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THE EFFECT OF THE RANGE OF FORCES REINFORCED AND THE
PROBABILITY OF REINFORCEMENT IN THE DIFFERENTIATION
OF THE PEAK FORCE OF RESPONSE

by

RICHARD M. SAMUELS

A dissertation submitted to the Graduate Faculty
in Psychology in partial fulfillment of the re-
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The City University of New York.

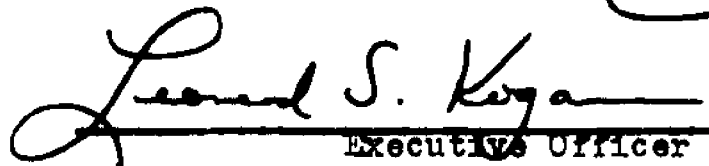
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Abstract

THE EFFECT OF THE RANGE OF FORCES
REINFORCED AND THE PROBABILITY OF
REINFORCEMENT ON THE DIFFERENTIATION
OF THE PEAK FORCE OF RESPONSE

by

Richard M. Samuels

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Rats were reinforced with food pellets on a band contingency in which a reinforcement-eligible response was defined as a lever press whose peak emitted force fell between specified upper and lower limits.

The apparatus consisted of a strain gauge coupled to a modified lever press manipulandum. A voltage, isomorphic with applied force was integrated during each response to provide a measure of peak emitted force for each response. Additional circuitry allowed the setting of response threshold and the upper and lower limits of the band.

In the first experiment, the probability of reinforcement for in-band responses was fixed at 100 percent. Three groups of rats were run for three Phases during which the width of the reinforcement band was systematically varied. The fourth Phase consisted of either extinction or regular reinforcement for all responses regardless of force.

Two groups were run on the same band widths (12-22g, 14-20g and 15-19g). One group was initially exposed to a narrow band which was subsequently made wider, while the second was initially run on the least stringent condition which successively became more stringent. The third group was exposed to a band contingency with a higher midpoint (18-28g, 20-26g and 22-24g). This group began on the least stringent variation and was shifted to increasingly more stringent conditions during the following two Phases.

In general, the data suggested that as the reinforcement criteria (the band in effect) became more stringent, the rate of responding tended to increase. In addition, the percentage of responses falling within the band in effect tended to decrease. An inverse relationship between accuracy and rate was suggested by the data.

It was also observed that a more stringent reinforcement criteria appears to generate an improvement in performance relative to the condition when the less stringent criterion was in effect. In fact, contrary to extinction theory, the extinction of those response variants outside of the now more stringent criteria, suggests an increase in the frequency of those variants. A model utilizing the concept of variance reduction was hypothesized to account for this data.

In general, analysis of the peak force distributions

indicated a consistent increase in peak forces as the band width was made more stringent. Peak forces in extinction indicated that those groups previously reinforced for higher responses tended to generate higher forces during extinction. Similar effects for the regular reinforcement Ss were not evident.

The second experiment held the band in effect constant (14-20g), while the probability of reinforcement for in-band responses was set at either 100 percent or 50 percent. One group of rats began with a 100 percent reinforcement condition, while a second group of animals began at 50 percent reinforcement, as determined by a random ratio reinforcement schedule. The second Phase of this experiment saw these percentages reversed.

The results showed a shift in the distribution of peak forces to a higher percentage of low force responses, when rats were shifted from a 50 percent to a 100 percent reinforcement condition. A reciprocal effect was not noted for animals switched from 100 percent to 50 percent reinforcement. A non-linear model relating force to the frequency of reinforcement was proposed to account for this data.

The accuracy of responding, as measured by the percentage of in-band responses was apparently insensitive to the percentage of reinforcement or the order to which the Ss were exposed to these two contingencies.

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Table of Contents

		Page
I.	ABSTRACT.....	3
II.	LIST OF TABLES.....	8
III.	LIST OF FIGURES.....	9
IV.	INTRODUCTION.....	12
V.	METHOD.....	34
	Subjects.....	34
	Apparatus.....	34
	Procedure.....	42
VI.	RESULTS.....	46
VII.	DISCUSSION.....	64
VIII.	REFERENCES.....	175

List of Tables

Table		Page
1	Experimental Design for Experiment 1	88
2	Assigned probability of reinforcement and experimental design for experiment 2	89
3	Mean response rate (responses/min) for groups 1, 2, and 3 of Experiment 1	90
4	Percentage of total responses within specified force ranges during Phases I, II, and III for rats of group 1, Experiment 1	91
5	Percentage of total responses within specified force ranges during Phases I, II, III for rats of group 2, Experiment 1	92
6	Percentage of total responses within specified force ranges during Phase I, II, and III for rats of group 3, Experiment 1	93
7	Percentage of total mean responses within specified force ranges during Phases I, II and III of Experiment 1	94
8	Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 1, Experiment 1	95
9	Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 2, Experiment 1	96
10	Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 3, Experiment 1	97
11	Index of force differentiation, percentage of rate change and product (absolute index of differentiation) for Experiment 1	98
12	Index of force dedifferentiation, percentage of rate change and product (absolute index of dedifferentiation), for Experiment 1	99
13	Mean reinforcement rate (reinforcements/min) for groups 1, 2, and 3 of Experiment 1	100

List of Figures

Figure		Page
1	Block diagram for the apparatus of Experiment 1	102
2	Individual response rates for the Ss of groups 1, 2 and 3 during Phases I, II and III of Experiment 1	104
3	Peak force of response distributions for the Ss of group 1 during Phase I of Experiment 1	106
4	Peak force of response distributions for the Ss of group 1 during Phase II of Experiment 1	108
5	Peak force of response distributions for the Ss of group 1 during Phase III of Experiment 1	110
6	Peak force of response distributions for the Ss of group 1, Phase IV, of Experiment 1	112
7	Peak force of response distributions for the Ss of group 2 during Phase I of Experiment 1	114
8	Peak force of response distributions for the Ss of group 2 during Phase II of Experiment 1	116
9	Peak force of response distributions for the Ss of group 2 during Phase III of Experiment 1	118
10	Peak force of response distributions for the Ss of group 2, Phase IV, of Experiment 1	120
11	Peak force of response distributions for the Ss of group 3 during Phase I of Experiment 1	122
12	Peak force of response distributions for the Ss of group 3 during Phase II of Experiment 1	124
13	Peak force of response distributions for the Ss of group 3 during Phase III of Experiment 1	126
14	Peak force of response distributions for the Ss of group 3, Phase IV, of Experiment 1	128
15	Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 1 of Experiment 1	130

Figure		Page
16	Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 2 of Experiment 1	132
17	Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 3 of Experiment 1	134
18	Mean peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of groups 1, 2 and 3 of Experiment 1	136
19	Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of groups 1, 2 and 3 of Experiment 1	138
20	The mean rate of responding in responses per minute as a function of the mean percentage of in-band responses for groups 1, 2 and 3 of Experiment 1	140
21	Mean percentage of in-band responses as a function of sessions for the Ss of groups 1 and 2 of Experiment 2	142
22	Mean responses per minute as a function of sessions for the Ss of groups 1 and 2 of Experiment 2	144
23	Mean reinforcements per minute as a function of sessions for the Ss of groups 1 and 2 of Experiment 2	146
24	Peak force of response distributions for R1 and R3 of group 1, Experiment 2	148
25	Peak force of response distributions for R5 and R 7 of group 1, Experiment 2	150
26	Peak force of response distributions for R9 and R11 of group 1, Experiment 2	152
27	Peak force of response distributions for R2 and R4 of group 2, Experiment 2	154

Figure		Page
28	Peak force of response distributions for R6 and R8 of group 2, Experiment 2	156
29	Peak force of response distributions for R10 and R12 of group 2, Experiment 2	158 ¹
30	Mean peak force of response distributions for groups 1 and 2 of Experiment 2	160
31	Below, in-band and above band percentages for R1 and R3 of group 1 for both Phase I and Phase II of Experiment 2	162
32	Below, in-band and above band percentages for R5 and R7 of group 1 for both Phase I and Phase II of Experiment 2	164
33	Below, in-band and above band percentages for R9 and R11 of group 1 for both Phase I and Phase II of Experiment 2	166
34	Below, in-band and above band percentages for R2 and R4 of group 2 for both Phase I and Phase II of Experiment 2	168
35	Below, in-band and above band percentages for R6 and R8 of group 2 for both Phase I and Phase II of Experiment 2	170
36	Below, in-band and above band percentages for R10 and R12 of group 2 for both Phase I and Phase II of Experiment 2	172
37	Mean below, in-band and above band percentages for the Ss of groups 1 and 2 for both Phase I and Phase II of Experiment 2	174

Introduction

According to Skinner, "...the main datum to be measured in the study of the dynamic laws of an operant is the length of time elapsing between a response immediately preceding it or, in other words, the rate of responding." (Skinner, 1938, p. 38)

With this assumption, Skinner and his associates do not address themselves to the properties of the response itself. Rather, they treat each response as an all-or-nothing event. In essence, the organism is considered a generator of binary events, a response either occurs or does not occur.

One of the advantages of treating the response as an all-or-nothing event involves the relative simplicity of measuring that response. By ignoring certain variations of an organism's performance, one can simply record the frequency of a class of events with relative ease. This assumes of course, that the definition of response is clearly established prior to obtaining this data. Thus a response in this strict Skinnerian sense, comprises a family of events that fit the definition of that response.

To omit from analysis, the properties of the response itself, is analogous to conscientious counting,

with only a vague notion of what is being counted. Indeed such variables as response duration, response force, response topography, effort of response, etc., are as likely to be as important to the understanding of behavior as is the rate of responding.

The present study, in addition to examining the rate of response, focuses on the particular variations of responding that occur when specifically defined variations of the original response are placed under selective reinforcement through changes in the reinforcement criteria. This analysis is directed at the peak force of response.

In addition, since changes in the reinforcement criteria also produce the effect of changing probabilities of reinforcement, the second part of this study involves the proportion of responses being reinforced and the subsequent effect on the peak force of response as well as the response rate.

Notterman and Mintz (1965) suggest that, "it is possible to redefine operant behavior as behavior that is tantamount to the organismic emission of forces." They continue to develop this argument and conclude with the statement that the peak force of response appears to be an appropriate index of energy expenditure.

When a rat makes a bar press response, he is essentially emitting forces against a manipulandum. With the conventional microswitch - lever arrangement,

a specified force must be exerted on the lever in order for the microswitch to operate. This snapping action of the microswitch causes a set of contacts to close which signals the onset of the response. When the force exerted by the organism no longer exceeds the requirement of the microswitch, the contact opens and the response is considered terminated.

If one wished to increase the force requirement of the response, the lever could be loaded with weights, or the spring could be tightened. It is also possible to design an apparatus that allows the force levels needed to produce a "response" to be varied electronically.

Using such a system Notterman and Mintz (1965) showed that rats pressing an operandum incorporating a strain gage^o generated forces which started at zero, increased until the reinforcement criteria was met, and then returned to zero. In their discussion of the relationship between force, work and energy expenditure, they conclude with the statement that the peak amplitude of force during a response is closely related to work and energy expenditure and is thus a useful measure to obtain for the analysis of these variables. They state; "With a lever-press response taken for the basis for reinforcement contingencies, the time integral of force of that response, remains the appropriate index of organism energy expenditure.

"However, in those behavioral situations in which "holding" behavior is infrequent, (that is, emitted force reaches its peak value then decreases rapidly to zero) and in which

the work done by the organism goes into compressing or stretching a spring or strain gage, peak force of response should be a satisfactorily valid index of energy utilization." (p. 8)

Organismic energy expenditure, how much energy is exerted by the S in emitting a particular response, concerned Hull (1943), who saw the construct of reactive inhibition as a work-related phenomena. He states: "It is supposed that each response evocation produces in the organism a certain increment of a fatigue-like substance or condition, which constitutes a need for rest. The mean net amount deposited at each response appears to be a positively accelerated increasing function of work or energy expenditure (W) consumed in the execution of the act. It is assumed further that this substance or condition has the capacity to directly inhibit the power of S to evoke R; for this reason it is called reactive inhibition (Ir) " (p. 391).

Solomon, in his 1948 article, observed that the construct of reactive inhibition influenced numerous other experiments which he systematically reviewed after classifying them into four categories: the Law of Least Effort, effort per unit time in conditioning and learning, avoidance of repetition of responses, and the role of kinesthesia in the control of behavior.

Thus, energy expenditure, as measured by the peak force of response appears to be a relatively important variable in the understanding of operant behavior. It is within this framework that the peak force of response will be examined as a function of varying reinforcement criteria.

It is generally understood that the probability of a response being emitted by an organism is determined largely by the organism's prior history of reinforcement with that response. Under a continuous reinforcement schedule (CRF), the organism's probability of reinforcement is determined by the degree to which the behavior conforms to the reinforcement criteria, in other words, success depends upon the accuracy of a response. This is as true for a rat pressing a lever, as it is for a child learning to speak. The criterion in the later case would be determined by some measure of social intelligibility.

This process of matching a response to the reinforcement criteria has been called response differentiation. It is possible, as Skinner (1938) points out, to alter the relative frequency of a variation of a particular response by selectively reinforcing only that specific variation while at the same time extinguishing other variations of that same response. Thus the differentiation process is a result of concurrent extinction and strengthening procedures; the extinction acting on certain variations of the response while the strengthening operation is conducted on yet other variations of that response. When this procedure is carried out, a shift in the relative frequency of the variations is noted. Skinner has labeled this shift in frequency through selective reinforcement and extinction, the differentiation of a response. He has also called it, perhaps more colloquially, shaping.

When the reinforcement contingencies are manipulated to establish the differentiation of a response, the behavioral changes tend to exhibit typical acquisition styles; i.e., a gradual refinement of responding with an increasing tendency to conform to the special requirements of the reinforcement contingency. In that vein, Notterman and Mintz (1965) point out the need for a distinction between a response and those response variations eligible for reinforcement. They state that, "Response remains a behavior sampling unit, the basic datum in a study. Not all members of this class need be eligible for reinforcement. The criterion defines the reinforcement eligible sub-class of a response. Thus, any response exceeding a pre-determined force is recorded as a response, while only some of these responses, those for example between X and Y g would be eligible for reinforcement." (p. 16) The eligibility would be determined by the experimental design. For example, in the present study, Experiment 1 saw all in-band responses being reinforced (100%), while in Experiment 2, eligibility was set at either 100 percent or 50 percent.

Experiments concerning the properties of individual responses have been relatively sparse when compared to the quantity of literature dealing with the rate of responding.

