progressively less than the criterion, and hence reflected greater differentials between emitted and reinforced response values.

The existence of a common relationship between the relative extremeness of differential reinforcement and asymptotic value of a response property in these examples suggests the operation of a common process. The research reported in this dissertation is concerned with isolating the determinants of this process and illustrating its role in seemingly disparate situations. For example, it will be shown that the power function relationship in differentiation experiments may be derivable from the results of Percentile Reinforcement experiments.

The response dimension chosen for study in this dissertation was the length of runs of pigeons' key peck responses. Since differentiation experiments using other response properties have often found a power function relating mean or median response value and the minimum value required for reinforcement, Experiment I was performed to determine whether run-lengths exhibit the same relationship.

In Experiment II the relationship between the proportion of the distribution of run-lengths exceeding a reinforcement criterion and asymptotic mean run-length was examined in a Percentile Reinforcement procedure. Three proportions (15%, 30%, 45%) were assigned both between- and within-subjects. Probability of reinforcement was held constant at 0.15 in all conditions. Experiment II will indicate whether higher asymptotic run-lengths are obtained when more extreme portions of the run-length distribution are reinforced while reinforcement probability is held constant. Although an effect in Experiment II could not be attributed to reinforcement probability, this experiment would not exclude the possibility that different probability values could affect differentiation. This potential effect was investigated in Experiment III, where the proportion of the distribution exceeding the criterion was held constant at 30% and different reinforcement probabilities (0.30 and 0.15) were given between- and within-subjects.

Platt (1973) described the measure of differential reinforcement represented by the proportion of responses exceeding the criterion as the selectiveness of the criterion, "the uniqueness of criterion behaviors among behaviors currently being emitted by the organism . . . if only a relatively narrow range of behaviors currently being emitted satisfies the reinforcement criterion, higher selectiveness exists than if a wider range meets this criterion." (p. 276-277) While selectiveness is thus equated with the range of reinforced response values, it is specified in terms of the percentile value of the criterion. The range of reinforced response values, or the area of the distribution eligible for reinforcement is thus confounded with their relative extremeness, or

the differential between emitted and reinforced response values. An additional purpose of this research is thus to determine the relative contributions of these two factors to differentiation.

One example of a differential reinforcement procedure which separates the area of the response distribution reinforced from the relative extremeness of reinforced response values was reported by Kuch (1974). Kuch's procedure reinforced rats' lever press durations falling between t and t+t' seconds. The area of the duration distribution reinforced could thus be adjusted by varying t'. Kuch found that the proportion of response values reinforced was relatively constant over different t values (2, 4, 8 seconds) when the area was proportional to the criterion t, that is when the t'/t ratio was constant.

Kuch also plotted the relationship between the (lower) criterion value (t) and the median press duration. The relationships were adequately described by power functions, although the functions were increasingly linear when the range of reinforced duration values was narrower (lower t'/t ratios).

A different approach to controlling the area of the distribution of response values eligible for reinforcement while differentially reinforcing particular response values was considered in Experiment IV. A variant of the Percentile Reinforcement paradigm was used to differentially reinforce a fixed proportion of the distribution of response values closest to a prescribed target value. The area was held constant (15% or 30%) and each subject was exposed to target run-lengths ranging from 5 to 40. Of particular interest in this experiment was the relationship between target and mean run-length. Kuch's results indicated that the

shape of the power function relating criterion and mean press durations was influenced by the area of reinforced values. Different functions when different areas of the run-length distribution were eligible for reinforcement in Experiment IV would provide further evidence that the form of this relationship is largely a function of the parameters of differential reinforcement.

An additional purpose of Experiment IV was to examine the rate of change of run-lengths as a function of the differential between emitted and reinforced run-lengths. With other potentially important variables such as the probability of reinforcement and area of the distribution eligible for reinforcement held constant, a relationship between the magnitude of the differential and rate of change would demonstrate that the relative extremeness of reinforced response values, the differential between the central tendencies of the distributions of emitted and reinforced response values, determines the effectiveness of differential reinforcement.

EXPERIMENT I

Introduction

Mechner (1958) and Platt and Senkowski (1970) reinforced runs of rats' lever presses which exceeded fixed minimum run-lengths. Platt and Senkowski also reported that the function relating mean run-length to criterion values of 4, 8, 12 and 16 was linear. This finding is at variance with the results of other differentiation experiments which have generally found a progressive decline in mean response value, relative to the reinforcement criterion, as described by a power function.

Experiment I used the differential reinforcement procedure of Mechner and of Platt and Senkowski with pigeon subjects. A run was defined as at least one peck on an illuminated key before insertion of the pigeon's head into the food hopper. Reinforcement was provided for runs of at least n key pecks, where n was either 5, 10 or 20, for different groups. The primary purpose of this experiment was to determine whether the relationship between criterion and mean run-length is linear, as reported by Platt and Senkowski for rats, or a power function.

Method

Subjects: The subjects were 12 experimentally naive homing pigeons maintained at 80% of their free-feeding weights. In addition to Purina Pigeon Checkers provided as reinforcement in the experimental chamber, each subject was given a supplementary ration in its home cage. Water was available at all times in the home cage, but not in the experimental chamber.

Apparatus: Four single-key operant conditioning chambers were located in an isolated room. Each ventilated, sound-attenuating chamber was equipped with a panel containing a houselight, the response key, and a centrally located food hopper. The addition of a photocell to the food hopper enabled detection of the subject's head in the hopper. White noise in the room during testing helped to mask extraneous sounds. Stimulus events and reinforcement contingencies were programmed with a Digital Equipment Corporation PDP-8/I computer. Data were stored on paper tape for subsequent analysis.

Procedure: Subjects were trained to peck the key using a procedure combining hopper training and autoshaping (Brown & Jenkins, 1968). On the first day of this training, each subject received 25 trials in which an 8-second key light presentation was followed immediately by operation of the food hopper. Food remained available until the hopper photocell had been interrupted for a cumulative total of 4 seconds. The termination of food presentation was followed by a variable intertrial interval (mean = 60 seconds, range = 30 - 120 seconds) in the presence of the houselight. All subjects were eating from the hopper by the end of the first day of pretraining.

In the second and subsequent sessions, the hopper operation was altered so that food remained available for only 4 seconds, regardless of the time spent eating. Otherwise the procedure was the same: an 8-second key light presentation followed by hopper operation and an average 60-second interval in the presence of the houselight. Throughout this initial pretraining, a peck on the key while the key light was illuminated was immediately followed by extinction of the key light and hopper operation. All subjects acquired the key peck response to a criterion of responding on 50% of trials by the end of the sixth pretraining session. Two additional sessions of continuous reinforcement (CRF) were then given in which 4-second access to food was contingent on a single key peck. Each food presentation was followed by a 10-second intertrial interval during which both key light and houselight were darkened.

Following pretraining, the subjects were randomly assigned to 3 groups of 4 subjects each and given 5 sessions of fixed-ratio (FR) training in which reinforcement was delivered following completion of a sequence of n key pecks. This training was included in order to give the subjects experience with sequences of responses before introducing them to the fixed criterion. In the first FR session, the value of n was progressively incremented from 1 to either 5, 10 or 20; one value of n for each group. Four additional FR sessions were then given with the same n values. Each session continued until 30 reinforcements were delivered, with each reinforcement followed by a 10-second intertrial interval.

In the final phase of this experiment a criterion (n) was specified and reinforcement made contingent on completion of a run of

at least n responses on the key before a hopper entry broke the beam of the photocell. Hopper entries following fewer than n responses reset the requirement to n, but were not followed by any exteroceptive stimulus change. Each reinforcement was followed by a 10-second intertrial interval. A total of 27 sessions of 30 reinforcements each were carried out in this phase.

Results

All results to be reported for Experiment I are based on data collected over the final 4 sessions. The relative frequency distribution of run-lengths for each individual subject in these sessions is presented in Figure 1. The criterion value is indicated by a dashed vertical line. Run-lengths greater than the criterion were followed by reinforcement, and are indicated by dark areas. Non-reinforced runs are represented by open areas. The proportion of reinforced responses is given for each subject and as a mean for each group, in the first column of Table 1. There is no overlap between groups. The relationship between the proportion of run-lengths reinforced and the criterion is illustrated in the top right-hand panel of Figure 2.

Statistical descriptions of the distributions in Figure 1 are also given in Table 1. The mean, standard deviation, and the ratio of these values are presented for each subject and as a mean for each group. There is no overlap in mean run-length between groups. The relationship between the criterion and mean run-length is shown in the top left-hand panel of Figure 2. Mean run-length (N) for each subject is plotted against the criterion (n) in logarithmic coordinates and these points fit with a straight line accounting for 94% of the between-subjects variance. This fit defines a power function with parameters $N = 2.63\ n^{0.69}$.

The lower left-hand panel of Figure 2 plots standard deviation against the criterion for each subject. Although the variability of this statistic is high, there is a definite trend toward higher standard deviations at higher criterion values. The ratio of standard deviation to mean shows a tendency to decrease at higher criterion values, as seen

FIGURE 1

Relative frequency distributions of run-lengths for each subject in the final 4 sessions. The value of the criterion (n) is given for each group, and is indicated in the distribution by dashed vertical lines. Run-lengths greater than the criterion were reinforced, and are represented by dark areas. Non-reinforced runs are represented by open areas.

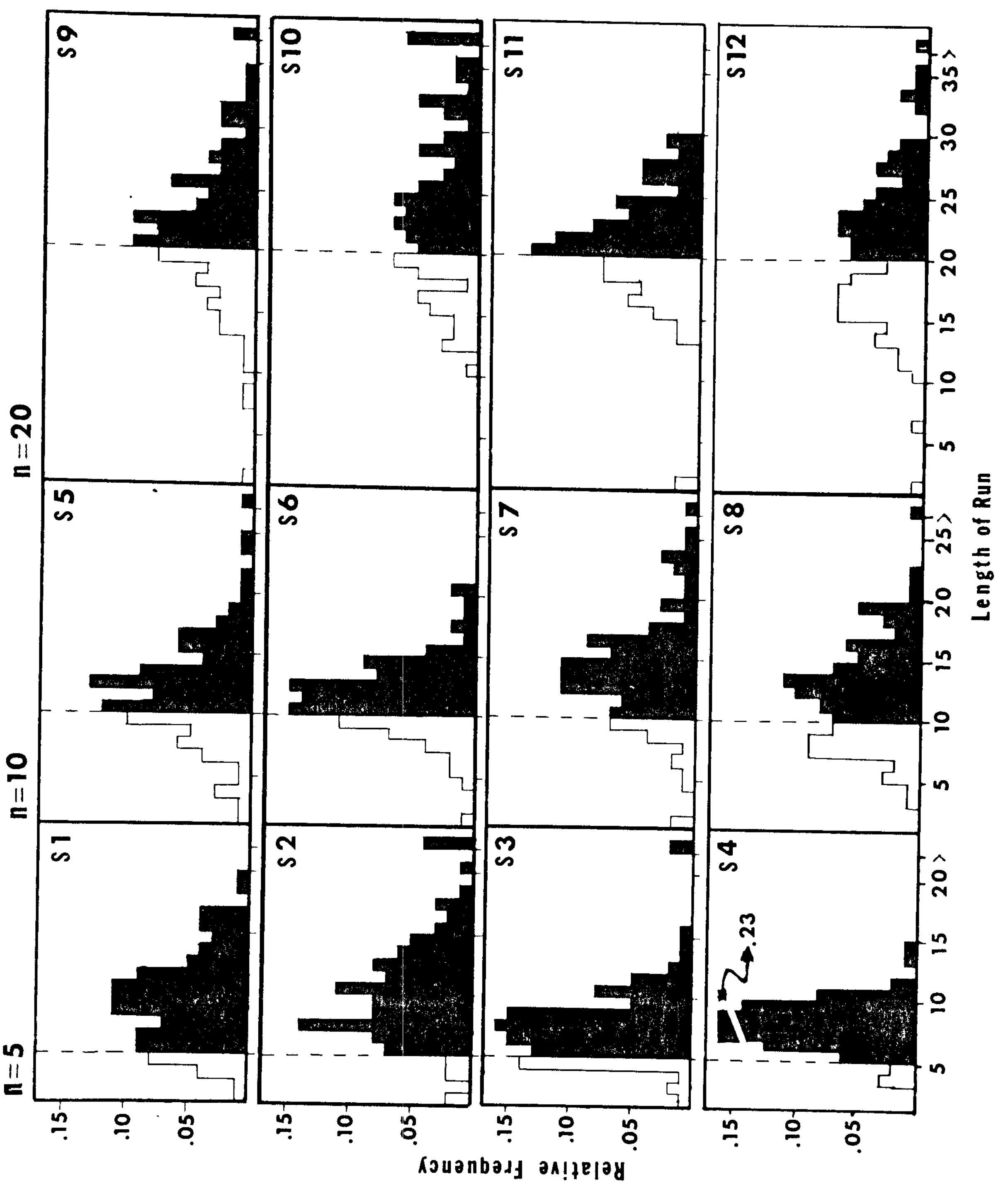

n=5
n=10
n=20
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
.15
.10
.05
.23
Relative Frequency
5
10
15
20>
25>
30
35>
Length of Run