Millenson and Hurwitz (1961 a) examined the inter-response time (IRT) generated by rats during continuous reinforcement (CRF) and subsequent extinction. They observed that extinction produced an increase in the mean IRTs as well as an increase in the standard deviations of these measures, when compared to the prior CRF training. These

same authors then studied the effect of several reinforcement schedules on response duration. They observed that when rats were shifted from CRF to a Fixed Interval (FI) contingency, an increase in response duration occurred. Animals on a random ratio schedule showed a duration maximum when the probability of reinforcement was equal to 0.11. The authors however, offered no explanation of this interesting finding. Under a Fixed Ratio (FR) 5 schedule, low median durations with a small standard deviation were noted. No systematic differences in duration were observed as a function of the position of the response within any given FR cycle (Millenson and Hurwitz, 1961 b).

Margulies, (1961) examined response duration in operant level, CRF and extinction. His study showed that mean response duration tended to be high in operant level, declined and stabilized during CRF, and again increased during extinction. When the distribution of response durations over CRF sessions was examined, it appeared that the mean duration decreased as a function of sessions.

Keller and Schoenfeld (1950) reviewed a number of studies where selective reinforcement of a response sub-class results in a change in the form of response, i.e., the process of response differentiation. Among the studies cited is one by Skinner (1938) and another by Hays and Woodbury (1943). In both of these studies, higher than average force requirements were imposed on rats previously trained

to bar-press at lower force requirements. The effect of this criterion change was a gradual shift in the distribution of emitted force.

Murphey (1943) using human Ss and a modified pin-ball machine, imposed an upper force limit as well as a lower force limit used in the above two experiments. He discovered that as the "tolerated range", i.e., the "band" of reinforcement-eligible responses between the upper and lower criteria was narrowed, the percentage of reinforced responses decreased and, that Ss learned to differentiate one reinforcement band from another, and demonstrated this with a shift in distribution.

Herrick, (1964) examined response differentiation using lever displacement as his dependent variable. The apparatus was such that the animal could be required to move the lever downward a certain distance in order for reinforcement to occur. It was possible to set upper and lower limits of lever displacement that would be reinforced. He defined these upper and lower limits as the "zone of reinforcement". In essence, Herrick could reinforce the animal for a sub-class of the original response. To look at it another way, by narrowing the zone of reinforcement Herrick was making the criterion for reinforcement more stringent. He observed that when the response zone was narrowed, the animals tended to peak their responses at the lower limit of the "reinforcement zone", i.e., reflecting

least displacement. He also noted that most of the non-reinforced responses fell just below the lower limit of displacement of the "reinforcement zone".

A later study examined further the characteristics of a lever displacement response. This time Ss were placed on a FR 5 reinforcement contingency. Essentially he noted an increased variability during extinction and no tendency to repeat the last reinforced response. He also reported a decrease in the mean displacement as a function of the ordinal position of the response following reinforcement within FR cycle (Herrick, 1965).

Examination of the peak force of response as a response variable began with Notterman (1959) and was expanded subsequently by Notterman and Mintz (1965).

Notterman (1959) used a modified bar-press manipulandum equipped with a strain gage to measure the peak force produced by rats during a series of CRF acquisition and extinction sessions. He observed that peak force tended to decline toward the criterion for reinforcement while at the same time, force variability decreased. This is in contrast to the effect found during extinction, where peak force tended to rise concomitant with an increase in force variability.

Notterman and Mintz (1965) published the results of a systematic series of studies in response differentiation using peak force as the dependant variable. They demonstrated

that when the criterion was switched from 2.5 g to 16 g, the response level shifted in the appropriate direction. They also observed that extinction tended to generate force levels that were correlated with the force criterion during acquisition (p. 25).

The authors were impressed with the possibility that the Ss used in their experiments appeared to be responding on a self-imposed variable ratio (VR) schedule, that is, although the criterion for reinforcement was sufficiently low to permit the rats to exceed that value 100% of the time, most Ss seemed to stabilize with about 65% reinforced responses. Although large changes in reinforcement criteria could decrease the percentage of "success", this finding indicated that Ss tended to stabilize on a reinforcement schedule of this type.

In an attempt to extend the earlier work of Frick (1948) who examined the consequence of a discrimination procedure on the rate of responding, Notterman and Block (1960) measured the peak force emitted by rats during a successive light-on light-off discrimination. The data obtained indicated that force emission during the unreinforced cycle was consistently higher than during the reinforced cycle, even though the rate of bar-pressing was lower during the S^Δ (unreinforced) condition.

Notterman and Mintz extended this work further by incorporating into the design several degrees S^D - S^Δ disparity.

The data revealed that S^D (reinforced condition) rate of response was fairly constant from group to group, while S^A points yielded a function that increased as the S^A stimulus approached the S^D level. Examination of the force data indicated that while S^A forces were constantly higher than S^D forces, no systematic relationship was noted as a function of S^D/S^A brightness ratio (1965, ch.4).

Speculation as to why force increased during the S^A condition, produced a procedure in which an upper as well as a lower reinforcement criterion was imposed. In essence then, this produced a "band" of reinforceable responses. (This procedure was similar to that of Murphey (1943), and Herrick (1964). The principle findings were that the imposition of an upper criterion produced a reduction in peak force, when compared to a group run on the same lower criterion but without the upper limit. It was also shown that the frequency distribution of peak force for Ss run under the band condition tended to peak at the lower limits of the band (ch. 5). These data indicated that rats were able to differentiate force within a restricted range.

Skinner (1938) described a procedure in which either of two possible responses were cued to separate exteroceptive stimuli. He called that procedure "double discrimination" (p. 338).

Notterman and Mintz designed an experiment to determine the feasibility of exteroceptive cuing of response force with a "double-band procedure". In this experiment two peak force

bands were established, the low band was 5-10 g while the high band was 15-20 g. For half of the Ss, a light-off condition was the stimulus for the low band contingency, while a light-on condition served as the stimulus for the high-band contingency. Exteroceptive stimuli were reversed for the remaining Ss. The data clearly showed that the exteroceptive stimulus had developed control over the emitted force levels. Low-band distributions tended to peak within the band, while high-band force distributions tended to peak slightly below the lower limit (1965).

It is interesting to note that the percentage of in-band responses for the low-band condition stabilized at about 60%, a figure not too different from the 65% value obtained by the animals run earlier with only a lower criteria.

An analysis of the first response following a shift from one to another reinforced band, indicated that: "based on a sign-test, the entire group shows a significant (5% level) increase in peak-force for the first response in the presence of each high-band stimulus, and a significant decrease for the first response following each change to the low-band stimulus" (p. 121). It was also shown that: "for both high and low-band performance, there was a tendency for the peak force distributions to peak somewhat below the midpoint of the reinforcement range". This downward displacement actually had the effect of bringing high-band modal performance below the band itself. The high-band

condition generated a higher degree of response variability and subsequently, a lower percentage of reinforced responses.

When feedback was introduced to a group of animals previously trained to an 8-16 g band, no systematic changes in responding were noted. Feedback was designed to signal to the animal when he was below, in or above the band. However, when that feedback was removed, a significant shift towards a higher force distribution was obtained. Notterman and Mintz suggest that cues added to a previously stabilized behavior may gain control over that behavior, even though the control may not be observable as a change in that behavior.

When similar feedback was applied to Ss during a band "close-in", that is a condition where the reinforcement criterion becomes narrower (i.e., 8-15 g changing to 10-14 g), these Ss more frequently met the criterion than did a similar group run without the added feedback (p. 137).

Both groups however, did share a common form of feedback not mentioned by the authors, namely the change in reinforcements per unit time. This reinforcement frequency, being reduced by a band-close in, provides feedback to the organism. The behavior is subsequently modulated to restore the original reinforcement rate. It is however, less momentarily specific than the exteroceptive feedback described by the authors. Exteroceptive feedback such as a light or a tone is related to the individual response while reinforcement

rate is integrated feedback, thus, it is necessary for an organism to respond over a relatively long period of time before the effects of reinforcement density can be utilized as feedback. The effect of response differentiation on the reinforcement rate will not be noticed immediately by the organism, as with the application of some form of exteroceptive feedback.

Using a solution of procaine to interfere with kinesthetic feedback, Notterman and Mintz showed that the percentage of in-band responses decreases in animals whose paws have been anesthetized. The remaining control demonstrated by these Ss suggested the role of muscular feedback as well as feedback from the skin itself (p. 144).

Mintz et al (1971), have shown that feedback in the form of pressure sensation apparently may play a modest role in the differentiation of a finger response at a level of 150 g in human Ss. Apparently, muscular feedback mediates the differentiation under these circumstances. The authors speculate that at lower force levels, cutaneous feedback may play a more potent role in the mediation of this behavior. This hypothesis is in agreement with the earlier Notterman and Mintz finding described above.

Filion, Fowler and Notterman (1969 a) using human Ss, examined the effect of reduced feedback on the precision of force emission. With two Ss, xylocaine hydrochloride was injected into the index finger used by those Ss on a finger

task similar to the one employed by Mintz et al (1971). The results of the two days of running with xylocaine (after 10 pre-injection days) indicated a significant increase in force variance under the anesthetic condition. This increase was not noted however, at the highest force tested, 200 g. The authors propose a dual system, whereby kinesthetic, rather than cutaneous feedback plays the dominant role in high force conditions, a position similar to that taken by Mintz et al (1971) and Notterman and Mintz (1965). The second part of this experiment compared visual numerical feedback to a non-visual feedback condition. An absence of visual feedback produced a 20% increase in variance when compared to the feedback condition.

In a similar pilot study, Mintz and Barber (1972) showed differences between human Ss in their ability to maintain accurate force emissions when numerical feedback was withdrawn. Reaching 80% within-band responses, one S maintained 72% in-band responses for the first 50 non-feedback trials while the other maintained about 40% in-band responses. On the second block of 50 trials the first S dropped to about 45% while the second appeared to stabilize at about 40%.

These studies underscore the complex role of feedback on the maintenance of precision force emission. They raise speculation as to what exactly constitutes feedback and to the relative importance of exteroceptive feedback versus internally mediated feedback.

-15-

Notterman and Mintz examined the relationship between effort expenditures and various schedules of reinforcement. They ran rats on either FR or FI schedules and measured the effort (time integral of force) exerted by these Ss during each response. They showed that during FR performance, "the mean effort of response tends to increase with an increase in the effort requirement (criterion) for either step advances in a ratio count or reinforcement. When the criterion is low, an increase in the ratio length also produces an increase in the effort expenditure of responding. With higher criteria, this effect does not appear" (p. 181).

They also showed that the first response immediately following reinforcement was generally lower in peak force than those responses immediately preceding reinforcement. In fact, a correlation between response effort and position in the FR cycle was noted. Animals run on the FI condition showed little change in response effort as a function of position in the cycle. However, changes in reinforcement criterion, produced a commensurate change in the mean effort (chapter 8).

Although the evidence at the present is sparse, Notterman and Mintz (1965) draw some tentative conclusions from the preliminary findings which measured response magnitude as a function of the amount of reinforcement and "drive" level. Their findings suggest a decrease in emitted force with an increase in the quantity of response

contingent reinforcement. There is also a tendency for response force to increase with an increase in "drive" state, defined as longer food deprivation times in the context of the experiment. Data obtained from runway studies, for example Hillman, Hunter and Kimble (1953), generally agree with these findings.

Since the quantity of reinforcement exerts control over response force one may conjecture as to what might happen in an experimental situation in which quantity of reinforcement is proportional to response force. Notterman and Mintz (1965) trained rats on a traditional fixed-reinforcement schedule. The animals were then switched to a force-proportional contingency. The general conclusion was that rats under these conditions at least, do not work harder to get more reinforcement even though they are physically capable of doing so (ch. 10).

This finding was confirmed by Filion, Fowler and Notterman (1971) who showed that rats, switched off of a pre-feeding schedule, made up for the loss by electing to press more frequently rather than harder during the subsequent sessions.

These same authors also determined that rats do not take advantage of an effort-proportional reinforcement contingency, although the data suggested that the Ss increased in "efficiency", as measured by the amount of food obtained per unit effort exerted (Filion, Fowler and Notterman, 1970 a).

There are two properties of its behavior which the animal can vary in order to maintain or modify his reinforcement rate. They are response rate and the precision of responding. Fillion, Fowler and Notterman (1969 b) showed that the force of response and the rate of responding were differentially sensitive to electric shock and that the apparent nature of this effect suggested the existence of a tendency for a compensatory interaction between the two dependant variables. Essentially, their findings showed that a high probability of shock had a significant effect on the mean emitted peak force resulting in a decrease of peak force. However, no changes in rate were noted between the high probability group when compared to the low probability group.

Examining this interaction more closely, the authors used a band-discrimination procedure with a close-in technique on three groups of rats receiving varying amounts of pre-feeding. An advantage of the band close-in technique is with the ease by which the difficulty of the task can be modified simply by adjusting the band width to the desired point. The close-in technique consists of training on the wide band, in this case 8.0-13.9 g with a subsequent narrowing in of the band to 10.0-13.9 g. The results indicated that the rate of responding appeared to be a non-monotonic function of the amount pre-fed. The mean peak force of response was not however, differentially sensitive to the amount pre-fed. Data for the shift from the wide-

band condition to the narrow-band condition had the effect of increasing the rate of responding for all Ss. At the same time, the accuracy or percentage of responses falling within the now narrowed band decreased. The data also suggested that the rate of response and differentiation of a response, interacts in a compensatory manner to keep the amount of reinforcement obtained per minute relatively constant. (Fillion, Fowler, and Notterman, 1970 b).

Mintz, Samuels and Barber (1971) examined peak force as a function of a changing criteria for reinforcement in a variable interval (VI schedule). They observed that switching the animals to a more stringent criterion always produced an increase in the absolute rate of the now-reinforced variation. Of particular interest was the means by which this absolute rate change came about. The authors suggest that the absolute rate of the now-reinforced variation could increase either by an over-all rate increase, or by a change in the distribution of response, or a combination of both. The data suggested that if the variation of the response was already relatively frequent in the animals repertoire, a shift in criteria would probably result in further changes in the force distribution, reflected by a relative increase in the frequency of the now-reinforced variation. If the variation was rare to begin with, then the organism would tend to increase the overall rate while the relative distribution remained unchanged.

Although a basic literature exists regarding the

response variation of the peak force of response, there remains a paucity of information concerning the effect of band shifts on response differentiation and response rate, and further on the relative effect of these in maintaining the reinforcement rate. It can be argued that if a band is narrowed, the organism responds as if a random ratio schedule had been imposed, at least during the initial exposure to the new schedule. Of course, the basic process of differentiation would predict a distribution shift or a rate change, however, not before the organism would experience a lower percentage of reinforcement.

This change in the percentage of reinforcement which occurs when a band width is varied, raises questions regarding the effect of externally imposed random ratio schedules of reinforcement on the process of response differentiation, or more specifically, on the distribution of the peak force of response.