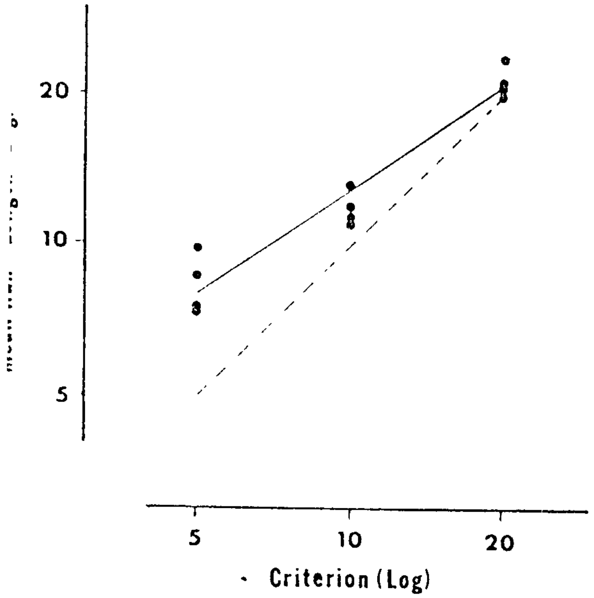
TABLE 1

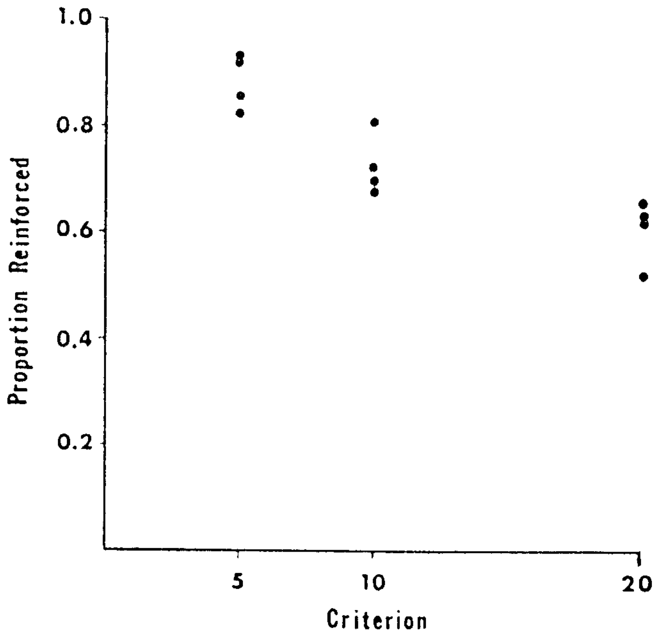
Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean. These values are given for each subject and as a mean for each group.

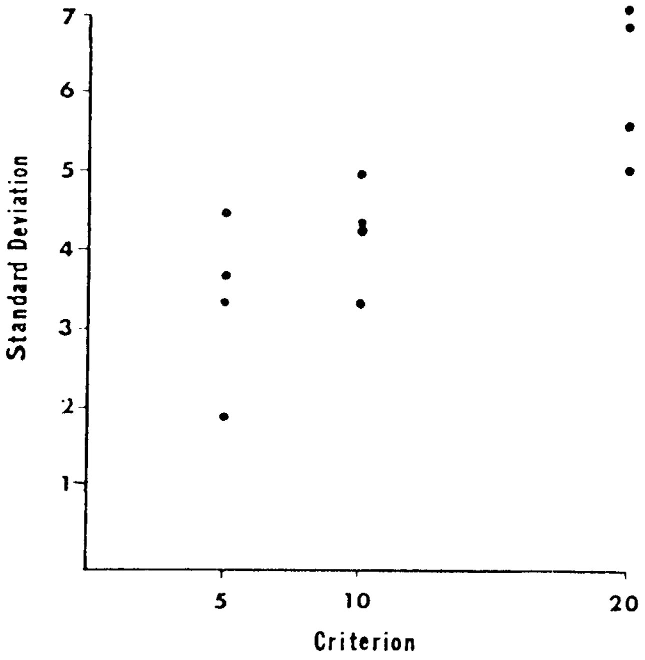
	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
	1	0.86	8.68	3.68	0.42
	2	0.94	9.83	4.43	0.45
Criterion=5	3	0.83	7.25	3.32	0.46
	4	0.94	7.40	1.88	0.25
	Mean	0.89	8.29	3.33	0.40
	5	0.69	11.36	4.22	0.37
	6	0.73	11.18	3.24	0.29
Criterion=10	7	0.81	13.31	4.86	0.37
	8	0.69	11.93	4.26	0.36
	Mean	0.73	11.95	4.15	0.35
	9	0.66	21.36	5.65	0.26
	10	0.68	23.63	7.04	0.30
Criterion=20	11	0.63	20.23	5.01	0.25
	12	0.53	20.16	6.64	0.33
	Mean	0.63	21.35	6.09	0.29

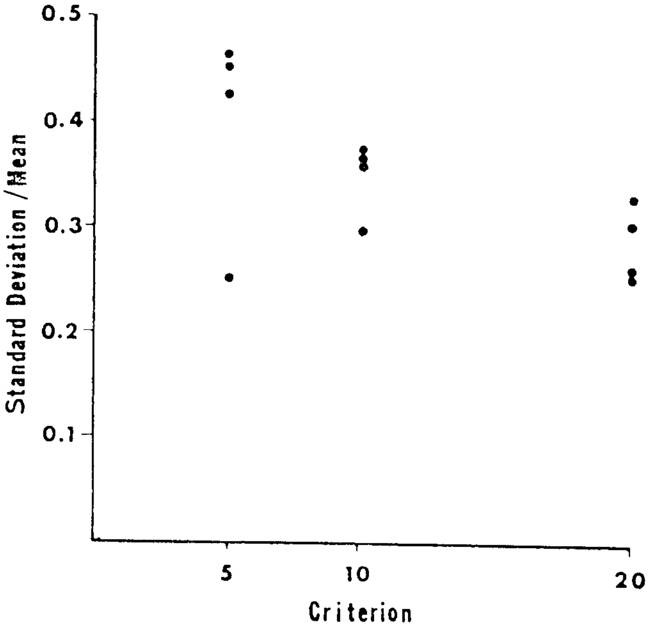
FIGURE 2

Relationships between properties of the run-length distribution and the criterion. The top right-hand panel shows the proportion of the distribution exceeding the criterion as a function of the criterion. The top left-hand panel plots mean run-length (N) against the criterion (n) in logarithmic coordinates. The solid line, which accounts for 94% of the variance, is a power function with parameters $N = 2.63\ n^{0.69}$. The diagonal dashed line represents perfect matching between mean and criterion. The lower left-hand panel shows standard deviation as a function of the criterion. The ratio of standard deviation to mean run-length is shown for different criterion values in the lower right-hand panel.


20
10
5
5
10
20
Criterion (Log)


1.0
0.8
0.6
0.4
0.2
Proportion Reinforced
5
10
20
Criterion


7
6
5
4
3
2
1
Standard Deviation
5
10
20
Criterion


0.5
0.4
0.3
0.2
0.1
Standard Deviation /Mean
5
10
20
Criterion

from the lower right-hand panel of Figure 2.

Discussion

The results of Experiment I demonstrate that run-length differentiation with pigeons obeys laws similar to those found with other response dimensions. The results of a number of previous differentiation experiments can be described by power functions with fractional exponents relating the mean or median response value to the value of a reinforcement criterion. In Experiment I the relationship between mean run-length and criterion value also took the form of a power function with a fractional exponent. The fractional exponent indicates that mean run-lengths decline, relative to the criterion, at higher criterion values. Since only run-lengths exceeding the criterion were reinforced, this relationship also means that at higher criterion values a lower proportion of the run-length distribution was reinforced, and hence, the differential between emitted and reinforced run-lengths was greater. The fact that the exponent of the power function was positive indicates that higher criterion values were associated with higher mean run-lengths. The results of Experiment I thus show that higher asymptotic mean run-lengths were associated with a greater differential between emitted and reinforced run-lengths.

EXPERIMENT II

Introduction

Experiment I showed that higher reinforcement criteria resulted in both higher asymptotic mean run-lengths and reinforcement for a smaller, more extreme proportion of the run-length distribution. The correlation between asymptotic mean response value and the proportion of the distribution of response values exceeding the reinforcement criterion suggests that the effectiveness of differential reinforcement may be a function of the proportion of the distribution reinforced. Demonstration of this relationship would require an experimental manipulation of the proportion of the distribution reinforced.

Alleman and Platt (1973) found that when the most extreme 5% or 10% of the distribution of IRTs was reinforced using the Percentile Reinforcement procedure, higher asymptotic response values were obtained. When less extreme response values were reinforced (25% or 50%), no consistent change in the distribution of response values was obtained. One purpose of Experiment II was to use the Percentile Reinforcement procedure of Alleman and Platt to determine whether reinforcement of relatively extreme response values generates higher asymptotic values on the run-length dimension. An additional purpose of this experiment was to determine whether the rate of increase of run-lengths is also a function of the proportion of the distribution reinforced.

Method

Subjects: The subjects were 12 experimentally naive white carneaux and white king pigeons maintained at 80% of their free-feeding weights. Grain was provided as reinforcement in the experimental chambers, and each subject was given a supplementary ration in its home cage. Water and grit were available at all times in the home cage but not in the experimental chamber.

Apparatus: Four Lehigh Valley Electronics 3-key operant conditioning chambers were modified by the addition of a photocell to detect the subject's head in the hopper. The chambers were controlled by a Digital Equipment Corporation PDP-8/e computer and data were recorded on magnetic tape for subsequent analysis.

Procedure: The subjects were trained to respond on the left key using the pretraining procedure described for Experiment I. All subjects acquired the key pecking response to a criterion of responding on 50% of trials by the end of the third pretraining session. Both keys were then illuminated and a response on the right key following at least one response on the left key was required for reinforcement (4-second access to grain). The behaviour required by this schedule was acquired by all subjects in one session of 32 trials, and in the second and third sessions reinforcement probability was reduced to 0.5 and 0.25 for 64 and 128 trials, respectively, while reinforcement was provided non-differentially (selectiveness = 100%; run-lengths in the upper 100 percentage points were eligible for reinforcement). In the next session, reinforcement probability was reduced to 0.15 while reinforcement remained non-differential. Non-reinforced runs were followed by a 4-

second intertrial interval in which key lights and houselight were darkened. This Baseline Phase continued for 4 sessions of 150 trials each.

In the subsequent Differential Selectiveness Phase, subjects were randomly assigned to 3 groups of 4 subjects each. In this phase reinforcement was provided for run-lengths in the most extreme 15%, 30% or 45% of the distribution (selectiveness = 15%, 30% or 45%). However, to maintain reinforcement probability constant at 0.15, only a random half of the available reinforcements for the 30% group and only a third of those for the 45% group were actually delivered. These conditions remained in effect for 32 sessions, at which point performance appeared stable. For the next 34 sessions, all groups were differentially reinforced with the same selectiveness (15%) and probability (0.15). This Equated Selectiveness Phase was followed by a second Differential Selectiveness Phase in which each group was returned to the conditions in effect during the first Differential Selectiveness Phase. After 16 sessions, a second Baseline Phase was instituted for 6 sessions. Each session in all phases continued until 150 runs were completed or a 2-hour time limit expired.

Several details of the Percentile Reinforcement procedure used in this experiment require clarification. A basic assumption underlying Percentile Reinforcement is that a random sample of the current distribution of response values is available for computing a reinforcement criterion. In practice, this sample is a continuously updated list or memory of the preceding m response values. Alleman and Platt (1973; Experiment II) found no difference in IRT differentiation with m ranging

from 4 to 40. Accordingly, the value of m was arbitrarily set to 13 for all groups in the present experiment.

Another problem associated with the memory of response values is how to treat the first m responses of each session, before there are m responses in the memory. In Alleman and Platt's experiment, this situation was dealt with by setting a fixed criterion for the first m responses with a value which would have provided reinforcement with the proper selectiveness for the final 10 responses in the preceding session. In the present experiment, each session's final memory was saved on magnetic tape and became the initial memory in the following session.

A problem of some importance with an integer response dimension such as the number of responses in a run is the fate of "ties" (separate responses with the same value) in deciding reinforcement with the percentile contingencies. This problem would be particularly acute early in training when most runs have a length of 1 or 2 responses. The solution adopted in this case was to randomly reinforce (0.15) run-lengths which did not exceed k of the m runs in memory, but which were not themselves exceeded by more than m - k runs.

Results

The overall effect of selectiveness on the shaping of run-lengths is best seen in the "learning curves" illustrated in Figure 3. Here, the mean of the mean run-lengths for each group of 4 subjects is plotted on a logarithmic scale over sessions. The two Baseline Phases, at the beginning and end of the experiment, indicate the length of runs when reinforcement was provided non-differentially for 0.15 of runs. When differential reinforcement for the most extreme 15%, 30% or 45% of runs was applied in the first Differential Selectiveness Phase, substantial increases over this baseline were found for all groups, and the rate and extent of these increases were related to the degree of selectiveness. In the Equated Selectiveness Phase, with all groups exposed to the most extreme selectiveness value (15%), run-lengths for all groups approached the value reached by the 15% group in the preceding phase. The second Differential Selectiveness Phase resulted in the return of run-lengths to approximately the levels reached in the first Differential Selectiveness Phase.

The relationship between selectiveness and asymptotic run-length is shown in Figure 4. The mean of mean run-lengths for each group over the final 4 sessions of each differential reinforcement phase is plotted in logarithmic units as a function of the upper percentage points of the run-length distribution for which reinforcement was available. Triangles represent the 15% group, squares represent the 30% group and circles represent the 45% group. Dark symbols stand for the first Differential Selectiveness Phase, open symbols for the second Differential Selectiveness Phase, and half-shaded symbols for the Equated Selectiveness Phase. Longer run-lengths were obtained both between and within subjects when a lower

FIGURE 3

Mean mean run-length (in logarithmic units) for each group of 4 subjects in each session. Groups are identified by the upper percentage points of the run-length distribution for which reinforcement was available (selectiveness) during the Differential Selectiveness Phases. In the Equated Selectiveness Phase, all groups had a selectiveness value of 15%. The Baseline Phases show the length of runs under non-differential reinforcement. Reinforcement probability was constant at 0.15 throughout the experiment.

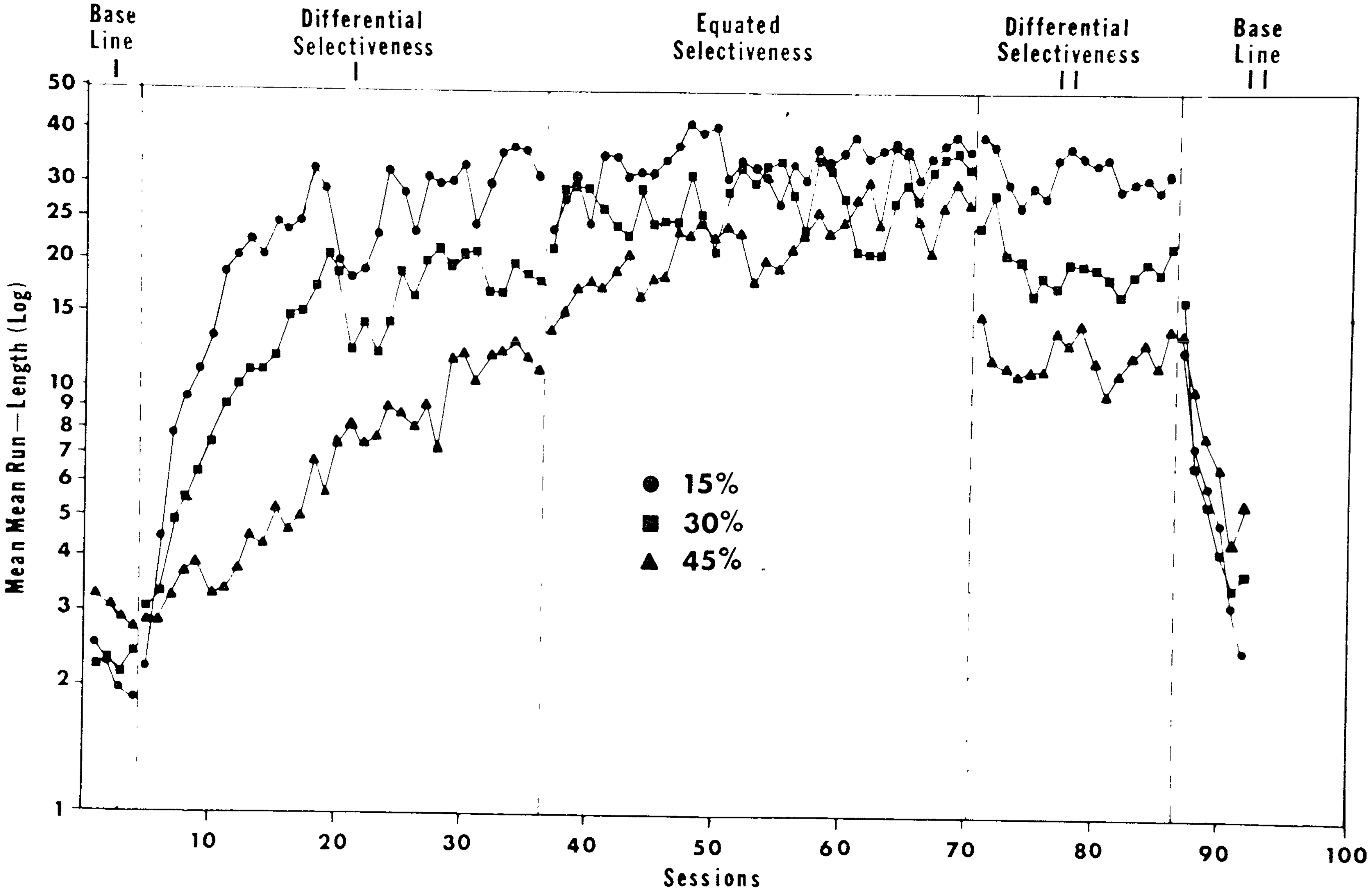
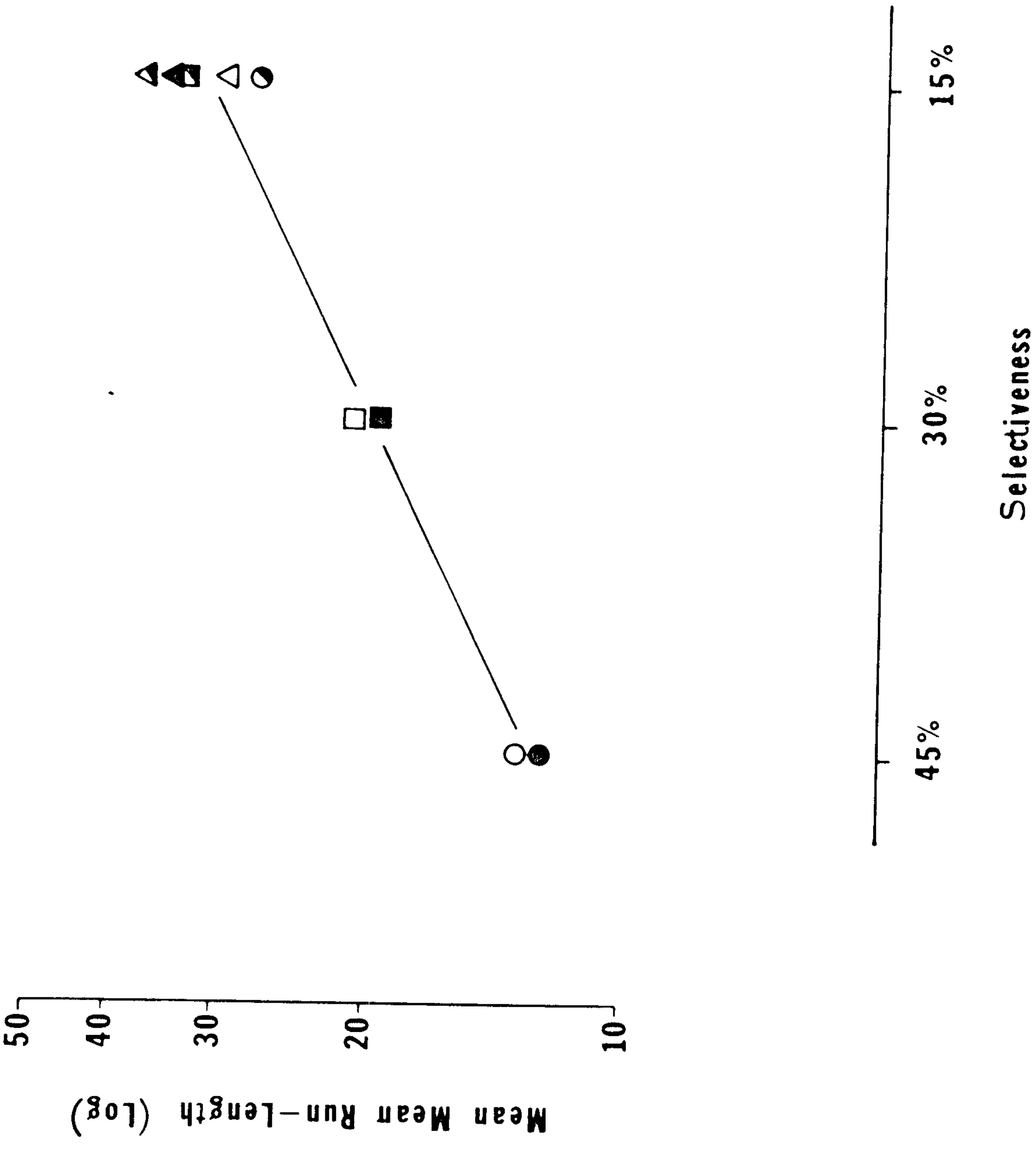

Base Line I
Differential Selectiveness I
Equated Selectiveness
Differential Selectiveness II
Base Line II
Mean Mean Run—Length (Log)
50
40
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
Sessions
● 15%
■ 30%
▲ 45%

FIGURE 4

Mean mean run-length (in logarithmic units) for each group over the final 4 sessions of each differential reinforcement phase. Triangles represent the 15% selectiveness group, squares the 30% group, and circles the 45% group. Dark symbols stand for the first Differential Selectiveness Phase, open symbols for the second Differential Selectiveness Phase, and half-shaded symbols for the Equated Selectiveness Phase.


Mean Mean Run–Length (Log)
50
40
30
20
10
Selectiveness
45%
30%
15%

proportion of the distribution was reinforced (higher selectiveness).

Figure 5 presents relative frequency distributions of run-lengths for individual subjects collected over the last 4 sessions in each differential reinforcement phase. Dark areas represent runs followed by reinforcement and open areas signify non-reinforced runs. Statistical descriptions of these distributions are presented in Tables 2, 3 and 4. The first column in each table, labelled "PROP. REINF.", gives the proportion of runs followed by reinforcement. It can be seen that these values tend to be slightly higher than their nominal value of 0.15 for the 12 sessions represented in these tables. When data for all 92 sessions are considered, however, close control of this proportion was maintained, with a mean of 0.16 and standard deviation of 0.03. The "MEAN RUN-LENGTH" columns show that all subjects in the 45% group and 3 of the 4 subjects in the 30% group produced higher mean run-lengths during the phase in which selectiveness was increased to 15%. The "STANDARD DEVIATION" and "S.D./MEAN" columns show that variability was much greater than in Experiment I, and that the ratio of standard deviation to mean was relatively constant for all groups and phases.

FIGURE 5

Relative frequency distributions of run-lengths for each subject over the final 4 sessions of the 3 differential reinforcement phases. Each group of 4 subjects is identified by the selectiveness value in effect during the Differential Selectiveness Phases.

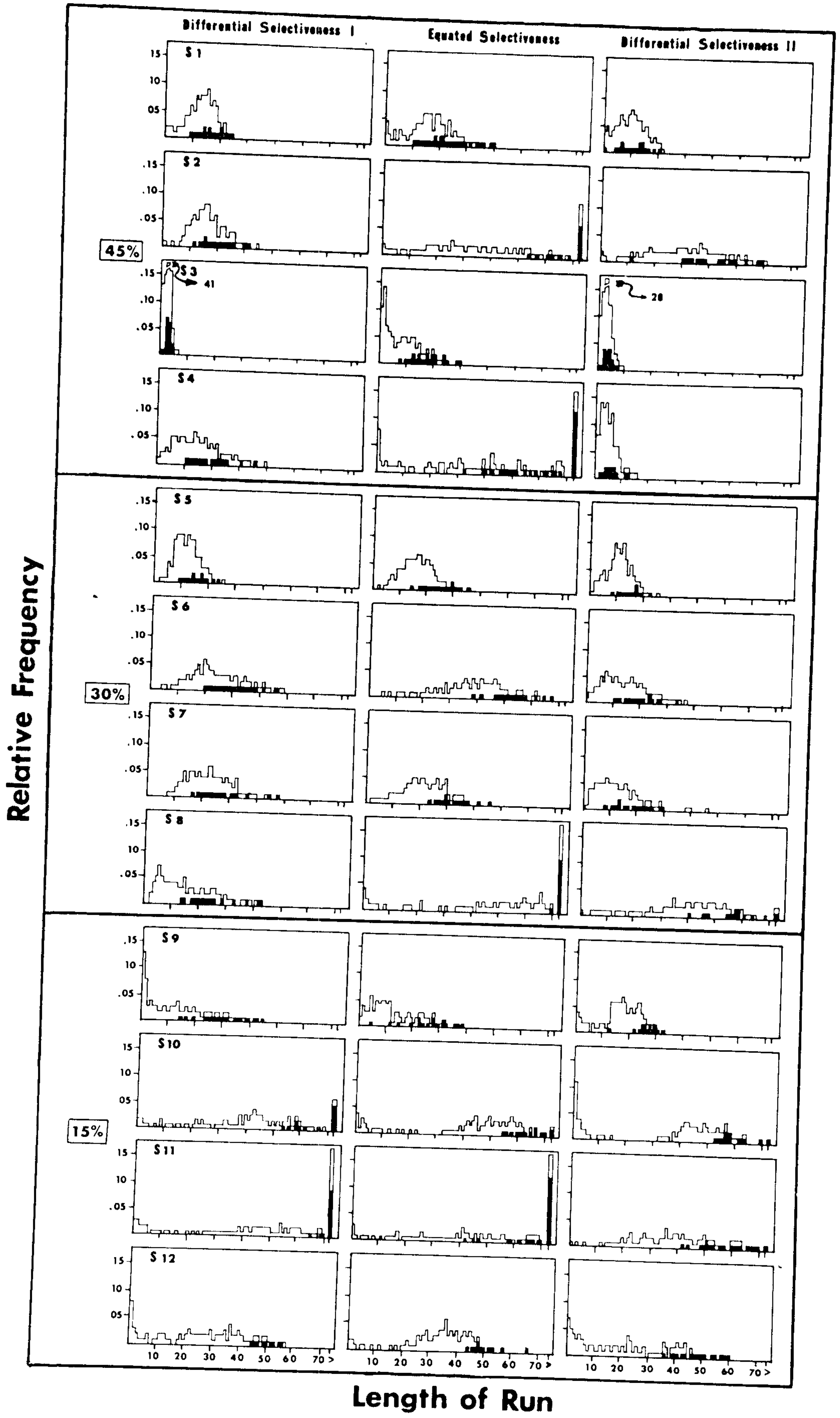

Differential Selectiveness I
Equated Selectiveness
Differential Selectiveness II
Relative Frequency
Length of Run
45%
30%
15%
S 1
S 2
S 3
S 4
S 5
S 6
S 7
S 8
S 9
S 10
S 11
S 12
41
28
.15
.10
.05
10
20
30
40
50
60
70 >

TABLE 2

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 45% selectiveness group. These values are given for the final 4 sessions of each of the 3 differential reinforcement phases.