Indeed, if an externally imposed random ratio schedule of reinforcement were imposed in addition to that of the band contingency, the S's likelihood of reinforcement would be influenced by the externally imposed schedule of reinforcement, plus one related to his own behavior, based upon the likelihood that each response met the reinforcement criteria. Thus the only time that an animal would be reinforced would be if his response met the reinforcement criteria, and at the same time the external schedule determined reinforcement eligibility. Reinforcement would

not occur if either one or both of these two conditions were not met.

Experimental evidence on the effects of random ratio schedules on response rate and accuracy remains scant. Sidley and Schoenfeld (1964) examined behavior stability and response rate as a function of reinforcement probability on random ratio schedules. They were unable to find a simple relationship between response rate and reinforcement probability, although response rates under a 1.0 probability were lower than with a probability of reinforcement less than unity. Stability was reached after 40-50 days of exposure to any of the six probabilities used ranging from $p = .0068$ to 1.0.

An organism exposed to a band contingency does in effect, determine his own probability of reinforcement. The resultant ratio would be a function of band-width and the Ss accuracy, the percentage of responses falling with the band. Inasmuch as there appears to be a relationship between ratio and rate (Sidley and Schoenfeld 1964), the S in effect indirectly controls his rate through the mode of its self-generated ratio of reinforcement.

Given the apparent inverse relationship between accuracy and rate (Filion, Fowler and Notterman 1969 a, 1970 b) one can hypothesize that a trade-off between accuracy and rate would occur at a particular band width. Thus accuracy or percentage in the band, would affect the reinforcement ratio, while the resultant ratio would influence the rate of

responding. However, if the resultant ratio by virtue of a low reinforcement rate drives the rate of response higher, then this would in turn, tend to increase the reinforcement rate in terms of reinforcements per unit time. Based on the Fillion, Fowler and Notterman (1969 a, 1970 b) studies, one could expect accuracy to decrease with a subsequent reduction in the rate of reinforcement. Apparently, the organism stabilizes at some point of interaction between rate and accuracy, the exact degree of each depending on training history, band width and individual S differences.

In all of the previously reported band studies, the probability of reinforcement for within-band responses was set at 1.0. Thus, any within-band response was reinforced. If the reinforcement probability for within-band responses was set at some value other than 1.0, then in effect a random ratio schedule would be superimposed on an effectively random ratio-self generated reinforcement schedule. With this type of procedure it may be possible to examine interactions between differential criteria versus direct intermittent reinforcement schedules on rate and accuracy.

The purpose of this study, is to examine those relationships and interactions in an attempt to determine the relative contribution of each on the measures of reinforcement rate and accuracy of responding in the band contingency.

METHOD

SUBJECTS:

The Ss for both experiments were two groups of male Sprague-Dawley CFE rats, 50 days old and weighing from 230-240 g each when acquired from Carworth Incorporated, New City, New York. They were housed in individual cages in an animal vivarium where the temperature and humidity were controlled within normal limits of comfort. A water dispenser and food cup filled with Purina Laboratory Mash were continuously available when the animals were initially housed in the laboratory.

For one week prior to the onset of each experiment, the appropriate groups of animals were placed on a twenty-three hour food deprivation regimen. After completion of an experimental session, the Ss were allowed to eat freely for one hour in their home cages. Water was available in the home cage at all times and was also available in the experimental test chamber.

APPARATUS:

The apparatus for both experiments was similar in function to that devised by Notterman and Mintz (1965). A number of modifications were necessitated by differences in equipment. A block diagram (Figure 1) shows the basic system. Recent advances in digital electronic design have rendered the specific equipment obsolete and numerous improvements could be readily accomplished by anyone wishing to construct a similar system.

The basis for any force measuring system is the transducer. This device converts applied force into a usable voltage. For this purpose the Statham Model UC-3 force transducer was selected. This unit is capable of measuring force applied to its shaft within a range of from 0 to 60 g with a displacement of less than 1 mm at maximum force. The output voltage is linear with applied force within a tolerance of 1%.

This transducer was the core component of the operandum. The transducer body was a cylinder 1.9 cm in diameter. At the upper end, a small force sensitive shaft .32 cm in diameter and .63 cm high protruded. Attached to this shaft was a small cylinder of aluminum, 1.27 cm in diameter and 1.27 cm high. The top edge of this cylinder served as the contact surface for the rat. This cylinder and the transducer body were mounted within a larger hollow aluminum cylinder with the contact surface protruding .63 cm above the support. This was done to minimize lateral forces exerted by the rat even though the transducer itself was insensitive to applied lateral force.

The resonant frequency of the transducer and operandum assembly, was approximately 300 hertz, a frequency well above the highest response rate produced by the rats in these studies. This operandum assembly was mounted in a modified Scientific Prototype Model A102 Skinner Box, 17.76 cm wide, 25.40 cm long and 20.32 cm high, centrally along one of the 17.78 cm walls.

The center of the contact surface was 2.22 cm away from the wall, while the contact surface itself was 2.54 cm above the floor of the chamber. The floor consisted of parallel stainless steel rods .32 cm in diameter and spaced 1.58 cm apart. These rods ran across the 17.78 cm width of the chamber.

The food cup and water tube were conventionally mounted; the brass food cup located 3.81 cm to the left of the manipulandum, the water tube being located an equal distance to the right. The experimental chamber itself was mounted on a two-inch thick polyurethane pad for vibration isolation, on a table .91 m high. A Scientific Prototype feeder was connected to the brass food cup with a rubber tube. The feeder was also mounted on the polyurethane pad to damp the vibration produced when the feeder dispensed each P. J. Noyes 45 mg Standard formula rat pellet, which served as reinforcement. The experimental chamber was housed in an isolation room with interior dimensions of 1.52 m long, 1.22 m wide and 1.52 m high. The interior walls and ceiling were covered with two layers of 1.27 cm thick acoustical tile. The structural walls of the room consisted of a 7.62 cm thick sandwich of plywood-urethane insulation-plywood. The floor was constructed of the same material and was additionally carpeted on the inside. The ceiling of the room was of similar construction with the addition of a second ceiling containing ventilation ducts and additional soundproofing material.

Ventilation was provided by a 7.13 cu m/min blower. Air supply to this blower was either air conditioned or

heated so that the internal temperature was constant at a subjectively comfortable level. The isolation room itself was mounted on Celotex and plywood sandwich which itself was placed over a 1.27 cm thick fiber carpet padding.

Although no noise attenuation measurements of the isolation room were made, subjective reports indicated essentially complete attenuation of normal outside noises. In addition, during the experiment, noise was supplied to the isolation room to further mask outside noise. Due to its bulk, the isolation room also had the effect of damping outside vibrations from the operandum.

Illumination in the room was supplied by two, 20-wt Cool White florescent fixtures, mounted along the length-wise walls near the ceiling. The centers of these 45.72 cm fixtures were .76 m from the experimental chamber. A television camera mounted above the chamber allowed the observation of the rat from outside the isolation room.

A shielded cable connected the transducer to the control center. Additional cables were fed into the isolation room for other control functions. The voltage from the transducer was connected to the high impedance input of an integrated circuit operational amplifier. This amplifier had both gain and range controls and allowed for the calibration of the transducer, so that applied force was isomorphic with output voltage. Thus, an applied force of 5 g produced an output voltage of .5 v while an applied force of 50 g produced an output voltage of 5 v. The amplifier was linear from 0 to 5.8 v (equivalent to applied force from 0 g to 58 g), with an error of less than one percent across its range.

This calibrated and isomorphic voltage was connected to the inputs of three independently adjustable level detectors. These level detectors could be set to operate at any applied voltage from .1 to 7.0 v (equivalent to applied forces of from 1 to 70 g). Level detectors of the type used in this experiment were designed with a hysteresis of approximately .005 v. Thus, a level detector set to turn on at a voltage of 3.0 v (equivalent to a force of 30 g), would not turn off until the voltage dropped somewhat below that level. This characteristic minimized the effect of operandum oscillation which might occur after a large force response.¹

Operandum oscillation was also responsible for what was termed "double printing", i.e., a large force response would be followed by a short duration (1-3 ms), low force (.5-6 gm) response, even though the animal clearly did not make this response. This problem was eliminated by a modification to the first level detector (which was to serve as the response threshold detector). This modification filtered out all responses shorter than 10 ms. Since nearly all responses made by the rats were longer than 15 ms, only the "double prints" were eliminated from the system.

¹ Although it is true that the end of the response was determined when the response fell below a level detector set point, it was found that except for preliminary shaping procedures all rats ended a response by lifting their paw from the operandum, thus making terminal force generally equal to zero g.

Notterman and Mintz point out the need for a distinction between a response and those responses eligible for reinforcement. They state that, "Response (s) remain a behavior sampling unit, the basic datum in a study. Not all members of this class need be eligible for reinforcement. The criterion defines the reinforcement eligible subclass of a response" (Notterman and Mintz, 1965. p. 16). Thus, any response exceeding a predetermined force is recorded as a response while only some of these responses, for example between 12 g and 22 g would be eligible for reinforcement. The eligibility would be determined by the experimental parameter; for example, in the present study, Experiment 1 had all in-band responses being reinforced, while during the second experiment, eligibility was set at either 100 percent or 50 percent.

The first level detector was designated as the threshold detector and was set at 5 g for all parts of both experiments. Level detectors 2 and 3 were adjusted to operate at the lower and upper limits of the force range eligible for reinforcement, respectively. The force range eligible for reinforcement will hence be referred to as the band. Thus, any applied force above 5 g was defined as a response, any applied force above level detector 2 but not above 3 was considered an in-band response and was eligible for reinforcement.

Logic levels from all three level detectors were interfaced to standard, 28 v reed programming equipment. The reed programming equipment established reinforcement contingencies for the rat. It was observed that it was

possible for the rat to become eligible for reinforcement faster than the feeder could dispense pellets, thus a minimum inter-reinforcement time of 100 ms was programmed into the system to prevent this from happening.

Logic outputs of the three level detectors energized both cumulative recorders and electromechanical counters. In addition, similar counters recorded reinforcements and total running time for each animal. The programming equipment turned off the operandum and the isolation-room lights automatically after the experimental session.

The peak force for each response was recorded. In order to store this peak response voltage (isomorphic with peak force), and to control the operation of the Systron Donner Model 1201 Digital Volt Meter (DVM) which read the peak voltage, and the Hewlett Packard Model 561 B Digital Printer which recorded it, the analog voltage from the operational amplifier and the level detector 1 logic output were connected to the peak detect and hold circuit (PDH).

The PDH consisted of integrated circuit logic for the timing functions and a intergrating circuit which stored the peak voltage (which was isomorphic with applied force) until it could be read and recorded. Due to the characteristics of this circuit, a droop in voltage at the rate of .1v/sec occurred. This was equivalent to the drop of 1 g/sec. Since the duration between the peak emitted force and the end of response was seldom longer than 80 ms (.08 g) this was not considered to be a serious source of error.

The logic section of the PDH triggered the DVM to read and store the peak voltage held in the intergrating circuit upon completion of a response. The DVM required 20 ms to read the applied voltage. At the completion of the read cycle, an "end-of-read" command was sent back to PDH. This signal initiated a reset to zero of the peak storage intergrating circuit, and opened the threshold circuit which was locked out during DVM read time.

At the same time, a print command caused the printer to read DVM voltage. The printer took 200 ms to print the applied voltage and upon completion, signaled the PDH that it was finished. If a response had occurred during that print cycle, that voltage, now stored in the peak circuit, would be read by the DVM, and the cycle would continue. If a second response occurred during the DVM read cycle, it would be locked out of the system. Thus, the IRT between the first two responses of a high rate burst, could be as short as the cycle time of the DVM; namely 20 ms, while the minimum IRT between the second and third response would be 220 ms, the combined cycle times of the DVM and printer.

Operating in conjunction with the PDH logic was a parametric coder which recorded reinforcement contingencies and other parameters onto the printer tape for each response. In addition to this equipment, a peak force frequency distribution accumulator was built. This device accumulated frequency distributions of an experimental session on a real time basis with a resolution of one g.

Due to the irrevocable breakdown of certain critical components prior to the onset of Experiment 2, a number of modifications were made to the basic apparatus. Since both the DVM and the PDH malfunctioned, it was impossible for the data to be recorded on paper tape as had been done in Experiment 1. However, the frequency distribution accumulator was still available and critical peak force distributions could still be recorded. As the PDH timing circuits served as parameters during Experiment 1, it was necessary to duplicate these parameters for the second experiment by means of standard reed programming equipment. It was possible for the frequency distribution accumulator to operate at 10 responses/sec, thus the programming equipment was designed to allow for faster operation of the system (10 responses/min vs. 5 responses/min for original system).

As in the original apparatus, all responses shorter than 10 ms were filtered out and a DRL 100 ms was imposed. The difference between the two systems was the minimum IRT which was now 100 ms between any two responses. For the experimental operations affecting the Ss, the two systems were identical with the exception of minimum IRT. However, since maximum response rates were well under 5 responses per second, the two systems were essentially considered as the same.

PROCEDURE:

Both groups of experimental animals received tray training prior to bar press training. Each rat was placed in the experimental chamber for thirty minutes during which

one P.J. Noyes 45 mg Standard Formula Pellet was delivered to the food cup at 30 sec. intervals for a total of 60 pellets.

Bar training was carried out in an identical fashion for both groups as follows: Each animal was placed in the experimental chamber. The apparatus was adjusted so that the criterion for reinforcement was equal to the threshold set point, or 5 g. Each response was then reinforced with one pellet of food. The animals were allowed to self shape with no intervention by the experimenter for a total of 60 reinforcements. The rats used for Experiment 1 received an additional session of CRF training at a criterion of 20 grams, for a total of 60 reinforcements. This procedure was not repeated for the rats of Experiment 2.

EXPERIMENT 1:

After CRF training at 5 and then 20 g criterion, the rats of Experiment 1 were divided into three groups of four rats each. Group 1 consisted of rats RB 1,2,3,4. Group 2 consisted of rats RB 9,10,11, and 13, while group 3 consisted of rats RB 5,6,7, and 8. The experiment was divided into four Phases, I,II,III,IV. Phases I, II, and III were conducted for 12 consecutive sessions with a two day break between Phases. Phase IV was carried out for five consecutive sessions.

A band criterion was imposed for Phases I, II, and III. The assigned band criteria and experimental paradigm are shown in Table 1. Each of the three experimental groups was started

on a different band. Group 1 began on a 12-22 g band. For this condition any response with a peak force falling within 12-22 g would be eligible for reinforcement. This group was shifted to a narrower band during the next two Phases. The Phase II band was 14-20 g while the Phase III condition was 15-19 g.