	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
Differential Selectiveness I (45%)	1	0.16	13.49	5.33	0.40
	2	0.16	17.28	6.47	0.37
	3	0.16	2.93	1.13	0.39
	4	0.17	15.71	8.78	0.56
	Mean	0.16	12.35	5.43	0.43
Adjusted Selectiveness (15%)	1	0.22	17.62	8.81	0.50
	2	0.16	39.36	23.13	0.59
	3	0.19	9.08	6.94	0.76
	4	0.22	43.89	26.55	0.60
	Mean	0.20	27.49	16.36	0.61
Differential Selectiveness II (45%)	1	0.17	10.31	5.36	0.52
	2	0.15	33.05	14.54	0.44
	3	0.15	3.53	1.81	0.51
	4	0.12	5.63	3.66	0.65
	Mean	0.15	13.13	6.59	0.53

TABLE 3

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 30% selectiveness group. These values are given for the final 4 sessions of each of the 3 differential reinforcement phases.

	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
Differential Selectiveness I (30%)	5	0.13	12.61	4.49	0.36
	6	0.23	25.20	10.96	0.43
	7	0.18	23.62	8.94	0.38
	8	0.15	16.63	10.76	0.65
	Mean	0.17	19.53	8.79	0.46
Equated Selectiveness (15%)	5	0.17	17.75	6.63	0.37
	6	0.18	39.41	14.08	0.36
	7	0.17	23.16	9.17	0.40
	8	0.16	52.44	25.69	0.49
	Mean	0.17	33.19	13.89	0.41
Differential Selectiveness II (30%)	5	0.14	11.82	4.95	0.42
	6	0.17	15.71	9.23	0.59
	7	0.17	14.07	8.85	0.63
	8	0.16	41.00	17.46	0.43
	Mean	0.16	20.65	10.12	0.49

TABLE 4

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 15% selectiveness group. These values are given for the final 4 sessions of each of the 3 differential reinforcement phases.

	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
Differential Selectiveness I (15%)	9	0.20	15.92	12.79	0.80
	10	0.15	42.03	20.30	0.48
	11	0.15	48.65	25.45	0.52
	12	0.15	28.13	17.71	0.63
	Mean	0.16	33.68	19.06	0.61
Equated Selectiveness (15%)	9	0.24	16.24	10.78	0.66
	10	0.15	44.28	20.85	0.47
	11	0.22	51.05	26.86	0.53
	12	0.14	34.22	13.11	0.38
	Mean	0.19	36.45	17.90	0.51
Differential Selectiveness II (15%)	9	0.16	17.33	8.09	0.47
	10	0.14	37.35	22.97	0.61
	11	0.18	41.00	17.88	0.44
	12	0.15	23.30	16.92	0.73
	Mean	0.16	29.75	16.47	0.56

Discussion

The results of Experiment II demonstrate that selectiveness of differential reinforcement, the proportion of the run-length distribution exceeding the reinforcement criterion, can affect both the rate of change of run-lengths and the value on the run-length dimension at which an asymptote is reached. Both the rate of increase and the asymptotic value of the mean run-length were highest for subjects reinforced for run-lengths in the upper 15% of their run-length distribution. The rate and asymptote were lowest for the group reinforced for the most extreme 45% of run-lengths. A similar relationship between mean run-length and the relative extremeness of differential reinforcement was noted in Experiment I. Higher criteria for reinforcement resulted in higher mean run-lengths and reinforcement for a smaller, more extreme proportion of the run-length distribution. The similarity of this relationship in Experiments I and II is particularly significant in view of the reversal of roles between independent and dependent variables in the two experiments. In Experiment I, the reinforcement criterion was the independent variable and the proportion of the distribution exceeding the criterion a dependent variable. In Experiment II, the proportion of the distribution exceeding the criterion was the independent variable, and the criterion value a dependent variable.

EXPERIMENT III

Introduction

The effect of selectiveness on differentiation in Experiment II was obtained despite the fact that the probability of reinforcement per response was equated across groups and phases. Alleman and Platt (1973) found similar IRT differentiation whether reinforcement probability varied with selectiveness or was held constant, and concluded that differentiation was a function of the selectiveness of differential reinforcement, independent of reinforcement probability. However, neither Alleman and Platt's experiment nor Experiment II directly addressed the question of whether non-differential reinforcement variables such as reinforcement probability may influence differentiation.

One mechanism by which reinforcement probability could affect differentiation has been called subjective, or marginal utility (Brandon, 1969). Briefly, this account states that when responses are reinforced with a high probability, each reinforcement has a relatively low subjective value; and is, therefore, less effective than a reinforcement occurring in the context of lower reinforcement probability. Thus differential reinforcement may be more effective when reinforcement probability is low. Platt (1973) has discussed reinforcement probability as a measure of contact of the subject's behaviour with the criterion for reinforcement. In Experiment III, Percentile Reinforcement is used to reinforce run-lengths in the most extreme 30% of the distribution, but for different groups either all or half of these runs were reinforced. The proportion

of the distribution exceeding the reinforcement criterion (selectiveness) is thus held constant at 30% while reinforcement probability (contact) is varied (0.30 and 0.15).

Method

Subjects: The subjects were 12 experimentally naive white carneaux pigeons. These subjects were maintained under the conditions of Experiment II.

Apparatus: The apparatus was the same as that described in Experiment II.

Procedure: Pretraining was carried out as in Experiment II, and all subjects met the criterion of 50% responding by the end of the third pretraining session. On the following day, subjects were divided into 3 groups of 4 each and given continuous reinforcement for right-key responses following a run of at least one left-key response. In the second session, the probability of reinforcement per run (contact) was reduced to 0.30, although reinforcement remained non-differential (100% selectiveness). This session was followed by 6 sessions of non-differential reinforcement (selectiveness = 100%) and differential contact between groups. One group received reinforcement with probability 0.15 and the other two groups with probability 0.30. The 0.15 contact group was given 150 trials per session, for an expected 22.5 reinforcements. One of the 0.30 groups also received 150 trials, for an average of 45 reinforcements per session. The other 0.30 group was given only 75 trials per session, but matched the 0.15 group in expected number of reinforcements (22.5). Following this Baseline Phase, differential reinforcement was instituted for all groups with selectiveness of 30%. Each group had the same degree of contact and number of trials per session as in the Baseline Phase. This Differential Contact Phase was continued for 48 sessions, and was followed by 26 sessions of Equated Contact, in which all subjects received

differential reinforcement with selectiveness of 30%, contact of 0.15, and 150 trials per session.

Results

Figure 6 shows the mean mean run-length (in logarithmic units) for each group in each session. All groups showed increasing run-lengths during differential reinforcement, but no systematic differences existed between groups in either rate or asymptotic extent of these increases. The "learning curves" for these groups are very similar to that of the group in Experiment II which was also reinforced with 30% selectiveness.

Relative frequency distributions of run-lengths for each subject for the final 4 sessions of both differential reinforcement phases are presented in Figure 7. These distributions resemble those reported in Experiment II in their general form and variability. The higher reinforcement probability of the 0.30 groups during Differential Contact can be seen in the larger area of the dark region of the distributions representing reinforced run-lengths.

Some statistical properties of these distributions are given in Tables 5, 6 and 7. Probability of reinforcement (contact), the primary independent variable in this experiment, is shown in the first column. These values are slightly greater than their nominal values of 0.15 and 0.30. When data for all 80 sessions are considered, the mean values of contact were 0.16 and 0.32, with standard deviations of 0.03 and 0.05. The "MEAN RUN-LENGTH" column shows no systematic differences in mean either within or between subjects under different contact conditions. The small increase by 3 of the 4 subjects in the 0.30 (75 trial) group could be due to the greater number of trials per session (150 in the 0.15 condition; 75 in the 0.30 condition). Standard deviation and the ratio of standard deviation to mean run-length are comparable to these statistics

in Experiment II, and are generally higher than in Experiment I.

FIGURE 6

Mean mean run-length for each group of 4 subjects (in logarithmic units) for each session. Groups are identified by their probability of reinforcement (contact) and number of trials per session during the Baseline Phase and the Differential Contact Phase. In the Equated Contact Phase, all groups had contact of 0.15. Selectiveness was constant at 30% during the differential reinforcement phases.

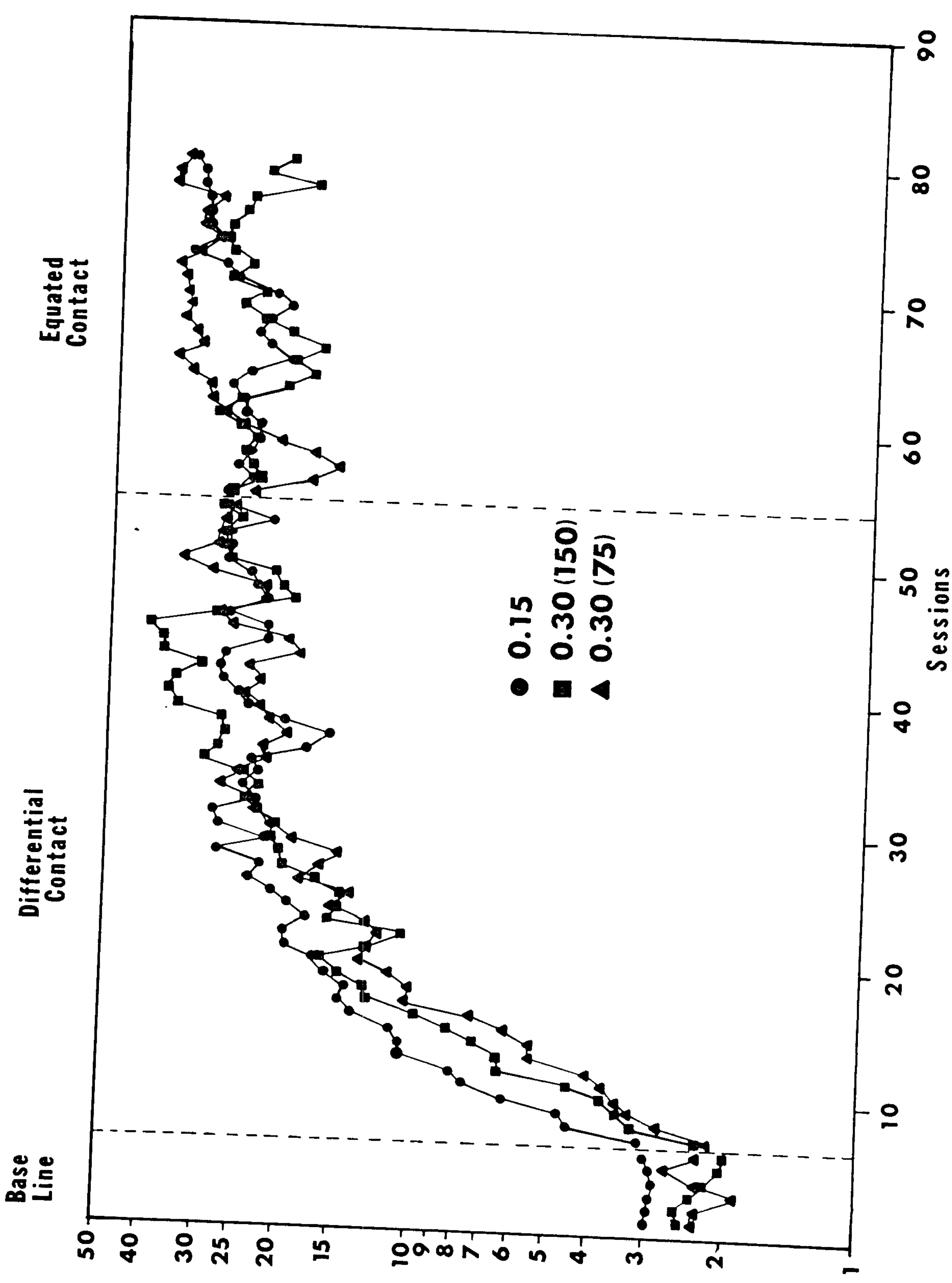

Base Line
Differential Contact
Equated Contact
● 0.15
■ 0.30 (150)
▲ 0.30 (75)
Mean Mean Run—Length (Log)
50
40
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
Sessions

FIGURE 7

Relative frequency distributions of run-lengths for each subject over the final 4 sessions of each differential reinforcement phase. Groups are identified by the probability of reinforcement and number of trials per session during the Differential Contact Phase.