Group 2 was complimentary to group 1 in that its Phase I condition was set 15-19 g. Phases II and III saw a widening of the band to 14-20 g and 15-19 g respectively. Group 3 was initially placed on an 18-28 g band which was narrowed to 20-26 g and 22-24 g during Phases II and III respectively.

Group 1 was identified as the low band, wide to narrow group; group 2 as the low band, narrow to wide group; while group 3 was identified as the high band, wide to narrow group. Low and high designations were based upon the mid points of the bands, 17.0 g for groups 1 and 2 versus 23 g for group 3.

Phase IV consisted of two animals per group being shifted to continuous reinforcement (CRF) with a criterion of 5 S, while the other 2 animals per group were placed on extinction.

Peak force for each response was recorded for each rat. Total responses, number of responses at or above level detector two, number of responses at or above level detector three and total run time were all recorded. Cumulative recorder graphs were obtained for responses at or above level detectors 1, 2 and 3. A real time frequency distribution accumulator recorded peak force distributions.

EXPERIMENT 2:

After one session of 60 reinforcements of CRF training at a 5 g criterion, the animals of Experiment 2 were divided into two groups of six rats each. Group 1 consisted of rats 1, 3, 5, 7, 9, and 11, while group 2 consisted of rats 2, 4, 6, 8, 10, and 12. The experiment was divided into two Phases, I and II. Both were conducted for 12 consecutive sessions with a one-day break between Phases. A band criterion of 14-20 g was imposed for both groups and was held constant for both Phases, however, the probability of reinforcement for within-band responses was varied according to the schedule shown in Table 2. Data collection was identical to that in Experiment 1 with the exception that peak force recording was limited to frequency distributions.

RESULTS

EXPERIMENT ONE:

Rate measures expressed as responses per minute (r/min) were calculated independently for each rat's daily performance. Figure 2 shows the rates for each band, based upon the mean of each rat's last three days of running during Phases I, II, and III. It can be seen that the narrower the band criteria, the higher the rate of responding in 23 of 24 criterion shifts. The one exception was RB 10 of group 2 on the Phase I to Phase II change.

A Wilcoxon T Statistic for related samples was calculated for Phase I, II and III rates of all three groups, and was found to be significant ($p < .001$), indicating that these rate changes probably did not occur by chance. It is also apparent that the group 3 response rates were consistently higher than group 1 and 2 rates. Group 1 and 3 response rates also appear to change more dramatically from one reinforcement criteria to another, as compared with the data from group 2. The degree of change for the group of rats going from a more stringent reinforcement criteria to a less stringent one (group 2), does not appear to be as affected by these shifts as those groups (1 and 3) shifting to a more stringent requirement.

Table 3 summarizes data from Figure 2, showing the mean response rate for each group of rats at each band criteria. Comparison of group 1 and group 2 data shows the effect of the direction of shift on the response rate, and also on

the relative change of response rate from one band criterion to another. The relative percentage change from the 12-22 g band contingency to the 14-20 g band contingency and from 14-20 g band contingency to 15-19 g band contingency was .57 and .27 versus .44 and .16 for group 1 and group 2 respectively starting at Phase I. In this case there is a smaller change in response rate for the group which was shifted from a more stringent to a less stringent criterion, than if the shift is to greater stringency.

Tables 4, 5 and 6, show the percentage of total responses in each reinforcement-eligibility band for the last three days of Phases I, II, and III for individual Ss of groups 1, 2 and 3 respectively. This table shows the percentage of total responses falling within each band regardless of which was in effect. Percentages underlined indicate the percentage of reinforced responses during any given Phase. For example, looking at the data for RB 1 it can be seen that during Phase I, when that animal was placed on the 12-22 g band contingency, 33.4 percent of its responses fell within that band and were reinforced. This same distribution of peak force showed 18.8 percent and 12.4 percent of its responses within the more stringent bands of 14-20 g and 15-19 g respectively. When the animal was shifted to the Phase II condition (14-20 g), 26.6 percent of the total responses were reinforced and fell within that band contingency, while 45.1 percent and 18.3 percent of its total responses fell within the 12-22 g and 15-19 g bands respectively.

During Phase III, the S was shifted to the reinforcement criterion of 15-19 g. During this Phase, 14.8 percent of the rats total responses were reinforced and fell into this band, while 42.4 percent were within the 12-22 g range and 22.0 percent appeared within the 14-20 g band. It should be noted that these percentages are inclusive; the narrowest being subsumed in the next wider and so on.

The data in Table 4 show a general tendency for the percentage of responses within a band to be greater when a more stringent force requirement is employed. This comparison can be made by examining the columns of the tables which show a general increase down each column related to progressively more stringent criteria for reinforcement. It can be seen that 18 of the 24 such comparisons reflect the effect, generally understandable as an increase in the proportion of responding in, and adjacent to, the reinforced range, as a function of the stringency of that range.

If no force differentiation occurred as a consequence of band change, then the relative percentages within these bands would not vary. A change in percentage indicates the measure of response differentiation that did occur.

Since the Phase I contingency for group 2 was the most stringent band, the resulting percentage change reflected a tendency for less accurate performance as the criterion became less stringent. This effect was referred to as de-differentiation. For Ss of group 2 (Table 5) the data indicates that de-differentiation occurred in 16 of 24 possible comparisons, while the animals from group 3 (Table 6) showed differentiation during 17 out of 24 possible comparisons.

Table 7 shows group means for the data in Tables 4, 5, and 6. For group 1, differentiation occurred six out of six times while group 2 showed de-differentiation five out of six times. Group 3 data showed differentiation five out of six times.

In the preceding analysis not all of the comparisons are independent, since the frequencies in wider bands subsume narrower contained bands (e.g., all responses within the 14-20 g band are also within the 12-22 g band). In order to permit an independent comparison of those portions of the bands that underwent changes in contingency, an analysis of the margins was developed.

The margin is that portion of the reinforced range that is under extinction when the criteria is shifted to a more stringent condition. Under the widest contingency, no margin exists since the entire range is being reinforced. For example, with groups 1 and 2, from the widest to the middle band a margin equal to the difference between the 12-22 g band and 14-20 g band is formed. This is referred to as the outer margin. Another margin is produced when the band is shifted to the narrowest condition. This is referred to as the middle margin and is formed by the difference between 14-20 g band and the 15-19 g band. With margins so calculated, it is possible to observe non-reinforcement effects on previously reinforced subsets of the reinforced range.

Tables 8, 9, and 10 show the percentage of responses falling within the margins during the three Phases of Experiment 1 for the Ss of groups 1, 2, and 3 respectively. Of most interest are the comparisons of margin percentages during a change from reinforcement to non-reinforcement, and in the case of group 2 Ss, from the non-reinforcement contingency to the reinforcement contingency.

Observation of the data indicates a weak trend for the percentage of responses falling in the margins to increase as the band is made more stringent, hence placing these margins under extinction. Group 1 (Table 8) shows this effect in 8 out of 12 comparisons, while the Ss of group 2 demonstrate this in 7 of 12 comparisons. This finding was not repeated for the high-band Ss of group 3 where only 5 of 12 shifts showed an increase in margin percentages.

Figures 3-14 display peak force distributions for all three groups during each of the four Phases of Experiment 1. Each figure represents the mean of the last three days of the appropriate Phase.²

Figure 3 shows the relative frequency distributions of the peak force of response for the rats of group 1 during the Phase I (12-22 g) condition. These animals show a high

2. The 3 day total N for each relative frequency distribution ranged from approximately 700 responses to 3,600 responses, depending on the band in effect and the individual S.

frequency of peak forces at and around the 5 g threshold. Relative percentages for higher force values tend to decrease above the upper limit of the band. During Phase II, when the band was narrowed to 14-20 g, there appears to be a general flattening of the distribution caused by a decrease in the relative frequency of responses below the band and subsequent increase in above the band responses (Figure 4).

Figure 5 shows Phase III data, a band width of 15-19 g. Little difference is noted from the Phase II condition. Phase IV data is presented in Figure 6. During the Phase IV condition two animals from each group were run on CRF for all responses above the 5 g threshold, while the remaining two were run on extinction. Data produced by RB 2 and RB 3, (the CRF animals), show fewer high force responses than RB 1 and RB 4. (the extinction animals).

Both CRF and extinction produce marked increases in low-force responses when compared with the distributions typical of the several bands.

Group 2, Phase I data, are shown in Figure 7. These animals began on the narrow 15-19 g band and tended to generate a more rectangularly shaped distribution than did the group 1 animals during the Phase III (15-19 g) condition shown in Figure 3. This condition also produced more high force responses above 40 g than were generated by the group 1 rats under this same reinforcement contingency (Figure 3). There is a downward shift in peak force distribution when these animals were changed to a less stringent contingency

(14-20 g) during Phase II, as seen in Figure 8. It is interesting to note the similarity between this distribution and that produced by group 1 on the same band width (Figure 4). Figure 9 provides the distribution produced by group 2 Ss when they were switched to the 12-22 g reinforcement contingency during Phase III. This distribution shows a further downward shift and is similar to the one generated by group 1 during Phase I, with the exception that the group 1 animals show a higher percentage of their responses within the reinforced band.

CRF and extinction data for group 2 are shown in Figure 10. Again, the extinction animals show a greater relative percentage of higher force responses than do the CRF animals of the same group. When the extinction animals of group 2 are compared with the extinction animals of group 1 (Figure 6), it can be seen that Ss of group 2 tend to generate still higher force responses. The CRF rats of group 2 also show higher peak force responses than do the CRF Ss of group 1.

Figure 11 displays the peak force distributions for the four rats of group 3 during the Phase I (18-28 g) condition. These animals produced relatively rectangular distributions of peak force. There are a rather large number of above 40 g responses for three of the four animals of the group. Phase II data, the 20-26 g band condition is presented in Figure 12. Little if any systematic change in the distributions can be seen. Figure 13 shows the Phase III condition (22-24 g). These data indicate a decrease in low force responses for all four Ss. Figure 14 presents

CRF and extinction data for the animals in group III. These figures are also based on the mean of the last three days of running. As with the other groups, extinction data is exemplified by higher peak force responses than the animals run on the CRF reinforcement schedule.

In order to more saliently summarize and to compare the frequency distributions, the 25th, 50th and 75th percentiles for each distribution were calculated. Figure 15 shows the 25th, 50th and 75th percentile peak force values for each of the four Ss of group 1. For the Ss of this group, there appear to be no systematic changes in force values at these points as a function of making the reinforcement criteria more stringent.

Figure 16 shows the percentile peak force values for the Ss of group 2. A downward shift of the distribution is evidenced as the reinforcement criteria is made less stringent over the three Phases. Figure 17, the group 3 data, displays an upward shift in the distribution as the Ss are moved to more progressively stringent reinforcement criteria. This may be due in part to the apparent extinction effect of being placed on a very narrow band (22-24 g) where reinforcement density is low.

The mean percentile values for all three groups is displayed in Figure 18. This figure more clearly shows the apparent consistency among Phases for group 1, the decrease in high forces for group 2 when shifted to progressively less stringent bands, and the increase in peak forces for group 3 when switched to successively more stringent re-

inforcement criteria.

CRF and extinction data are shown in Figure 19 which displays the 25th, 50th, and 75th percentiles for the Phase IV condition of groups 1, 2 and 3 for experiment 1. In general, extinction generated a high frequency of high peak forces for the two animals of each group that were subjected to extinction. Among groups, the highest forces were shown by group 3, the one group previously reinforced for various high force responses.

A series of three Mann-Whitney U Comparisons were calculated for CRF versus extinction data at the 25th, 50th, and 75th percentile values. Each test was significant at the .05 level, indicating that at least at these three percentiles, force levels were significantly different. It would be possible to discriminate between extinction or CRF contingencies by comparison of these force levels.

In order to more succinctly express the occurrence of differentiation (here defined as behavior more successfully meeting the reinforcement criteria), coefficients of force differentiation and of rate differentiation were developed. Tables 4, 5, 6 and 7 have shown that the percentage of responses falling within a less stringent band generally increase when the S is shifted to a more stringent band. Taking this as the basis of the statement of force differentiation, it is possible to calculate a coefficient based upon the degree of this increase.

For example, referring to Table 4, S RB 1, 18.8 percent of this animal's responses fell within the 14-20 g band while the 12-22 g band was in effect. This percentage increased to 26.6 percent when the S was shifted to the 14-20 g band. This increase is taken as a statement of force differentiation.

The general rule used to calculate the coefficients of force differentiation were as follows: The percentage of responses falling within the band of interest while the less stringent band was in effect, is compared to the percentage of responses falling within that same band when that band was in effect. The equation is:

$$\frac{\% \text{ in narrower band when wider band is under reinforcement}}{\% \text{ in narrower band when narrower band is under reinforcement}} = \text{coefficient of force differentiation.}$$

Thus, for RB 1, referring to Table 4, the first shift would be:

$$\frac{26.6}{18.8} = 1.42$$

while the second shift would be:

$$\frac{14.8}{18.3} = .81.$$

A coefficient larger than 1 would indicate that that the percentage increased, and thus peak force differentiation did occur. A coefficient of 1 would indicate that the Ss behavior did not differentiate, while a coefficient of less than 1 would indicate that de-differentiation had occurred.

The coefficients are shown in column 2 of Table 11. For the change from Phase I to Phase II, six out of eight animals in groups 1 and 3 (the wide to narrow groups), show differentiation, while 3 of the 4 rats in group 2 (the narrow to

wide group) showed de-differentiation. For the second change from Phase II to III, five of eight animals from groups 1 and 3 showed differentiation, while two of the four Ss in the second group showed de-differentiation. The other two rats in the group had coefficients near unity.

Since rate data was also considered a measure of differentiation, changes in rate were examined in a ~~similar~~ fashion by using the data shown in Figure 2 to calculate indices of rate changes. The index for rate differentiation was given as:

$$\frac{\text{rate after shift}}{\text{rate before shift}} = \text{index of rate differentiation.}$$

For subject RB 1, Phase I to Phase II condition, this coefficient would be expressed as follows: $\frac{48.3}{28.8} = 1.65$. A coefficient

above 1 indicates an increase in response rate, a coefficient below 1 indicates that the rate has decreased, while a value of unity indicates no change in response rate. These coefficients are shown in column 3 of Table 11.

An additional coefficient was calculated by obtaining the product of the previously calculated force and rate coefficients. This product was considered as an absolute coefficient of differentiation.

The absolute coefficient of differentiation is effectively a measure of the change in rate of occurrence of the now-reinforced response variation. This rate enters the coefficient through changes in the force distributions and changes in the absolute rate of response.

These coefficients are shown in column four of Table 11. The interpretation of the product reflects a combined statement of differentiation based on response rate and response conformity to the reinforcement criterion. For groups 1 and 3 differentiation occurred for 16 out of 16 shifts, while the data for group 2 Ss shows that de-differentiation occurred in 7 out of 8 shifts, with the remaining case equal to 1.02, a value near unity.

In order to account for the fact that group 2 Ss were run on increasingly less stringent bands, an index of de-differentiation was calculated using the modification of the formulae shown above. The coefficient for response de-differentiation was given as:

$$\frac{\% \text{ in wider band when narrower band is under reinforcement}}{\% \text{ in wider band when wider band is under reinforcement}} = \text{index of response de-differentiation.}$$

For example, RB 1's shift from Phase III to Phase II is:

$$\frac{22.0}{26.6} = .827. \text{ It should be apparent that the rate coefficients}$$

here are the inverse of the Phase II to Phase III shifts calculated for Table 11.

The indices of response differ however, with regard to the force ranges being examined. In Table 11 the data base is a narrower band compared to a condition when it is being reinforced versus when a wider band is being reinforced. In Table 12, a wider band is being examined when it is being reinforced as compared to when a narrower subsumed band is required for reinforcement.

Table 12 shows the force, rate and final produce coefficients for the absolute index of de-differentiation. The interpretation remains as before, with a value larger than one indicating de-differentiation, a value less than one indicating that differentiation occurred, while a value of unity indicated no change. It can be seen that de-differentiation did occur for seven of the eight possible shifts for the Ss of group 2, while differentiation occurred for 15 of the 16 shifts made by the Ss of groups 1 and 3.

Mean reinforcement rate for each experimental group based on the last three days of running during the first three Phases of Experiment 1, is shown in Table 13. It can be seen that group 3 produces a decreasing rate of reinforcement as a function of a narrowing reinforcement criterion. The data for group 1, however, shows a relatively constant rate of reinforcement regardless of band width. These animals were able to differentiate their responding in order to maintain the reinforcement rate at a relatively constant level. The animals of group 2 show an increasing reinforcement rate as the band width was widened. The reinforcement rates for groups 1 and 2 differed during the Phase I and Phase III conditions, but were identical during the Phase II conditions.³

3. These reinforcement rates were calculated by dividing the total number of reinforcements by time. It is also possible to calculate these values by multiplying percentage in-band responses by the rate of responding. When this was done, values obtained were within 5% of each other. This discrepancy can be accounted for by the fact that two in-band responses may have been made while only one reinforcement was delivered to the S, due to the relatively slow operating time of the feeder. It is also possible that recorded values of in-band responses may reflect small errors due to circuit drift, hysteresis of the level detectors, etc. A third possible source of error may have been the fact that independent level detectors determined reinforcement occurrence or nonoccurrence.

Figure 20 displays the relationship between the percentage of in-band responses and the rate of responding. It appears that at least for the parameters used in this study, a negatively accelerated curvilinear function exists between these two measures.

EXPERIMENT 2:

Group 1 was placed on a 100 percent reinforcement schedule during Phase I and was shifted to 50 percent reinforcement during Phase II. Group 2 was reinforced 50 percent of the time during Phase I and was switched to 100 percent reinforcement during Phase II. The response eligible band at all times was 14-20 g.

The percentage of in-band responses and the mean rate of responding were calculated for groups 1 and 2 for each day of running during both Phases of the experiment. Figure 21 shows the mean percentage of in-band responses taken daily for the rats of both groups. It can be seen that until the eighth day, acquisition data shows that group 1, reinforced 100 percent of the time during Phase I, generated a slightly higher percentage of in-band responses than did group 2, on a 50 percent schedule during Phase I. However, after day eight and until the completion of Phase I, these differences were no longer evident. The change from Phase I to Phase II, corresponding to a reversal of the percentage of reinforcement for in-band responses, showed no differences between groups. It appears that the 100 percent reinforcement schedule may facilitate acquisition slightly, but this

differential is minimized as training progresses beyond the eighth day, at least for the parameters used in this study.

It is interesting to note that the grand mean percentage of in-band responses for both groups combined, over the last three days of Phases I and II is 21.2, compared to 21.35 for the Phase II condition (14-20 g) of groups 1 and 2 of the first experiment. It appears that the percentage of in-band responses for a given band width and absolute level may be a relatively constant phenomenon.

Figure 22 shows the mean rate of responding taken daily for both groups 1 and 2 during both Phases of the study. It can be seen that the 50 percent reinforcement schedule generates higher rates than the 100 percent reinforcement schedule. It is interesting to note, however, that the rates do not merely switch position after the change of contingency. It appears that, relative to Phase I, group 1's (100%-50%) response rate increases, while the response rate of group 2 (50%-100%) decreases. Of interest is that the Ss of group 1 generated a final three day mean response rate of 66.5 for Phase I (100%), which compares to the mean three day response rate of 65.25 for groups 1 and 2, the Phase II (14-20 g at 100%) condition of Experiment 1. There again appears to be a consistency for a given parameter, in this case rate.

Figure 23 shows the mean reinforcements per minute for groups 1 and 2 during Phase I and Phase II of Experiment 2.

It is interesting to note that although 100 percent reinforcement tends to generate higher reinforcement rate during Phase I, the same is not true during Phase II. Apparently prior reinforcement history may in some way alter responding under a new schedule so as to affect reinforcement rate.

Figures 24, 25, and 26 display the peak force distributions for the last three days of running on Phases I and II for the Ss of group 1. These distributions show little systematic change in shape when these Ss were switched from the initial 100 percent schedule to the 50 percent schedule during Phase II.

Figures 27, 28 and 29 present the force distributions for the last three days of running on Phases I and II for the Ss of group 2. These distributions show no systematic change in the percentage of responses falling within the reinforcement-eligible band, although there are changes in the above and below band percentages. Group 2 distributions tend to drift downward and towards a greater percentage of low force responses, when changed to a schedule that provides greater reinforcement density for ongoing behavior. This in contrast to no change in distribution for the group 1 Ss, where, if the effect was consistent with that of group 2, one would have predicted an upward shift in the distribution to a greater percentage of high force responses.

Figure 30 displays the mean force distributions for Ss of groups 1 and 2 during both Phases I and II. Again, it is possible to see the downward shift in peak force distribution

when group 1 was shifted from 50 percent reinforcement to 100 percent reinforcement. The appearance of a downward shift towards higher peak force responses is not evidenced with the Ss of groups 1, when they were switched from the 100 percent reinforcement schedule to the 50 percent reinforcement schedule.

Figures 31, 32, and 33 display the percentages of below band, in-band, and above band responses for the Ss of group 1. As gleaned from the distributions, no systematic changes are evident as a consequence of a shift from 100 percent to 50 percent reinforcement. Figures 34, 35, and 36 show more saliently the downward shift of the distribution for Ss of group 2 when switched from 50 percent to 100 percent reinforcement. No systematic change of within band percentages can be noted, although an increase of below band responses occurs for six out of six animals during the 50 percent to 100 percent change. Above band responses tend to decrease for five of the six animals during the same change or reinforcement schedule.

The mean below, in-band, and above percentages for groups 1 and 2 of experiment 2 are presented in Figure 37. A slight increase of within and above band percentages can be noted, along with a slight decrease of below band responses for the Ss of group 1 when shifted from the 100 percent reinforcement schedule to the 50 percent reinforcement schedule.

A large increase of low band responses along with a decrease of above band responses accompanies a switch from

50 percent to 100 percent reinforcement for the animals of group 2. A slight decrease of within band responses can also be noted.⁴

It is interesting to note that from both groups 1 and 2, reinforcement at the 50 percent condition tends to generate slightly higher percentages of in-band responses than the 100 percent contingency. Although the absolute values are small (22.01 versus 20.94 for group 1 and 21.82 versus 18.64 for group 2), the fact that it occurred in both of these cases suggests that, at least for the parameters used in this study, a 50 percent reinforcement schedule seems to generate more "accurate" performance than the 100 percent reinforcement schedule, or perhaps more conservatively stated, 100 percent reinforcement clearly does not generate more "accurate" performance than 50 percent reinforcement.

⁴ The Phase I final three day mean response rate for group 1 was 79.7 responses/min compared to 66.7 responses/min for group 2. This resulted in a final three day mean reinforcement rate of 13.9 reinforcements/min for group 1 and 8.7 reinforcements/min for group 2. This compares to the combined mean reinforcement rate of 13.6 reinforcements/min for groups 1 and 2 of Experiment 1 during the Phase II condition, when the band was also 14-20g and the reinforcement probability was 100 percent. These data again suggest the relative stability of these measures from group to group.

DISCUSSION

To recapitulate the procedure, Experiment 1 consisted of three groups of rats which were started at three different band criteria. Groups 1 and 2 were run with the same band criteria, but in reversed order, while group 3 was run under a different set of band criteria. In the fourth Phase of Experiment 1, two rats of each of the three groups ran on CRF at threshold, while the other two animals of each group were run on extinction. A reinforcement ratio of 100 percent was in effect for all in-band responses.

During the second experiment, two groups of rats were run on identical band criteria (equal to the Phase II condition of Groups 1 and 2 of Experiment 1). Group 1 was reinforced for 100 percent of its in-band responses during the first condition, and was then shifted to a random ratio 50 percent reinforcement schedule during Phase II. Group 2 Ss were run with reversed reinforcement ratios, 50 percent during Phase I and 100 percent during Phase II.

The experimental procedure allowed the analysis of rate of response, accuracy of responding as measured by the percentage of responses falling within the band in effect, the distribution of peak forces and the rate of reinforcement (which is in essence a function of the above three). Each one of these measures of the differentiation process will be discussed below.

RATE OF RESPONDING

In general, the data obtained from these two experiments indicates that as the band becomes more stringent, the rate of responding tends to increase. Conversely, as the band becomes less stringent, the rate of responding tends to decrease. These findings are in agreement with those obtained by Filion, Fowler and Notterman (1970 b), who observed an increase in rate when the band in effect was shifted from 18-15.9g to 10-13.9g. The present data indicates that as the reinforcement eligible band becomes more stringent (that is narrower), the rate of responding increases. This may be due to the effect of extinction on the rate of responding, whereby a reduction in reinforcement rate brings about a higher response rate.

As the band is made more stringent, a lower percentage of responses falls within the reinforcement eligible band. Thus, the rate of reinforcement tends to decrease. These findings are compatible with those of Sidly and Schoenfeld (1964), who examined behavioral stability and response rate as a function of reinforcement probability on random ratio schedules. They determined that response rates were lower under a 1.0 probability than with a reinforcement probability of less than unity. In the present study, when the band was made more stringent, the percentage of responses being reinforced decreased. This was true particularly early in the shift before the animals responding was further

differentiated, so that more peak forces would fall within the now more stringent band. This narrowing of the band in effect, essentially lowered the probability of the reinforcement presented to the animal for his on-going behavior.

It is interesting to note that group 3, whose band at midpoint was 23g vs 17g for groups 1 and 2, always generated higher response rates than did the Ss of groups 1 and 2. This was true even though the band widths in some cases were identical. The data suggests that with equal band widths, the band with the higher midpoint seems to generate higher response rates. This finding differs from that obtained by Notterman and Mintz (1965) who examined the rate of responding, along with other measures, on a dual band contingency where the appropriate band was cued exteroceptively. They report that the rate of responding seemed to be more related to the relative frequency of reinforcement than to either band width or band midpoint.

These differences may be attributed to the fact that the Notterman and Mintz study utilized a dual band procedure, where two discrete bands were in effect sequentially as compared to the present study in which case one band was replaced by another. Indeed, the data of the present study actually disagrees with the notion put forth by Notterman and Mintz, since there appears to be no systematic relationship between reinforcement rate and response rate, at least

under the conditions of the present study which, unlike the Notterman and Mintz design, allows the organism to differentially respond in order to maintain the reinforcement rate which is being reduced by increasing band stringency.

Skinner (1958) points out that the rate of responding appears to remain unchanged as the force required for reinforcement is increased (p. 327). His finding implies that differing band midpoints do not seem to have any role in the determination of rate. The results of the present study are contrary to his findings. It is possible that the characteristics of band reinforcement and the subsequent alterations of peak force of response distributions, by virtue of the organism's tendency to maintain his reinforcement rate at its present level, may account for this discrepancy.

Skinner's statement is based on a procedure in which the lower limit of the band was varied. One can conceptualize the Skinner procedure as involving a band of reinforcement eligible responses, with a lower limit fixed by the procedure and the upper limit fixed by the maximum limits of organismic force emission. Skinner's procedure thus narrowed the band only from the lower limit, leaving the upper limit unmodified. A differentiation of this nature appears to be "easier" for the organism to learn in the sense

that reinforcement rate more readily stabilizes under these conditions than if the band was being made more stringent, as a result of both upper and lower band limits being shifted. Not having to differentiate the upper limit of force allows the probability of reinforcement to be more easily retained without concomittant changes in rate.

In Experiment 2, the rate of responding was related to the ratio of reinforcement, in that lower percentages of reinforcement (in this experiment determined by an externally imposed random ratio schedule) resulted in higher response rates within groups. That is, for each group, a random ratio schedule of 100% generated lower response rates than a random ratio schedule of 50%. These data confirm the findings of Sidly and Schoenfeld (1964). It is interesting to note, however, that the reversal of reinforcement probabilities between these two groups did not simply result in an inversion of response rates. Rather, the response rates resulting from this reversal appeared to reflect a tendency of the Ss to modulate the response rate in an attempt to maintain the reinforcement rate near its former value.

It appears that organismic response rates may not simply be related to the reinforcement ratio in effect at the moment, but may also be related to the relative difference between two successive rates of reinforcement. Thus, an organism initially run on a CRF schedule may,

when switched to a 50 percent random ratio reinforcement schedule, exceed the response rate of another organism initially run on a 50 percent random reinforcement schedule. Apparently, the existence of a "reference" reinforcement rate (a consequence of the reinforcement schedule in effect, as well as the rate of responding) plays an important role in determining the response rate at other percentages in reinforcement.

For example, when the random ratio was increased to 100 percent from 50 percent for group 2, the response rate actually decreased to below that generated by group 1 when that group was run on CRF. It is possible that the organism modulates response rate in an attempt to stabilize the reinforcement rate at its original value, even though the environment is now providing conditions for a higher rate of reinforcement. Ss reinforced on a CRF schedule in a sense attempt to maintain their reinforcement rate at the rate established initially, when they are shifted to 50 percent random ratio reinforcement. Another group, initially trained at a 50 percent reinforcement schedule and subsequently switched to 100 percent reinforcement, is receiving reinforcement at a rate higher than the initial value and seems to stabilize with a modest increase in reinforcement rate by responding less frequently. In essence, the organism

responds less frequently but receives more reinforcement.