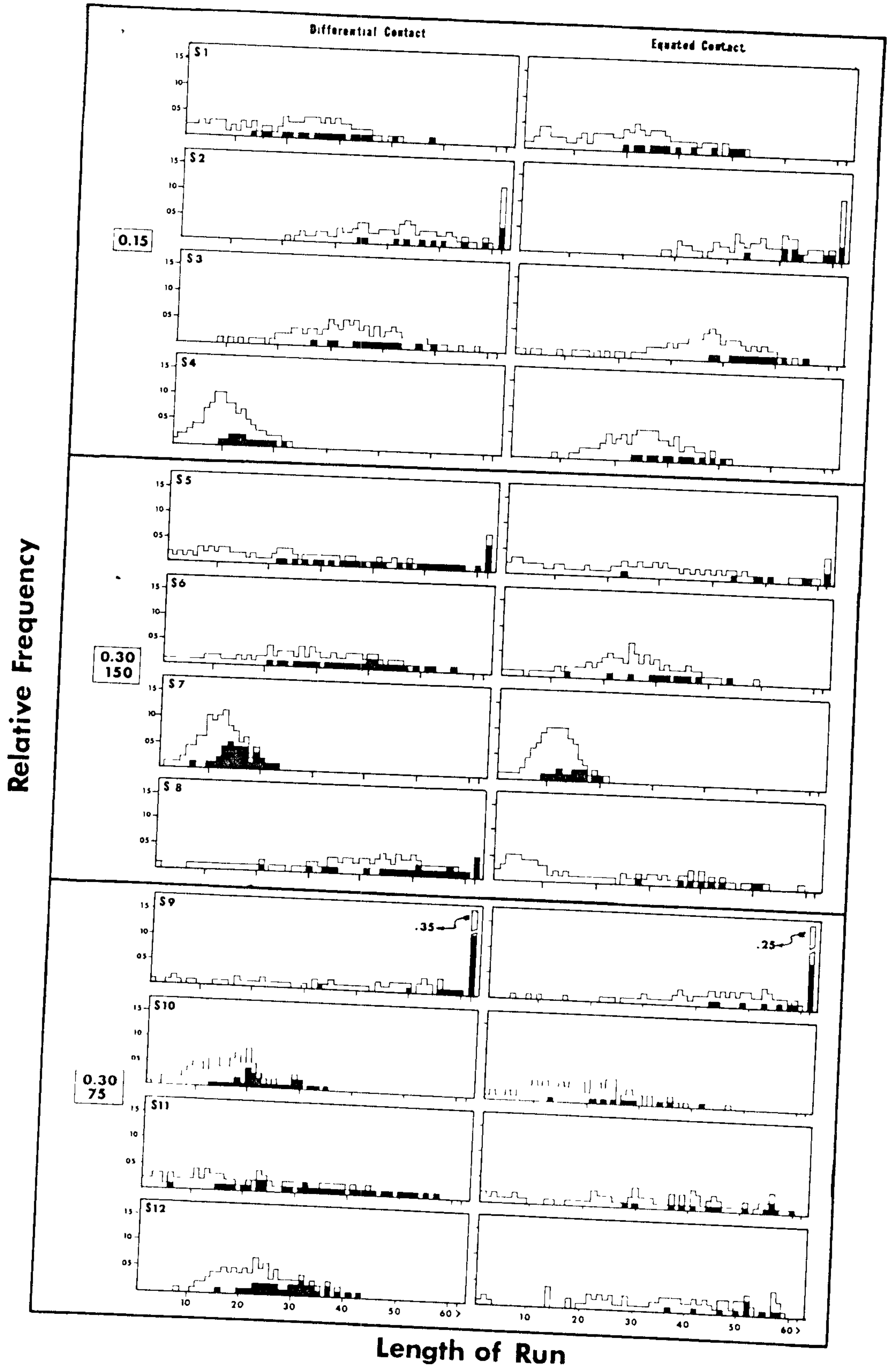

Differential Contact
Equated Contact
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
15
10
05
0.15
0.30
150
0.30
75
.35
.25
10
20
30
40
50
60>
Relative Frequency
Length of Run

TABLE 5

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 0.15 contact group. These values are given for the final 4 sessions of each of the 2 differential reinforcement phases.

SUBJECT		PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
Differential Contact (0.15)	1	0.16	21.39	11.18	0.52
	2	0.14	44.92	14.19	0.32
	3	0.15	33.22	10.63	0.32
	4	0.15	11.16	4.80	0.43
	Mean	0.15	27.67	10.20	0.40
Equated Contact (0.15)	1	0.18	21.03	11.13	0.53
	2	0.15	48.52	11.95	0.25
	3	0.17	35.27	11.94	0.34
	4	0.15	26.27	7.99	0.30
	Mean	0.16	32.77	10.75	0.36

TABLE 6

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 0.30 (150 trials) group. These values are given for the final 4 sessions of each of the 2 differential reinforcement phases.

	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
Differential Contact (0.30-150 Trials)	5	0.32	28.99	20.21	0.70
	6	0.31	28.40	12.65	0.45
	7	0.33	12.19	4.30	[illegible]
	8	0.33	40.46	14.97	0.37
	Mean	0.32	27.52	13.03	0.47
Equated Contact (0.15)	5	0.14	29.38	19.41	0.66
	6	0.16	24.29	10.00	0.41
	7	0.16	11.20	3.92	0.35
	8	0.16	22.71	16.84	0.74
	Mean	0.16	21.90	12.50	0.54

TABLE 7

Proportion of run-lengths reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for subjects in the 0.30 (75 trials) group. These values are given for the final 4 sessions of each of the 2 differential reinforcement phases.

	SUBJECT	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./MEAN
Differential Contact (0.30-75 Trials)	9	0.31	49.06	25.21	0.51
	10	0.30	16.48	7.11	0.43
	11	0.36	23.00	14.59	0.63
	12	0.32	24.12	8.01	0.33
	Mean	0.32	28.17	13.73	0.48
Equated Contact (0.15)	9	0.17	48.56	17.33	0.36
	10	0.15	19.71	10.64	0.54
	11	0.15	34.82	17.92	0.51
	12	0.15	41.01	15.38	0.37
	Mean	0.16	36.18	15.32	0.45

Discussion

The outcome of Experiment III suggests that contact of behaviour with the criterion, the probability of reinforcement per run, is not an important variable in response differentiation. Experiment II found large effects on both the rate and extent of increases in run-lengths when contact was held constant and selectiveness varied. Alleman and Platt (1973) found that IRT differentiation was essentially identical whether contact varied with selectiveness or was held constant. It is therefore possible to conclude that at least for these response dimensions and this range of values, contact of behaviour with the criterion has no appreciable effect.

EXPERIMENT IV

Introduction

Evidence from the experiments reported above and from other work reviewed in the introduction, indicates that the rate and extent of increases in dynamic values of responding as a result of differential reinforcement depends on a relationship between the distribution of response values and the reinforcement criterion. Response values increase at higher rates and to higher asymptotes when a lower proportion of the distribution exceeds the criterion (Experiment II; Alleman & Platt, 1973). The proportion of the distribution exceeding the reinforcement criterion is a measure of both the area of the response distribution eligible for reinforcement and the relative extremeness of reinforced response values. Platt (1973) referred to this measure of differential reinforcement as selectiveness. While selectiveness is clearly a potent variable in the differentiation of properties of a response with a fixed criterion, results of other differential reinforcement procedures suggests that the notion of selectiveness may require further refinement. For example, differentiation has been obtained in procedures where response values must not only exceed a criterion, but must also be less than an upper limit. In this type of differential reinforcement procedure the area of the response distribution eligible for reinforcement and the relative extremeness of reinforced response values are unconfounded. Change in response values occur when the range of reinforced values lies in an

extreme of the distribution, and an asymptote is reached when reinforced values are near the modal value of the distribution (e.g. Notterman & Mintz, 1962). Varying the area of the response distribution eligible for reinforcement by manipulating the difference between the criterion and upper limit produces relatively minor changes in asymptotic response values (e.g., Kuch, 1974). These results indicate that the effective component of selectiveness is the relative extremeness of reinforced response values - the differential between the overall distribution of response values and those values selected for reinforcement. The area of the distribution eligible for reinforcement appears to be of less importance.

Experiment IV is designed to confirm and extend this conclusion by comparing differentiation with different areas of the response distribution eligible for reinforcement. A variant of the Percentile Reinforcement Procedure is used to hold constant this area, while differentially reinforcing run-lengths closest to a specified target value. When a fixed target value is imposed on some dimension of behaviour, it divides response values into two mutually exclusive and exhaustive classes distinguished by whether they are less than or greater than the target. Once it is determined which of these classes a given response falls into, it is ranked against a sample of previous behaviour in the same class, and reinforced if its value is greater than k_1 of the m_1 values in memory less than the target, or less than k_2 of the m_2 values in memory greater than the target. Since these two responses classes are by definition independent, equating the conditional probabilities of reinforcement for responses in each class has the effect of holding the overall probability of reinforcement constant. At the same time, a specified area of the

distribution closest to the target is differentially reinforced.

As long as all response values fall on one side of the target, this procedure is indistinguishable from Percentile Reinforcement. Under these conditions, reinforcement is restricted to one tail of the distribution, and the relationship between emitted and reinforced responses is the same as what was meant by selectiveness in Experiments II and III. When response values occur on either side of the target, however, reinforced response values will not be confined to an extreme of the distribution, but occupy a fixed area anywhere within the distribution. The area of the distribution of response values for which reinforcement is available, measured in percentage points, is thus held constant. The extremeness of reinforced values varies according to the location of the distribution of response values relative to the target.

Method

Subjects: Eight experimentally naive white carneaux pigeons served as subjects. They were treated as were the subjects in Experiments II and III.

Apparatus: The apparatus was the same as that described for Experiment II.

Procedure: Pretraining was administered as before, except that both left and right key lights were illuminated and responding on either key produced reinforcement. All subjects were then given a single session of continuous reinforcement for right key responses following at least one left key response. The subjects were then divided into 2 groups of 4. For one group, run-lengths in the 15% of the distribution closest to the target were reinforced while the other group was reinforced for the closest 30%. Only a random half of the run-lengths for the 30% group were actually reinforced, thus equating the probability of reinforcement per run (contact) at 0.15.

Target values of 5, 10, 15, 20, 25, 30 and 40 were given. The first four values (5, 10, 15 and 20) were presented to the four subjects in each group in orders determined by a Latin square. The final three values were presented sequentially. All of the targets except 30 and 40 were in effect for a number of sessions equal to their value (e.g., 5 sessions with a target of 5; 25 sessions with a target of 25). The target value of 30 was given for 10 sessions and 40 for 12 sessions. Throughout the experiment, a session continued until a total of 40 reinforcements was presented, or a 2-hour time limit elapsed. Subject 7 died after Session 72.

Since little difference in performance was noted between the two groups at this point in the experiment, the 3 surviving pigeons from the 30% group were exposed to an additional treatment condition in which reinforced response values were drawn from different areas of the distribution about a single target value (25). They were first given 6 sessions in which reinforced responses were drawn from the 30% of the distribution closest to the target. This was followed by 6 sessions at 45%, 8 sessions at 60% and 10 sessions at 75%. In each of these different conditions, only a random proportion of responses eligible for reinforcement were actually followed by food, holding the probability of reinforcement constant at 0.15.

Results

Mean run-lengths for individual subjects, plotted in logarithmic units over sessions, are given in Figure 8. Dotted lines indicate the target run-length in effect for each session. The Latin square order of presentation of the first 4 target values is evident from this figure. Subjects 1 and 5 received these targets in an ascending order, subjects 4 and 8 in a descending order, and subjects 2 and 6, and 3 and 7 completed the Latin square. For the most part, the mean run-lengths corresponded to the target value and did not vary greatly over sessions, although there was a tendency for the mean to be less than the target at higher target values.

Relative frequency distributions of run-lengths for each subject over the final 2 sessions with each target value are presented for the 15% group in Figure 9 and for the 30% group in Figure 10. These distributions resemble those seen in Experiment I in their generally normal shape and relatively low dispersion, and in the correspondence of their modal values to the target. The form of this correspondence is illustrated for both groups in Figure 11. Here the mean run-length for the final 2 sessions under each target value (N) is plotted against the target (n) in logarithmic coordinates. For the 15% group these points are fit with a straight line accounting for 98% of the variance. This line describes a power function with parameters $N = 1.07\ n^{0.95}$. The analogous fit for the 30% group, accounting for 93% of the variance, describes a power function with parameters $N = 1.20\ n^{0.90}$. While power functions thus provide a good description of these results, the points can also be fit with linear functions accounting for 95% of the variance for the 15% group

FIGURE 8

Mean run-length, in logarithmic units, for each subject in each session. Dashed lines indicate target values. The 2 groups are identified by the area of the run-length distribution closest to the target for which reinforcement was available. Note that subject 7 died following Session 72.