PERCENTAGE OF RESPONSES FALLING WITHIN THE BAND IN EFFECT
(ACCURACY)

The data of Experiment 1 suggest that an inverse relationship between rate and accuracy exists (as measured by the percentage of responses falling within the band in effect).

A similar finding was reported by Fillion, Fowler and Notterman (1969 a, 1970 b). The apparent consistency of this relationship is evident when one enters the final three day mean rate of responding and percentage of in-band responses from the Phase I condition for group 1 of Experiment 2 (69.7 responses/min and 21.2 percent, respectively) onto Figure 20. This point falls almost exactly on the line generated by the data of the first experiment, suggesting that this relationship may exist as a more or less **general** function for experimental conditions of this type.

In general, the data presented in Tables 4-10 support the notion that a more stringent criterion tends to generate an improvement in performance relative to the condition when the less stringent requirement is in effect.

When an organism moves from a less to a more stringent contingency, fewer variations of the response are subsequently reinforced. In essence, a margin of responses previously reinforced on the less stringent requirement are no longer being reinforced when the band is narrowed. Thus,

certain variations of the responses (those variations furthest from the center of the band) are undergoing extinction. According to extinction theory, one would expect an eventual reduction in the frequency of responses falling in the now non-reinforced margins formed between the limits of the less and the more stringent bands.

Although no strong tendencies are shown, the data from groups 1 and 2 are somewhat suggestive that, contrary to these expectations, a more stringent criteria, (i.e., the extinction of the margins), produces a greater proportion of responses in the margins for 15 of the 24 possible comparisons. The evidence strongly suggests that adjacent areas undergoing extinction do not necessarily show a decrease in the frequency of responses falling within those areas. In fact, the data intimates that increases may actually occur.

These findings can perhaps be explained by conceptualizing the band discrimination task as having two discriminative variables; a target peak force which is actually the midpoint of the band in effect, and the allowable variance permitted for a response to meet the criteria, which is the band width. Using this model, the organism is being trained to respond at a central target with constraints being placed on the allowable variance of that response.

Initial training can be construed as learning to aim at a target. If the organism is given a large variance (i.e., the band is made less stringent) then the number of responses approximating the target that are reinforced is

high. If the variance is restricted, than the number of responses being reinforced for the same on-target behavior is low. The wide variance group, by virtue of a high percentage of responses being reinforced, would tend to generate a lower rate of responding. As the rate of responding decreases, the accuracy increases, further increasing the apparent reinforcement ratio. When the band is made more stringent, by a reduction in the allowable variance, the organism reacts by decreasing response variance. This may come about simply by the tendency for a response to become more stereotyped as training progresses (Skinner, 1938), or by the differentiation process that suggests that an organism's responses will conform to the response requirements.

Decreasing response variability appears to be a convenient mode for the organism to modulate. This model would predict that variance reduction would follow increased band stringency, until the band becomes more stringent than the animal can discriminate, or that the low percentage of responses falling within the band would resemble extinction, at which time the tendency for extinction to generate greater response variance would negate the tendency for the band stringency to generate low variance. At this point, response variance would stabilize.

If the initial behavior begins with a more stringent reinforcement criteria (i.e., a narrower band) the organism will obtain reinforcement at a relatively lower rate. This will generate a higher response rate and subsequently poorer accuracy, tending to reduce even further the percentage of responses falling within the band. As the range of allowable variance is expanded (due to the widening of the band criteria), the reinforcement rate would increase concomitant with an increase in the percentage of in-band responses. Thus, by widening the band, an increase in response variance would occur due to the increased probability that these more variant responses will be reinforced.

By viewing the band discrimination task in this manner, the increased percentage of responses falling within the narrow non-reinforced margins can be readily understood and be predicted.

This effect was not noted for the Ss of group 3. One possible explanation for the lack of this effect is that this band, by virtue of its higher midpoint and by its narrow band particularly during the Phase III condition, tended to resemble more closely the condition of extinction than did the other two conditions. Thus, the effect of such a contingency would be to generate a wider response variance, particularly during the Phase III condition. The effect of

This extinction-like schedule would be to increase the variance. This increase in variance brought about by extinction would tend to counter any reduction of the variance that might have occurred as a result of the differentiation process.

Skinner (1938) discusses certain aspects of the differentiation process in terms of negative and positive induction. He states that when an organism is reinforced for a particular variant of a response, the reinforcement effect of the stimulus that follows it, is "inducted to" other variants of that response. In essence, the strength of adjacent responses are increased by virtue of their similarities with the reinforced response. Conversely, when a variant of a response is placed under extinction by virtue of it not being reinforced, the extinction effect imparted to that variant "inducts" to the reinforced variant, weakening that response. This view also adequately explains the above phenomena.

The variance of the target response referred to earlier can be considered the product of multiple reinforcements and extinction of certain variation of a response. As those sub-classes closer to the target response are placed under extinction, the effect of induction would tend to minimize

the variance of the target response, thus accounting for the increase noted in the now-reinforced margins of the band. The similarity of this process to the algebraic summation by stimulus generalization gradients should be apparent to the reader.

PEAK FORCE DISTRIBUTIONS

In general, the distributions of peak force in the present study did not show clear modes in or near the reinforcement band. In most instances, modal frequencies occurred at the 5g lower limit of response threshold. Notterman and Mintz (1965) report similar experimental procedures in which such in-band or near band modes were formed. Herrick (1964), using a displacement apparatus, but incorporating a similar band procedure, corroborated the Notterman and Mintz findings.

There are a number of possible explanations for these differences. The apparatus used in the present study had a maximum frequency response of 5 responses/sec. This compares to a maximum frequency response of from 3-4 responses/sec for the equipment used by Notterman and Mintz. Although largely speculative, if the emission of low force responses tended to correlate with shorter IRT's, the systematic exclusion of short IRT's by the Notterman and Mintz apparatus could account for the large number of at or slightly above

threshold responses obtained in the present study.

A second difference between the two is procedural. The experiments emanating from the Notterman laboratory were designed with a threshold of either 2.5g or 3g, as compared to a 5g threshold used in the present study. The use of a 2.5g threshold would tend to favor the discriminability of threshold versus in-band responses, particularly since all Ss were given initial CRF acquisition training at threshold prior to being placed on the band schedule.

In general, analysis of mean peak force responses calculated from the peak force frequency distributions indicate a consistent increase in peak force as band width is made more stringent. Additionally, high band midpoints tended to generate high mean peak forces as well. These findings are consistent with those of Notterman and Mintz (1965), Mllion, Fowler, and Notterman (1970) and Herrick (1964). The authors all reported modal frequencies at or just below the lower limit of the band in effect. Since a symmetrical band closing procedure actually raises the lowest peak force being reinforced, the increase in mean peak force, or in the Herrick study, displacement, is not surprising.

A general flattening of the distributions was noted

as the Ss of group 1 were shifted to increasingly more stringent band widths. Low force responses tended to decline in frequency while high force responses tended to increase. These findings are consistent with the notion that a lower percentage of reinforced responses tends to cause an increase in response force, through the extinction effect.

This same effect is noted for the Ss of group 2 who were switched to increasingly less stringent band criteria, and also most strikingly, with the Ss of group 3. The dramatic increase in high force responses and concomitant decrease in low force responses during the Phase III contingency of group 3, strongly supports the notion that experimental conditions most closely approximating extinction, tend to generate a large response variance as well as higher peak forces.

Examination of the extinction distribution generated by two animals in each group during the Phase IV condition indicate that those groups previously reinforced for higher force responses tended to generate higher force responses during extinction. CRF animals however, did not show as clear a trend, as those groups tended to generate similar distributions of peak force. Apparently, five days of CRF training at threshold is sufficient to nullify the differential effects of various band contingencies. In agreement with

data published by Notterman and Mintz (1965), animals run on an extinction schedule tend to generate higher peak force values than those animals run on CRF.

Notterman and Mintz (1965) report that force elevation occurs with extinction. Contrary to their findings, the data obtained in the present study indicates that in addition to the force elevation, low force responses also tend to increase with some animals.

A possible explanation rests with the fact that the variability of responding increases during extinction. This has been shown by Herrick (1964) as well as by others. If the population of low force responses is low to begin with, then the increased variability would tend to increase the percentage of high force responses generated during extinction. However, if the population of low force responses is relatively high to begin with, then an increase of variability would tend to spread the distribution of forces higher and lower. This would create an elevation in the relative frequency of responses at the low end, as well as the high end of the distribution. Compared with the Notterman and Mintz findings, the data of the present study appear to contain relatively high percentages of low force responses and at the same time, lack the characteristic peaking previously observed in studies of this type. The

extinction procedure would then be predicted to increase the variability around the band and would therefore produce elevations of frequencies at both the high and the low ends of the distribution.

EXTERNALLY IMPOSED RATIO SCHEDULES AND PEAK FORCE

The parameters of Experiment 1 allowed some property of the response itself to determine the probability of a reinforcement. Under these conditions the organism's probability of reinforcement is directly related to the degree to which emitted response conformed to the criteria of reinforcement. The schedule in effect can be considered as being a response induced schedule. It is also possible, and indeed more commonly done in operant research, to specify reinforcement probability externally through the imposition of a reinforcement schedule. These probabilities are either determined by time, number of responses made or some random function.

Under these conditions, the occurrence of a reinforcement is a fortuitous event, not correlating with any particular sub-class of the response. Therefore, each member of the sub-class under partial reinforcement, has the same probability of being reinforced. One would not expect to see a change in the distribution of peak force under these conditions, since no variant would be systematically

reinforced or extinguished.

If a differential reinforcement schedule is superimposed on an externally imposed random ratio schedule, then the occurrence of reinforcement would both be a function of the degree to which a response conformed to the reinforcement criteria, as well as a fortuitous coincidence between that criterion response and the externally imposed reinforcement schedule. Experiment 2 allowed for the observation of this condition.

Observation of the mean peak force distributions obtained from both groups of Experiment 2 reveal an interesting effect. Little if any change in distribution is noted when the Ss of group 1 were shifted from the initial 100 percent reinforcement schedule to the 50 percent random ratio reinforcement schedule. However, a rather striking change in ~~distribution~~ is noted for the Ss of group 2 when they were switched from 50 percent random ratio reinforcement schedule to the 100 percent reinforcement schedule.

What is seen is a dramatic increase in the percentage of low force responses (here considered to be those responses falling below the band), along with a moderate but consistent reduction in above band responses. It appears that a group originally run on a 50 percent random ratio

schedule and then subsequently changed to 100 percent reinforcement, demonstrates two relatively dramatic changes. The first is that rate drops quite low, while the second is that peak forces also drop quite low.

To put it more concretely, when an organism is on a given experimental condition and is being reinforced approximately half the time for a response variant occurring with a .2 probability, that organism is getting reinforced approximately one in ten times. When the reinforcement ratio is increased to 100 percent that organism is now reinforced one out of every five times. When this happens, peak forces decline and the rate decreases. The dynamics of the change in the rate have been explained adequately by Notterman and Mintz (1965).

Mintz (1962) pointed out that low forces following reinforcement in a fixed ratio schedule were frequently lower than the low forces the same animals generated under CRF. In some sense, the force reducing properties of reinforcement reported by Notterman and Mintz (1965) may be in some measure more effective when they constitute a contrast relative to infrequent reinforcement. The fixed ratio experiment of Mintz (1962) suggested that as soon as reinforcement occurs, the forces exerted by an organism drop very sharply. A reduction of forces exhibited by an organism under a fixed ratio schedule is actually adaptive in the sense that the organism is exerting less force, but still meeting the criteria for counting out the ratio.

In the band contingency, a reduction of force may very well cause the animal to be responding outside of the reinforcement criteria.

The mitigating factor between these two experimental procedures consists of the proportional reinforcement study reported by Notterman and Mintz (1965). They demonstrated that a reduction in force occurs concurrently with an increase in reinforcement. Their procedure saw animals shifted from a condition of one reinforcement pellet for an 8g or above response, to one pellet for 8g plus an increment of one pellet for each additional 2g of force. The net result of this procedure was a force decline.

If one conceptualizes the random ratio reinforcement contingency as being, in a sense, proportional reinforcement, the overall effect of going from 50 to 100 percent is an increase in the amount of reinforcement for a given amount of work. Apparently there seems to be an effect which implies that given a particular condition, the addition of more reinforcement will tend to push forces down. Thus, the organism receives more reinforcement but generates lower forces. The present literature suggests that if the animal is exposed to a relatively sparse reinforcement contingency, the addition of more reinforcement tends to produce a decline in emitted force. The question remains as to why this effect does not work in reverse for

the other group of Experiment 2.

This dicotomy can perhaps be explained by assuming a non-linearity relating force to the frequency of reinforcement. If an animal is receiving reinforcement infrequently, or to look at it another way, if the frequency of non-reinforced responses is high, than the force generated by the organism tends to rise to some reference or adaptive level. This level is probably a function of organismic variables as well as the rate of reinforcement. Once this reference level is reached, a reduction in the frequency of reinforcement has little if any effect on emitted force. On the other hand, if reinforcement is made more frequent, then the forces will tend to drop. This explains the non-linear nature of the model, which admittedly was created from the present data. However, there is some measure of consistency between the present data and the data reported earlier. Mintz (1962) suggests that an asymptote of force is reached after about six or seven responses into the cycle. It is true that these data are derived from cyclical schedules while the present data is variable, but nevertheless a certain degree of consistency remains. The Mintz data also suggests in some measure, that if the reinforcement is occurring at a relatively low frequency, forces tend to reach their asymptote relatively quickly, while the occurrence of reinforcement brings them down

abruptly. A similar finding was reported by Skinner (1938). In addition, the band contingency of the present study puts a constraint on the upper limit of force elevation.

The suggested model has two major points; 1) if reinforcement is sparse then a distribution with relatively high forces is obtained and 2) if the rate of reinforcement is increased, then force tends to drop. Apparently there is no corollary which states that given sparse reinforcement, a sparser rate yet will push forces up higher. This is the non-linearity aspect of the model.

Finding corroboration for this model is difficult since none of the reported studies involved a combination of band criteria plus random ratio reinforcement schedules. However, the 8g criteria, force proportional reinforcement study of Hotterman and Mintz (1965) comes fairly close to it, in the sense that it is at least consistent with one part of the model. They demonstrated that with an increase in the rate of reinforcement, forces tend to go down. The Mintz (1962) study is consistent with the model in the sense that whenever reinforcement occurs (at least in the cyclical procedure) forces tend to decrease. It also indicated that in a sequence of unreinforced responses, forces tend to reach an asymptotic level relatively quickly. In a sense, when an organism is switched from a 50% to a 100% ratio reinforce-

ment schedule, he begins a string of unreinforced responses which may be progressively force elevating. However, during the 100% reinforcement contingency this string of unreinforced responses is interrupted sooner. The forces are in the process of being elevated, but what is happening is that on the average they are getting stopped on their progression half way up in the sequence. Since the reverse effect is not seen for the other group of animals of Experiment 2, this may not be a bi-directional phenomena.

These data suggest further examination of roughly equivalent sparse schedules, to determine if they would indeed generate parametric increases in force. It is possible that a sparse schedule generates high forces, while a shift to greater sparsity, given that the schedule is already sparse, may not generate higher forces yet. On the other hand, an increase in the rate of reinforcement may very well bring down the level of force. In some sense the reference level alluded to previously, may be an adaptation to a sparse schedule which is already dictated by the species, the situation, etc.

Once the reference or adaptation level has been reached, in other words, once the going rate of reinforcement and relative frequency of reinforcement of force are set, then changes in terms of greater frequency of reinforcement will

have an effect. It may well be that rates of change in terms of reinforcement in the negative direction, may be different in kind from rates of change of reinforcement in the positive direction.

EFFECT OF REINFORCEMENT RATIO ON ACCURACY

The results quite clearly indicate that the 100 percent reinforcement condition was not superior in maintaining in-band responses when compared with the 50 percent random ratio schedule. These findings were corroborated by a series of unpublished studies using human Ss with a similar experimental design (Samuels, 1971).

A possible explanation for this seeming indifference of accuracy to the reinforcement ratios employed in the present study, may be that the organism did not discriminate a condition of 50 percent reinforcement as being different from a condition of 100 percent reinforcement, at least in the short run. That is, being reinforced for every other in-band response is not very much different from being reinforced for every in-band response, particularly when the relative frequency of in-band responses is moderately low to begin with. (About 20 percent for each group.) It is possible that if the reinforcement ratio was reduced to 10 percent, then the degree of accuracy would decrease, but there is no data available for this speculation to be confirmed.

IMPLICATION OF PRESENT RESEARCH

This data suggests that in order to maximize organismic

reinforcement rate, i.e., a measure of overall successful performance, it is best to maximize the percentage of reinforcement early in training and then reduce it, rather than to begin with a lower percentage of reinforcement and increase it later. This would also tend to maximize overall task efficiency, i.e., the amount of reinforcement needed to establish optimum task success. Although the highest rate of reinforcement appears to be generated when an organism is reinforced 100 percent of the time (13.9 reinforcement/min for group 1, Phase I equivalent to 13.9 in-band responses/min) a rate almost as high (10.8 reinforcements/min for group 1, Phase II), is generated while the total number of reinforcements are reduced by 50 percent, (yielding 21.6 in-band responses/min). Taken with the findings of Experiment 1, the strategy for establishing the 100 percent random ratio reinforcement schedule, would be to start the organism on a stringent band and then, after stability is reached, narrow the band so as to make the reinforcement criterion more stringent. This would tend to increase the percentage of in-band responses. After stability is reached, the percentage of reinforcement could then be reduced to at least 50 percent. This would result in a modest reduction of reinforcement rate for the organism while accuracy would remain relatively stable. At the same time, the rate of criterion responses would increase, making the overall rate of in-band responses (however, now only reinforced 50 percent of the time) higher.

Table 1

Experimental Design for Experiment 1

(Band in effect expressed as grams peak force)

Band in Effect

Group and subject	Phase I	Phase II	Phase III	Phase IV
1 RB 1				extinction
RB 2	12-22 g	14-20 g	15-19 g	crf
RB 3				crf
RB 4				extinction

2 RB 9				crf
RB 10	15-19 g	14-20 g	12-22 g	extinction
RB 11				crf
RB 13				extinction

3 RB 5				crf
RB 6	18-28 g	20-26 g	22-24 g	extinction
RB 7				extinction
RB 8				crf

* Probability of reinforcement for within band response = 100%

Table 2

Assigned probability of reinforcement
and experimental design for experiment 2.

Group and subject	Phase I	Phase II
1 R 1 R 3 R 5 R 7 R 9 R 11	100 %	50 %

2 R 2 R 4 R 6 R 8 R 10 R 12	50 %	100 %

* Reinforcement eligibility criteria was 14-20 grams for all conditions.

Table 3

Mean response rate (responses/min)

Reinforcement band

Group	12-22 grams	14-20 grams	15-19 grams
1 (decreasing width)	42.3	66.5	84.3
2 (increasing width)	45.7	64.0	74.3

Reinforcement band

Group	18-28 grams	20-26 grams	22-24 grams
3 (decreasing width)	47.4	68.9	122.5

Table 4

Percentage of total responses within specified force ranges during Phases I, II, and III for rats of group 1

		RB 1		
		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>33.4</u>	18.8	12.4
	14-20	45.1	<u>26.6</u>	18.3
	15-19	42.4	22.0	<u>14.8</u>

		RB 2		
		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>33.7</u>	18.3	13.2
	14-20	38.6	<u>24.1</u>	15.1
	15-19	40.6	24.9	<u>15.6</u>

		RB 3		
		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>27.7</u>	15.2	9.2
	14-20	28.9	<u>18.7</u>	12.4
	15-19	29.4	16.6	<u>11.4</u>

		RB 4		
		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>26.9</u>	17.3	10.5
	14-20	30.7	16.6	10.8
	15-19	38.2	23.6	<u>16.0</u>

Table 5

Percentage of total responses within specified force ranges during Phases I, II, III for rats of group 2

band in effect

RB 9		% in band		
		12-22	14-20	15-19
12-22		<u>33.4</u>	18.4	10.3
14-20		33.1	<u>20.0</u>	15.1
15-19		23.7	15.0	<u>9.4</u>

band in effect

RB 10		% in band		
		12-22	14-20	15-19
12-22		<u>34.6</u>	20.1	13.9
14-20		31.7	<u>19.7</u>	12.8
15-19		34.7	21.5	<u>14.2</u>

band in effect

RB 11		% in band		
		12-22	14-20	15-19
12-22		<u>31.3</u>	18.4	12.5
14-20		35.8	<u>21.4</u>	14.6
15-19		42.5	24.4	<u>15.5</u>

band in effect

RB 13		% in band		
		12-22	14-20	15-19
12-22		<u>36.7</u>	21.2	14.1
14-20		39.1	<u>23.5</u>	15.8
15-19		39.3	24.1	<u>16.0</u>

Table 6

Percentage of total responses within specified force ranges during Phase I, II, and III for rats of group 3

		RB 5		
		% in band		
		18-28	20-26	22-24
band in effect	18-28	<u>20.7</u>	13.4	3.8
	20-26	24.2	<u>15.6</u>	3.9
	22-24	29.5	16.9	<u>5.5</u>

		RB 6		
		% in band		
		18-28	20-26	22-24
band in effect	18-38	<u>27.3</u>	15.2	3.5
	20-26	27.8	<u>17.0</u>	6.3
	22-24	29.6	19.0	<u>6.4</u>

		RB 7		
		% in band		
		18-28	20-26	22-24
band in effect	18-28	<u>29.0</u>	16.6	5.2
	20-26	25.4	<u>14.9</u>	5.3
	22-24	22.4	12.8	<u>4.8</u>

		RB 8		
		% in band		
		18-28	20-26	22-24
band in effect	18-28	<u>27.2</u>	14.5	4.2
	20-26	24.8	<u>15.0</u>	4.6
	22-24	31.5	18.4	<u>6.0</u>

Table 7

Percentage of total mean responses within specified force ranges during Phases I, II and III

		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>30.4</u>	17.4	13.8
	14-20	35.8	<u>21.5</u>	14.2
	15-19	37.7	21.8	<u>14.5</u>

Group 1, wide to narrow

		% in band		
		12-22	14-20	15-19
band in effect	12-22	<u>34.0</u>	19.5	12.7
	14-20	35.1	<u>21.2</u>	14.6
	15-19	35.8	21.5	<u>14.1</u>

Group 2, narrow to wide

		% in band		
		18-28	20-26	22-24
band in effect	18-28	<u>26.0</u>	14.9	4.2
	20-26	25.5	<u>15.6</u>	5.0
	22-24	<u>28.5</u>	16.8	<u>5.2</u>

Group 3, wide to narrow

Table 8

Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 1 (Low band, wide to narrow)

Outer margin = 12-14 g plus 20-22 g.
 Middle margin = 14-15 g plus 19-20 g.

		RB 1 Band in effect		
		12-22	14-20	15-19
Margin	Outer	14.6	18.5	20.4
	Middle	6.4	8.6	7.2

		RB 2 Band in effect		
		12-22	14-20	15-19
Margin	Outer	15.4	14.5	15.7
	Middle	5.1	9.0	9.4

		RB 3 Band in effect		
		12-22	14-20	15-19
Margin	Outer	12.5	10.2	12.6
	Middle	6.0	6.3	5.2

		RB 4 Band in effect		
		12-22	14-20	15-19
Margin	Outer	9.6	14.1	14.6
	Middle	6.8	5.8	7.6

		MEAN Band in effect		
		12-22	14-20	15-19
Margin	Outer	13.0	14.3	15.8
	Middle	6.1	7.4	7.3

Table 9

Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 2 (Low band, narrow to wide)

Outer Margin = 12-14 g plus 20-22 g.
 Middle margin = 14-15 g plus 19-20 g.

		RB 9 Band in effect		
		12-22	14-20	15-19
Margin	Outer	15.0	13.1	8.7
	Middle	8.1	4.9	5.6

		RB 10 Band in effect		
		12-22	14-20	15-19
Margin	Outer	14.5	12.0	13.2
	Middle	6.2	6.9	7.3

		RB 11 Band in effect		
		12-22	14-20	15-19
Margin	Outer	12.9	14.4	8.1
	Middle	5.9	6.8	8.9

		RB 13 Band in effect		
		12-22	14-20	15-19
Margin	Outer	15.5	15.6	15.2
	Middle	7.1	7.7	8.1

		MEAN Band in effect		
		12-22	14-20	15-19
Margin	Outer	14.5	13.8	11.3
	Middle	6.8	6.6	7.5

Table 10

Percentage of total responses falling within the "outer" and "middle" margins for Ss of group 3 ("High-band, wide to narrow")

Outer Margin = 18-20 g plus 26-28 g.
 Middle Margin = 20-22 g plus 24-26 g.

RB 5 Band in effect

	18-28	20-26	22-24
Outer	7.3	8.6	12.6
Middle	9.6	11.7	7.2

RB 6 Band in effect

	18-28	20-26	22-24
Outer	12.1	10.8	10.6
Middle	11.7	10.7	12.6

RB 7 Band in effect

	18-28	20-26	22-24
Outer	12.4	11.4	9.6
Middle	10.5	9.6	8.0

RB 8 Band in effect

	18-28	10-26	22-24
Outer	12.7	9.8	13.1
Middle	10.3	11.4	12.4

MEAN Band in effect

	18-28	20-26	22-24
Outer	11.1	10.1	11.5
Middle	10.5	10.8	10.1

Margin

Margin

Margin

Margin

Margin

Table 11

Index of force differentiation, percentage of rate change and product (absolute index of differentiation)

Phase I to Phase II

Group and subject	Index of force differentiation	x	Percentage of former rate	=	Absolute index of differentiation
(1)	RB 1	1.42	1.65		2.34
	RB 2	1.33	1.37		1.82
	RB 3	1.21	1.92		2.32
	RB 4	.96	1.32		1.27
(2)	RB 9	1.09	.75		.82
	RB 10	.98	1.04		1.02
	RB 11	1.16	.81		.94
	RB 13	1.11	.88		.98
(3)	RB 5	1.16	1.55		1.80
	RB 6	1.11	1.12		1.24
	RB 7	.89	1.53		1.37
	RB 8	1.03	1.55		1.60

Phase II to Phase III

Group and subject	Index of force differentiation	x	Percentage of former rate	=	Absolute index differentiation
(1)	RB 1	.81	1.35		1.09
	RB 2	1.02	1.24		1.27
	RB 3	.94	1.23		1.15
	RB 4	1.48	1.28		1.91
(2)	RB 9	.62	.77		.48
	RB 10	1.11	.69		.76
	RB 11	1.06	.76		.81
	RB 13	1.01	.66		.67
(3)	RB 5	1.43	1.68		2.39
	RB 6	1.00	1.75		1.75
	RB 7	.91	2.47		2.25
	RB 8	1.29	1.46		1.88

-97-
Table 12

**Index of force dedifferentiation, percentage of rate change
and product (absolute index of dedifferentiation)**

Phase III to Phase II

Group and subject	Index of force de- differentiation	X	Percentage of rate change	=	Absolute index dedifferentiated
(1)	RB 1	.83	.74		.61
	RB 2	1.03	.81		.83
	RB 3	.89	.82		.73
	RB 4	1.42	.78		1.10
(2)	RB 9	1.03	1.30		1.34
	RB 10	1.15	1.44		1.66
	RB 11	.87	1.32		1.15
	RB 13	.93	1.51		1.40
(3)	RB 5	1.09	.60		.65
	RB 6	1.16	.57		.66
	RB 7	.86	.41		.35
	RB 8	1.22	.68		.83

Phase II to Phase I

Group and subject	Index of force de- differentiation	X	Percentage of rate change	=	Absolute index dedifferentiated
(1)	RB 1	1.35	.60		.81
	RB 2	1.15	.72		.83
	RB 3	1.04	.52		.54
	RB 4	1.14	.78		.89
(2)	RB 9	1.34	1.33		1.78
	RB 10	.91	.96		.88
	RB 11	.88	1.24		1.09
	RB 13	.98	1.13		1.10
(3)	RB 5	1.17	.65		.75
	RB 6	1.02	.89		.91
	RB 7	.87	.65		.57
	RB 8	.91	.64		.59

Table 13

Mean reinforcement rate (reinforcements/min)

Group	Reinforcement band		
	12-22 grams	14-20 grams	15-19 gram
1 (decreasing width)	12.4	13.6	12.8
2 (increasing width)	15.6	13.6	10.7
Group	Reinforcement band		
	18-28 grams	20-26 grams	22-24 gram
3 (decreasing width)	12.4	11.0	7.2