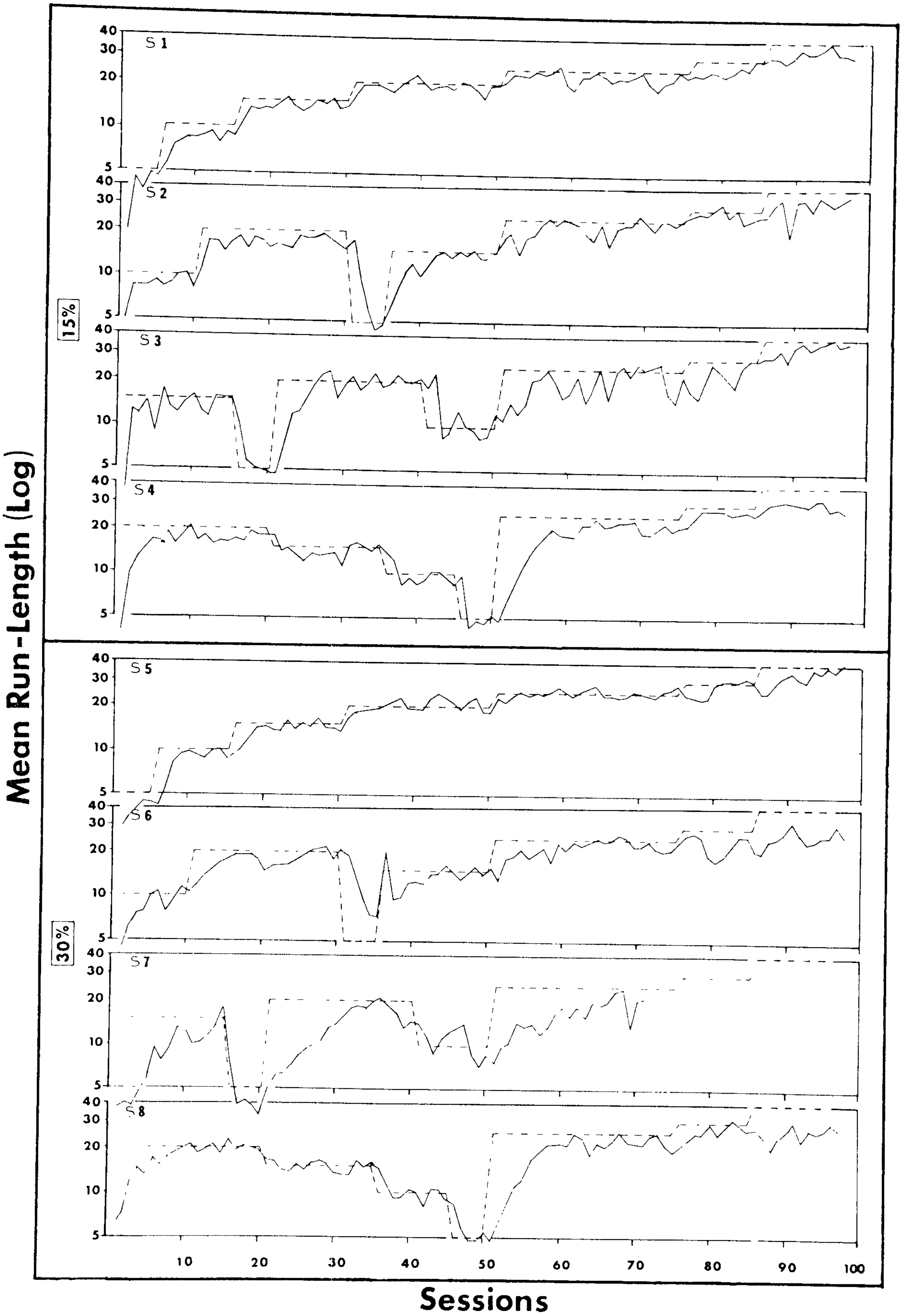

Mean Run-Length (Log)
Sessions
S 1
S 2
S 3
S 4
S 5
S 6
S 7
S 8
15%
30%
40
30
20
10
5
10
20
30
40
50
60
70
80
90
100

FIGURE 9

Relative frequency distributions of run-lengths for the final 2 sessions under each target value, for subjects reinforced for run-lengths in the 15% of the distribution closest to the target. Reinforced runs are represented by dark areas.

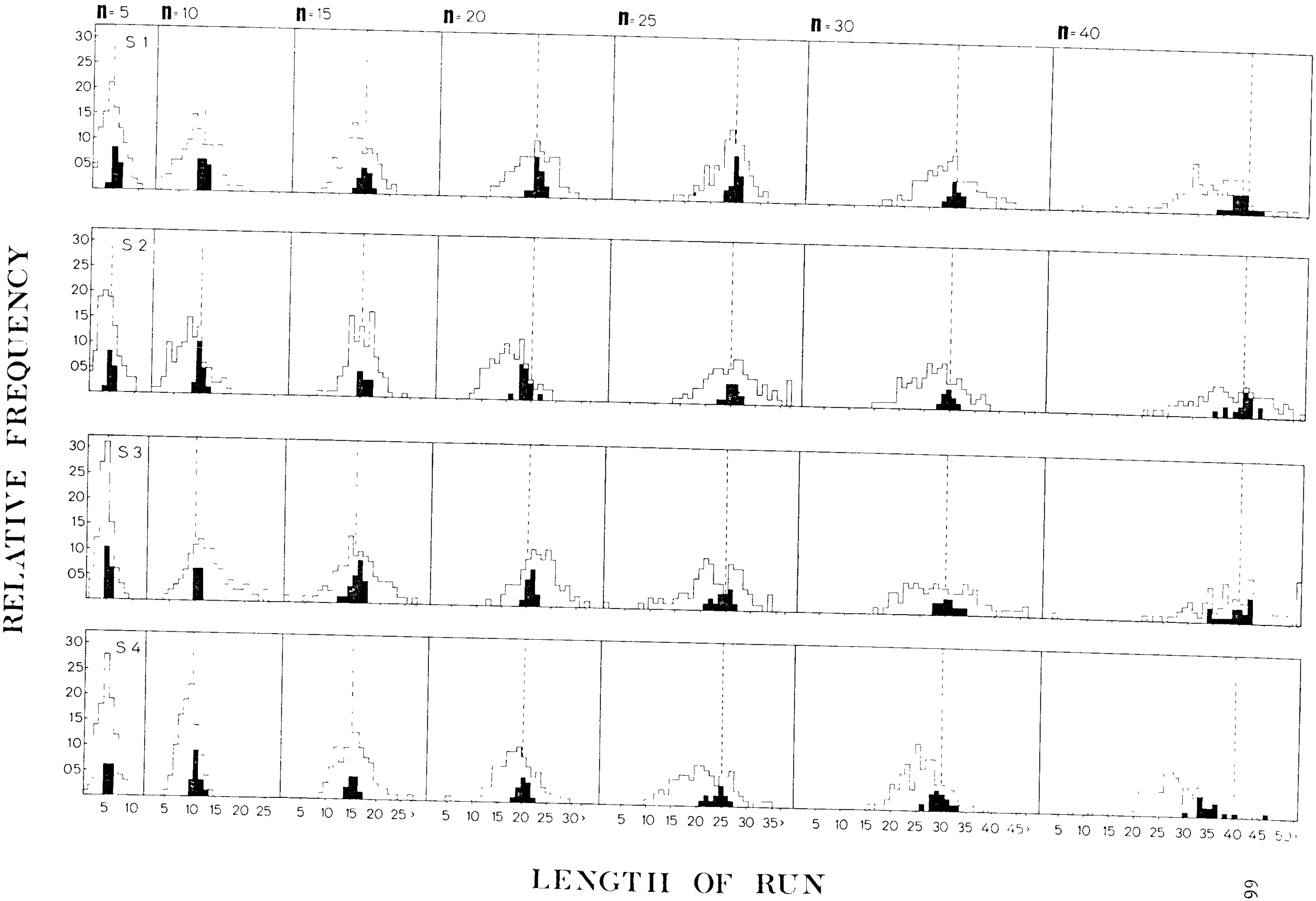

n = 5
n = 10
n = 15
n = 20
n = 25
n = 30
n = 40
S 1
S 2
S 3
S 4
30
25
20
15
10
05
5 10
5 10 15 20 25
5 10 15 20 25›
5 10 15 20 25 30›
5 10 15 20 25 30 35›
5 10 15 20 25 30 35 40 45›
5 10 15 20 25 30 35 40 45 50›
RELATIVE FREQUENCY
LENGTH OF RUN

FIGURE 10

Relative frequency distributions of run-lengths for the final 2 sessions under each target value, for subjects reinforced for run-lengths in the 30% of the distribution closest to the target. Reinforced runs are represented by dark areas.

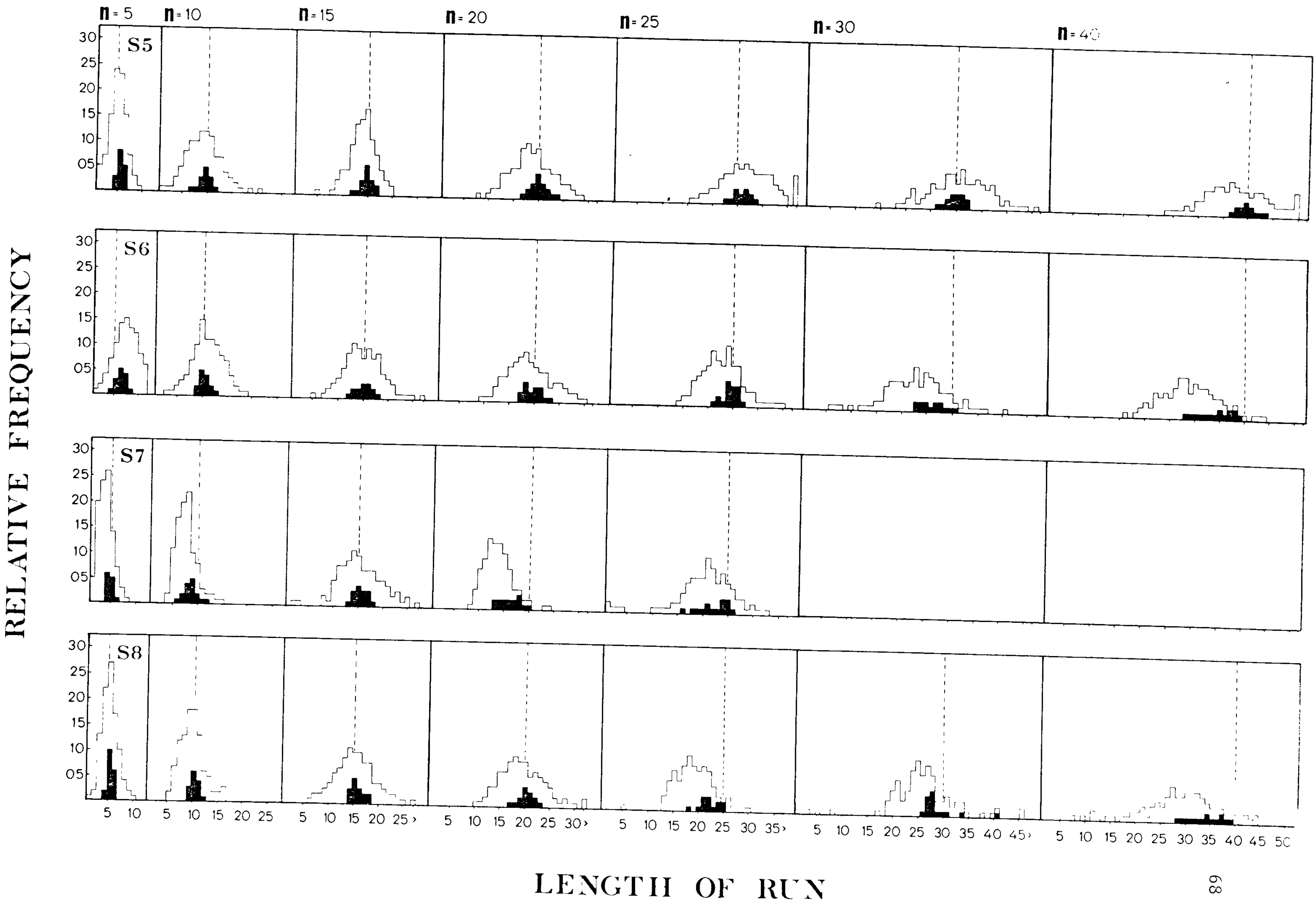

n = 5
n = 10
n = 15
n = 20
n = 25
n = 30
n = 40
S5
S6
S7
S8
RELATIVE FREQUENCY
30
25
20
15
10
05
5 10
5 10 15 20 25
5 10 15 20 25›
5 10 15 20 25 30›
5 10 15 20 25 30 35›
5 10 15 20 25 30 35 40 45›
5 10 15 20 25 30 35 40 45 50
LENGTH OF RUN

TABLE 8

Proportion of runs reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for each subject in the 15% group at each target value. Data are from the final 2 sessions at each target value.

SUBJECT	TARGET	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./MEAN
1	5	0.15	4.68	2.17	0.46
	10	0.16	8.96	3.36	0.38
	15	0.13	13.75	3.55	0.26
	20	0.17	19.43	4.69	0.24
	25	0.18	24.28	4.16	0.17
	30	0.15	29.27	5.27	0.18
	40	0.16	32.81	7.07	0.21
2	5	0.14	4.57	2.03	0.44
	10	0.14	9.37	3.39	0.36
	15	0.15	14.69	2.79	0.19
	20	0.16	15.50	3.73	0.24
	25	0.14	24.04	5.65	0.23
	30	0.12	26.45	5.92	0.22
	40	0.17	35.81	7.05	0.20
3	5	0.13	4.96	1.61	0.32
	10	0.15	10.82	4.13	0.38
	15	0.16	14.43	3.96	0.27
	20	0.17	21.39	4.11	0.19
	25	0.14	18.81	6.26	0.33
	30	0.15	29.46	7.00	0.24
	40	0.16	38.57	8.26	0.21
4	5	0.14	4.92	1.73	0.35
	10	0.15	8.94	2.09	0.23
	15	0.13	15.03	3.54	0.24
	20	0.15	18.43	4.41	0.24
	25	0.15	20.71	5.09	0.25
	30	0.15	26.73	5.35	0.20
	40	0.15	28.37	6.93	0.24

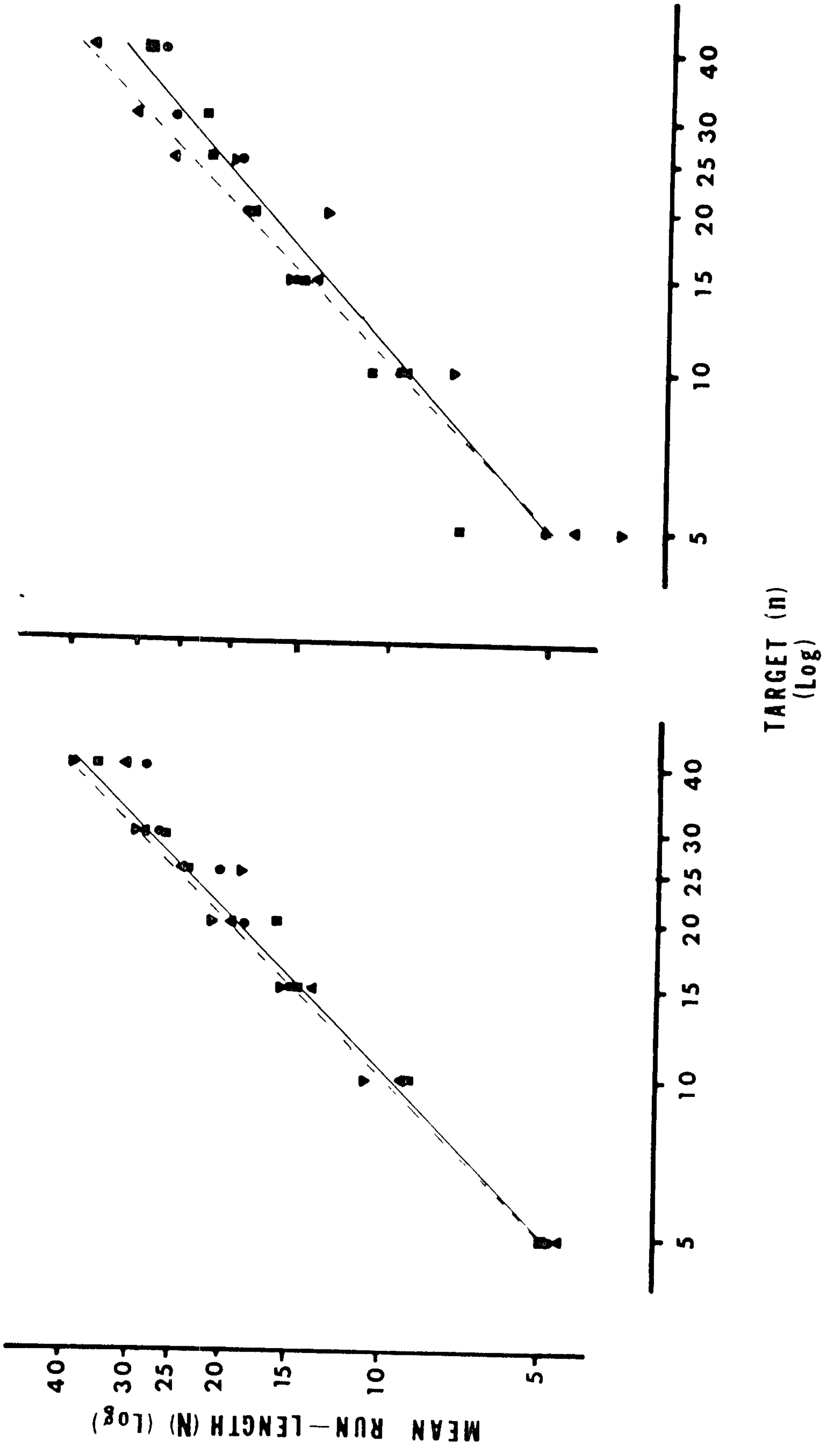
TABLE 9

Proportion of runs reinforced, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for each subject in the 30% group at each target value. Data are from the final 2 sessions at each target value.

SUBJECT	TARGET	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
5	5	0.16	4.50	1.71	0.38
	10	0.15	9.53	3.45	0.36
	15	0.15	14.01	2.97	0.21
	20	0.17	18.83	4.30	0.23
	25	0.13	27.05	5.52	0.20
	30	0.16	31.41	6.88	0.22
	40	0.15	37.55	7.41	0.20
6	5	0.15	7.51	3.09	0.[illegible]
	10	0.15	11.05	3.20	0.29
	15	0.13	14.90	4.22	0.28
	20	0.16	19.05	4.99	0.26
	25	0.17	22.08	4.21	0.19
	30	0.15	23.07	6.23	0.27
	40	0.15	29.12	6.34	0.22
7	5	0.14	3.63	1.48	0.41
	10	0.16	7.77	2.29	0.29
	15	0.16	15.38	4.36	0.28
	20	0.16	13.69	3.12	0.23
	25	0.15	20.56	5.97	0.29
	30				
	40				
8	5	0.18	5.11	1.69	0.33
	10	0.15	9.76	2.67	0.27
	15	0.16	15.11	4.26	0.28
	20	0.14	19.39	5.22	0.27
	25	0.15	19.97	5.24	0.26
	30	0.16	26.26	8.66	0.33
	40	0.17	28.19	8.84	0.31

FIGURE 11

Relationship between mean run-length and target value in logarithmic coordinates for the 15% group (left-hand panel) and 30% group (right-hand panel). Dashed diagonal lines represent perfect matching between mean and target. Solid lines are best-fitting power functions. For the 15% group this line accounts for 98% of the variance, and has parameters $N = 1.07\ n^{0.95}$. The power function for the 30% group has parameters $N = 1.20\ n^{0.90}$, and accounts for 93% of the variance.


MEAN RUN—LENGTH (N) (Log)
40
30
25
20
15
10
5
5
10
15
20
25
30
40
5
10
15
20
25
30
40
TARGET (n)
(Log)

and 90% of the variance for the 30% group. The additional 3% of the variance contributed by the curvilinear components of these relationships between mean and target run-lengths is probably not sufficient to justify the description of the relationships as power functions, in favour of a more parsimonious description of the relationships as linear.

One feature of the relative frequency distributions in Figures 9 and 10 which differs from any of the experiments reported thus far is the relationship between the distributions of emitted and reinforced run-lengths, seen in the figures as light and dark areas, respectively. While occupying the same area of the run-length distributions as most of the percentile reinforcement conditions in Experiments II and III (15%), these reinforced run-lengths are not confined to a tail of the distribution, but instead tend toward the mean. The steady state reached after training with the target shaping procedure is thus characterized by little or no difference in means between the distributions of emitted and reinforced run-lengths.

The relationship between the area of the distribution of response values eligible for reinforcement and differentiation can be seen more clearly in the results of the second part of Experiment IV, where the 3 surviving 30% subjects were given additional sessions with a constant target value but with different areas of the distribution eligible for reinforcement. Relative frequency distributions for each subject over the final two sessions of each phase are plotted in Figure 12. The greater areas of the distributions for which reinforcement was available can be seen as an increased dispersion in the distribution of reinforced run-lengths. Some statistical descriptions of the distributions are given

FIGURE 12

Relative frequency distributions of run-lengths for 3 subjects with a constant target value (25). The 4 distributions for each subject are for the final 2 sessions in each phase. The target value is indicated by a dashed vertical line in the distributions. Reinforced run-lengths are represented as dark areas. Phases are identified by the area of the distributions for which reinforcement was available (in percentage units).

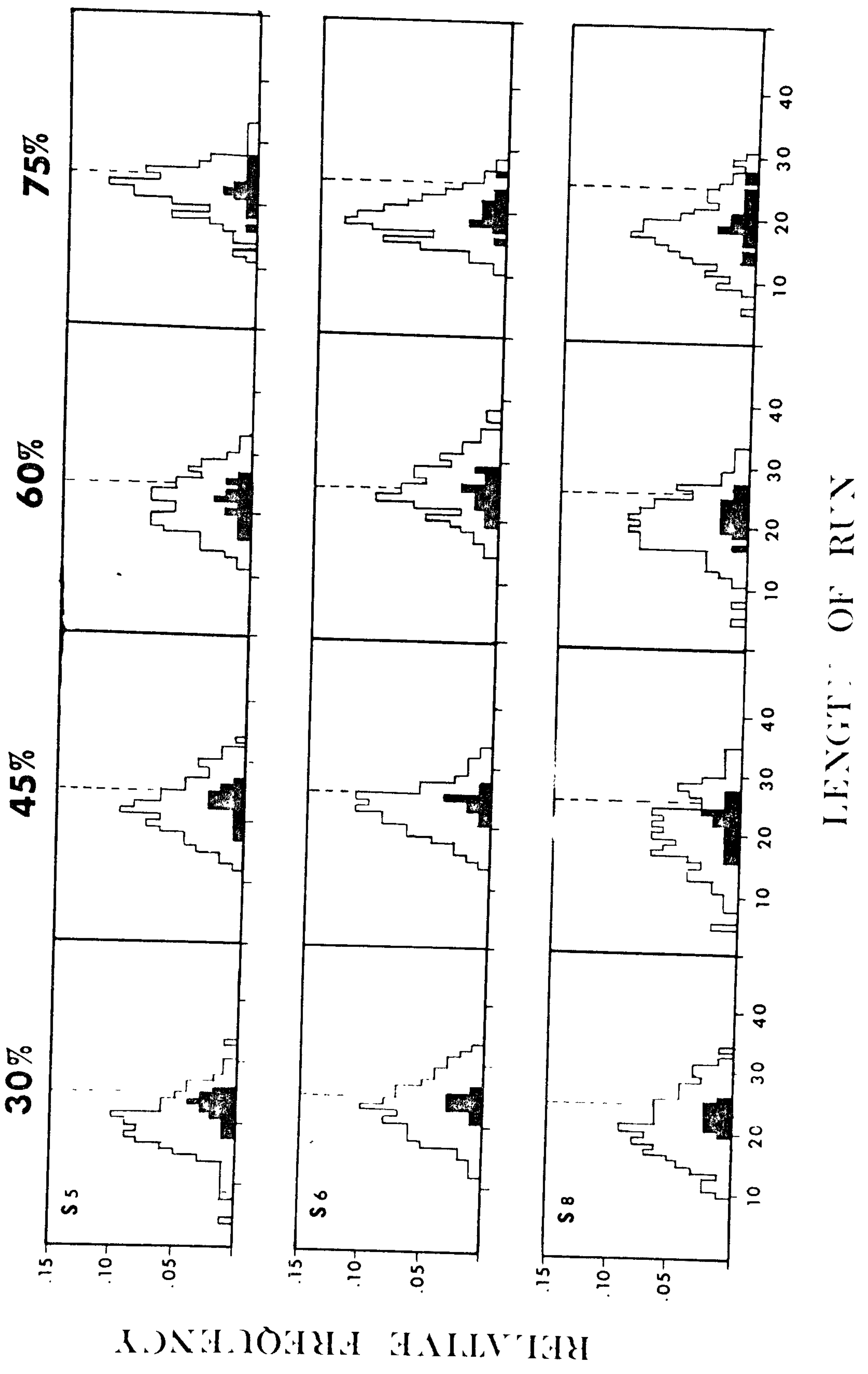

30%
45%
60%
75%
S5
S6
S8
.15
.10
.05
10
20
30
40
RELATIVE FREQUENCY
LENGTH OF RUN

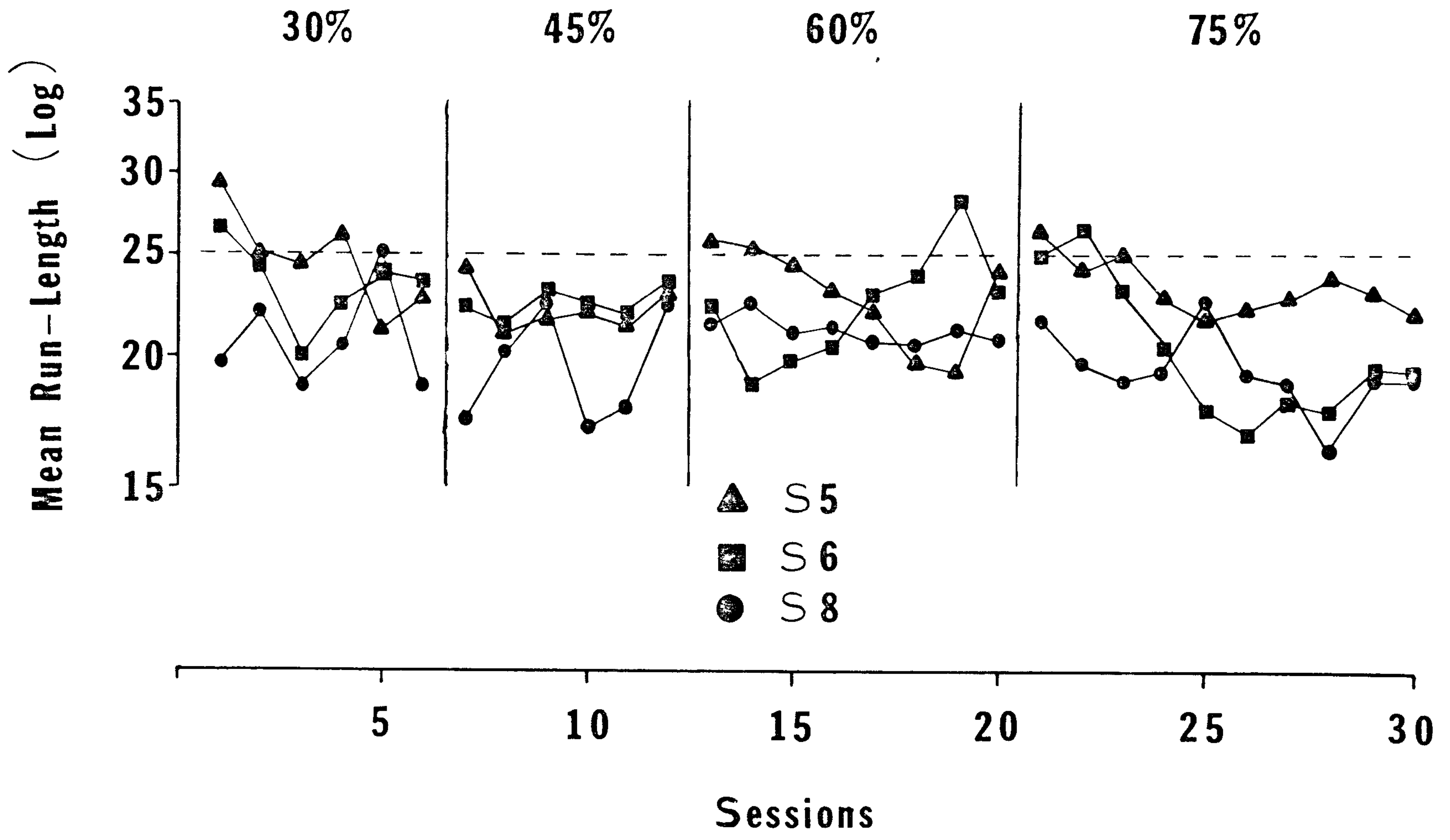
TABLE 10

Area eligible for reinforcement, mean and standard deviation of run-lengths, and the ratio of standard deviation to mean, for each subject in the second part of Experiment IV. Data are from the final 2 sessions in each phase.

SUBJECT	AREA	PROP. REINF.	MEAN RUN-LENGTH	STANDARD DEVIATION	S.D./ /MEAN
5	30	0.16	21.16	5.05	0.24
	45	0.16	22.50	4.74	0.21
	60	0.17	22.15	4.47	0.20
	75	0.15	22.59	4.52	0.20
6	30	0.13	24.02	4.63	0.19
	45	0.13	22.88	3.83	0.17
	60	0.16	26.04	4.85	0.19
	75	0.15	19.35	3.83	0.20
8	30	0.15	22.23	4.39	0.20
	45	0.16	20.22	5.80	0.28
	60	0.14	20.92	4.74	0.23
	75	0.17	18.96	5.16	0.27

FIGURE 13

Mean run-length, in logarithmic units, for the 3 subjects in each session of the second part of Experiment IV. Phases are identified by the area of the distribution eligible for reinforcement. The dashed horizontal line represents the target value (25).


30%
45%
60%
75%
Mean Run-Length (Log)
35
30
25
20
15
S5
S6
S8
5
10
15
20
25
30
Sessions

in Table 10. The most striking characteristic of these distributions is that little or no difference can be attributed to different areas of the distributions being eligible for reinforcement. This point is illustrated in Figure 13. Mean run-length for individual subjects is plotted in logarithmic units for each session. Phases are separated by vertical lines and identified by the area of the distribution for which reinforcement was available. Little systematic change in mean run-length is seen across phases.

Discussion

The most dramatic outcome of Experiment IV was the high degree of control over run-lengths. The extent of this control is demonstrated in the low dispersion distributions of run-lengths around the target values in Figures 9, 10 and 12; in the close correspondence between mean run-length and target seen in Figure 11; and in the low day-to-day variability in these means seen in Figures 8 and 13.

In Experiment I, the control of mean run-length by the criterion took the form of a power function. The present experiment used a procedure which controlled the area of the distribution of run-lengths eligible for reinforcement, while at the same time specifying a fixed target value on the run-length dimension. The resulting function relating mean and target was found to be more nearly linear than that obtained in Experiment I. It would thus appear that at least in the case of run-length differentiation, the shape of the function relating criterion and mean is dependent on the parameters of differential reinforcement.

It has been suggested that the effective component of the measure of differential reinforcement represented by the proportion of the distribution of response values exceeding the criterion is the differential between the central tendencies of the distributions of emitted and reinforced response values. With a Percentile Reinforcement schedule this differential is a component of selectiveness of differential reinforcement, and may be responsible for the greater effectiveness of differential reinforcement with high selectiveness. With the target procedure used in the present experiment, the differential between emitted and reinforced run-lengths was not under experimental control, but rather depended on

the location of the subject's distribution of run-lengths relative to the target. It is thus interesting to note the relationship between the differential and rate of behavioural change implicit in Figure 8. In these "learning curves" it is apparent that shaping was most rapid in sessions immediately following shifts in the target value. As mean run-length approached the target, however, rate of change of run-lengths decreased and an asymptote was reached with mean run-length at or near the target. It can be seen from the relative frequency distributions in Figures 10, 11 and 13 that this steady state was characterized by little or no differential between the distributions of emitted and reinforced run-lengths. It can be inferred that the initial high rate of change encountered after a shift in target values would be associated with a large differential. Since the area of the distribution of run-lengths reinforced was constant, and the rate of change was correlated with the differential between emitted and reinforced run-lengths, going to zero as the differential approached zero, it can be concluded that this differential is the important characteristic of differential reinforcement.

Further evidence on this last point is the negligible effect of increasing the area of the distribution reinforced in the second part of Experiment IV. Increasing the area of reinforced response values, without changing the differential between emitted and reinforced response values, produced no appreciable change in mean run-length.

CONCLUSIONS

The conclusions of the present research might be summarized best as an outline of a model for response differentiation. In this model, the principal parameter of differential reinforcement is some measure of the difference between response values emitted by the subject and those values reinforced. When a differential arises between the central tendencies of the distributions of emitted and reinforced response values, the distribution of response values changes in a direction which tends to reduce the differential, and at a rate dependent on the magnitude of the differential.

The relationship between the direction and magnitude of the differential between emitted and reinforced response values and the direction and rate of change of response values is best illustrated in the results of Experiment IV. In this experiment, only run-lengths closest to a target run-length were reinforced. When the target was remote from the subject's mean run-length, mean run-length changed toward the target. The rate of change decreased as mean run-length approached the target, and went to zero when the difference approached zero. The essentially linear function relating asymptotic mean and target run-lengths is one indication that little or no differential remains between the central tendencies of the distributions of emitted and reinforced run-lengths when a steady state is reached.

Although the present treatment of the model is non-quantitative,

the differential between emitted and reinforced response values might be measured in terms of the area of the distribution of response values separating the central tendencies of emitted and reinforced response values. For example, in a Percentile Reinforcement procedure which reinforced the most extreme 30% of the response distribution, the median reinforced value would be at the 85th percentile. The area between the median response value and the median reinforced response value would, therefore, be 35% of the response distribution. In Experiment II, Percentile Reinforcement was used to maintain constant differentials of 27.5%, 35%, or 42.5% of the run-length distribution. Higher rates of change were obtained with greater differentials. While the relationship between differential and rate of change is thus confirmed, a further aspect of these results presents a problem for the model as developed to this point. Since Percentile Reinforcement holds constant the differential between the central tendencies of the distributions of emitted and reinforced response values, the model would predict that response values should continue to change at a constant rate. Instead, it was found in Experiment II that the rate of change of run-lengths decreased as run-lengths increased and mean run-length reached an asymptote which was a function of the differential between emitted and reinforced run-lengths. Further assumptions are therefore necessary to account for the decrease in rate of change and eventual asymptote reached despite maintenance of a constant differential.

A third result of Experiment II is important in considering reasons for the apparent limit to the differentiation process. In the first Baseline Phase, when reinforcement was presented non-differentially

for a random 0.15 of run-lengths, subjects emitted very low run-lengths. This was to be expected, since subjects initially emitted low run-lengths and there was no differential between mean emitted run-length and mean reinforced run-length, and thus no tendency for run-lengths to increase. However, in the second Baseline Phase, after run-lengths had been raised to high levels by differential reinforcement, reinforcement for a random 0.15 of run-lengths brought a decrease in mean run-length. If the differential between emitted and reinforced response values were the only factor influencing change in response values, there would be no reason for run-lengths to decrease in the second Baseline Phase of Experiment II; rather they should remain the same. The same argument applies to the decrease in mean run-lengths shown by the groups for which the degree of differential reinforcement was reduced in the second Differential Selectiveness Phase. Again, the present model, as discussed thus far, would predict no decrease in mean run-lengths. The decreases which did occur with reduction or elimination of explicit differential reinforcement in Experiment II suggest the existence of an opponent process which produces change toward lower response values. While there is little evidence in the present experiments to indicate the nature of this opponent process, two sorts of explanation can be suggested. The first explanation assumes that the act of responding is accompanied by a certain amount of effort. Responding with lower force or duration, or emitting a short run-length, would decrease the effortfulness of the response. This tendency of organisms to respond with lower dynamic values has been referred to as the Law of Least Effort (Keller & Schoenfeld, 1950). The second explanation of the hypothetical opponent process notes that

with time-related response dimensions such as IRT, latency and run-length, the value of the response has implications for the immediacy of reinforcement. Lower values on these response dimensions are differentially reinforced by more immediate reinforcement.

Regardless of the nature of the opponent process, if it can be assumed that the strength of the process is an increasing function of response value, then the asymptote reached after differential reinforcement can be seen as an equilibrium in the two opposing processes. More effective differential reinforcement parameters, those which control greater rates of change, overcome the opponent process to a greater extent, and produce equilibrium at a higher value on the response dimension.

A model of response differentiation based on the relationship between the differential and rate of change, and incorporating an opponent process, can also account for the results of fixed criterion differentiation experiments such as Experiment I. These experiments also typically find a relationship between asymptotic response value and the proportion of the distribution of response values exceeding the criterion. This relationship is generally expressed as a power function with fractional exponent. It describes the progressive decline in mean or median response value, relative to the reinforcement criterion, at higher criterion values. According to the present model, establishment of a criterion for reinforcement typically creates a differential between the distributions of emitted and reinforced response values. The distribution of response values will therefore change in a direction which tends to reduce the differential. Reduction of the differential reduces the rate of behavioural change, and an asymptote will be reached

when the tendency to increase response values brought about by the existence of a differential is balanced by the tendency to decrease due to the opponent process. Furthermore, since the opponent process is assumed to be an increasing function of run-length, a greater differential would be required to overcome the opponent process and reach equilibrium at higher response values. This greater differential at higher run-lengths, expressed as the progressive decline in mean response value relative to the reinforcement criterion, can be described as a power function with a fractional exponent.

While the proposed model of response differentiation can thus explain the results presented in this thesis, the model is limited by its exclusive concentration on the first moment of the distribution of response values. Changes in distributions of response values have been expressed in terms of means, and the concept of the differential between distributions of emitted and reinforced response values has been restricted to differences in their central tendencies, expressed as areas of the response distribution. It is possible that differentiation may affect other moments of response distributions. To consider a single example, differential reinforcement of a narrow band of values surrounding the mean of a distribution of response values would not be expected to produce changes in mean response value, since the differential between the central tendencies of the distributions of emitted and reinforced response values is zero. However, if the dispersions of the distributions were very different, change in the dispersion of the response distribution might occur. A more general statement of the parameters of differential reinforcement might thus include differentials between second, or even

higher order moments of distributions of emitted and reinforced response values.

The conclusions reached in this thesis have been described in terms of relationships applicable to any dynamic response dimensions with ordinal properties. It should be understood, however, that other classes of response properties may not display all the same processes. For example, the assumed opponent process to differentiation may only be relevant to dynamic response properties. Other properties of behaviour, for example spatial, probably would not produce the same results. Antonitis (1950) performed an experiment in which rats inserted their noses into a long slot in one wall of the conditioning chamber. This response could be made with wide variability in its spatial location. It seems likely that if a constant differential were maintained between the distributions of emitted and reinforced response placements, the rate of change of the distribution of response placements would be constant. Since there is no obvious opponent process resisting change on such a response dimensions, an asymptote would notbe expected. Despite this possible limitation of the present treatment of response differentiation, most research into differentiation has utilized dynamic response properties. The present model thus provides an alternative to previous interpretations of experimental results. To take one example, Catania's (1970) contention that the power function in temporal differentiation experiments is a fundamental characteristic of time perception, a "temporal, operating characteristic" (p. 30), is called into question. The model proposed in this thesis can explain the power function relating mean and criterion latencies, like other dynamic response properties,

without appealing to non-linearity in the subject's perception of the response dimension.

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