Figure 1

Block diagram for the apparatus of Experiment 1

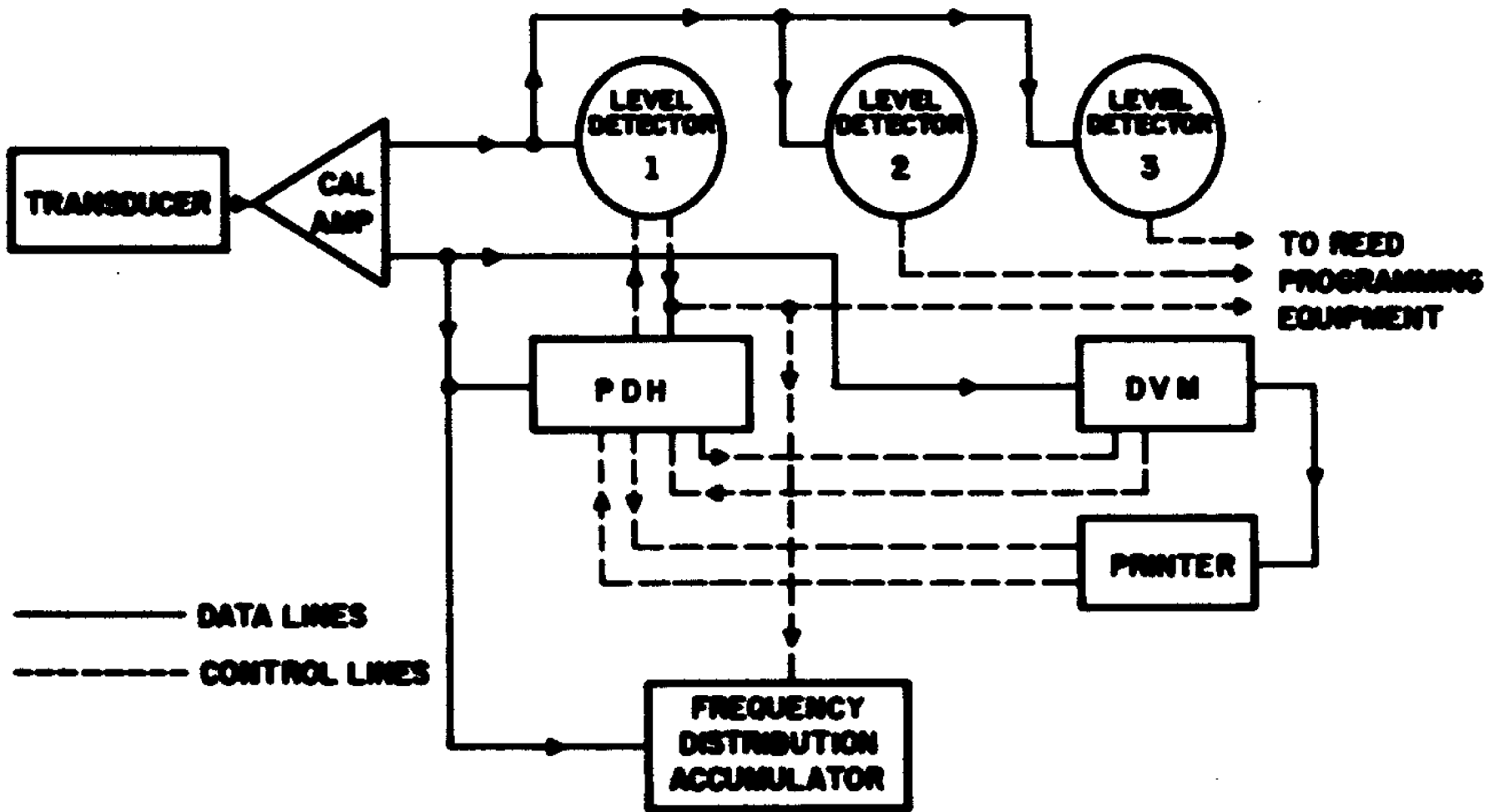


Figure 2

Individual response rates for the Ss of groups 1, 2 and 3 during Phases I, II and III of Experiment 1. Each data point is based on the mean of the last three days of each Phase.

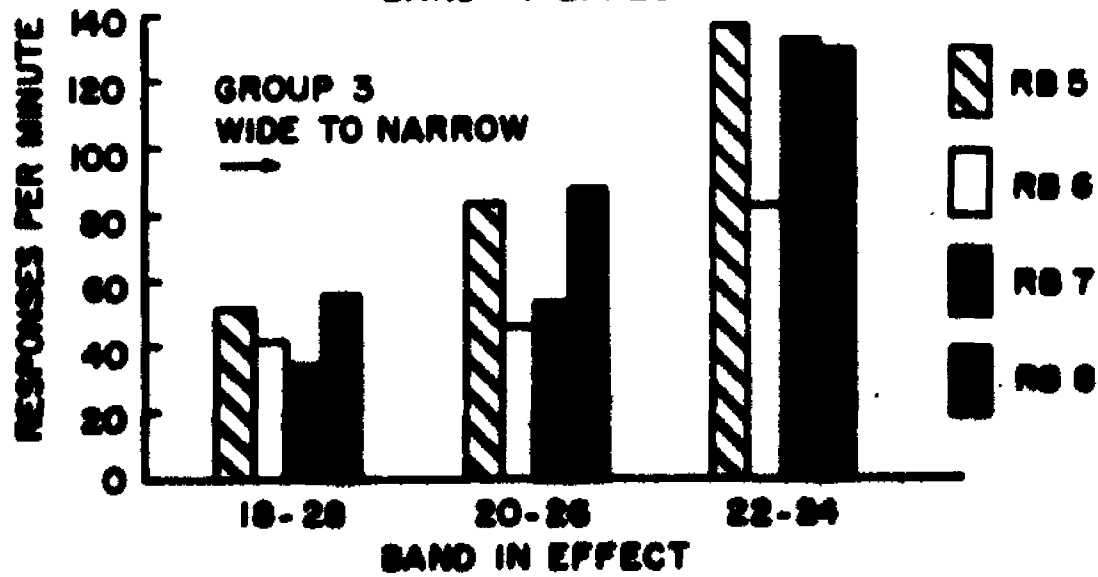
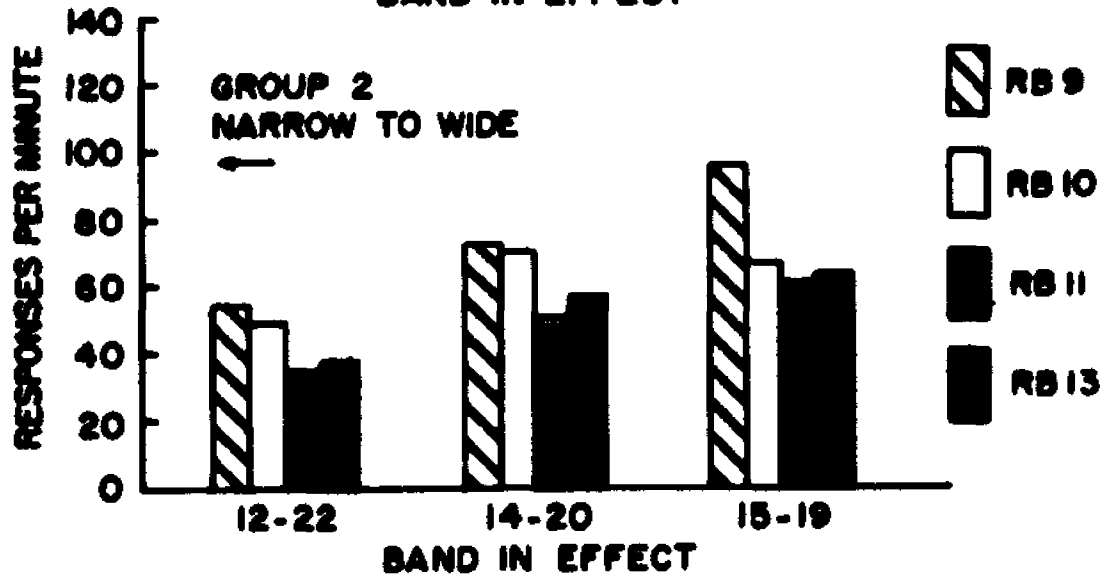
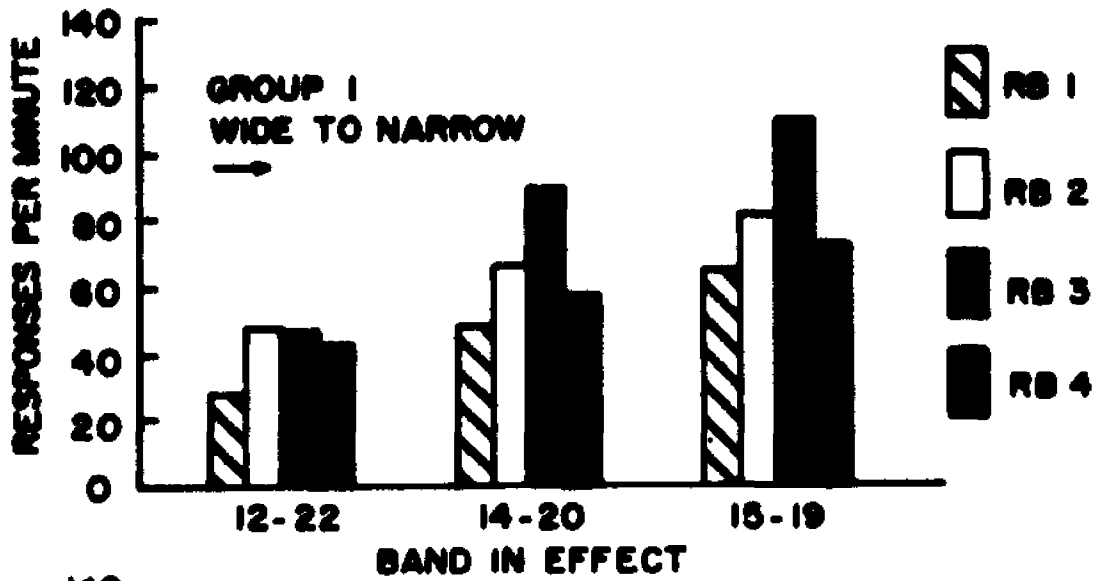


Figure 3

Peak force of response distributions for the Ss of group 1 during Phase I of Experiment 1. The band in effect for this condition was 12-22 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

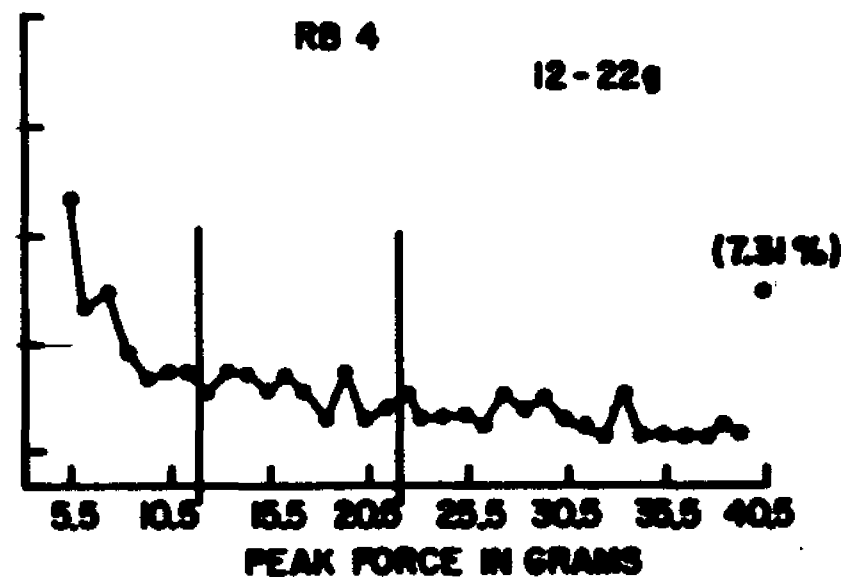
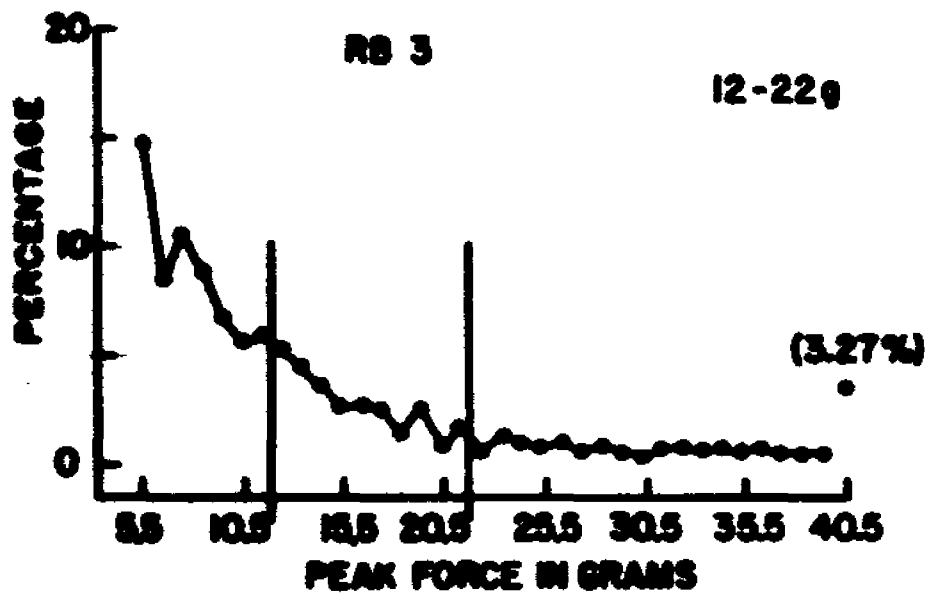
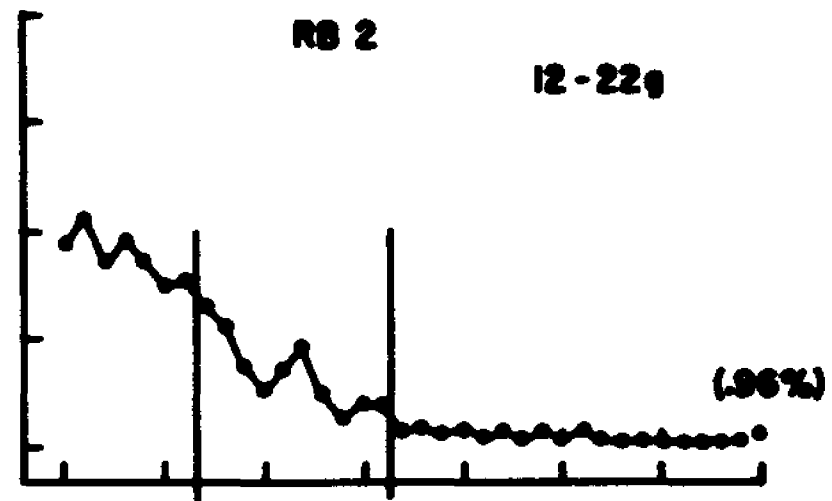
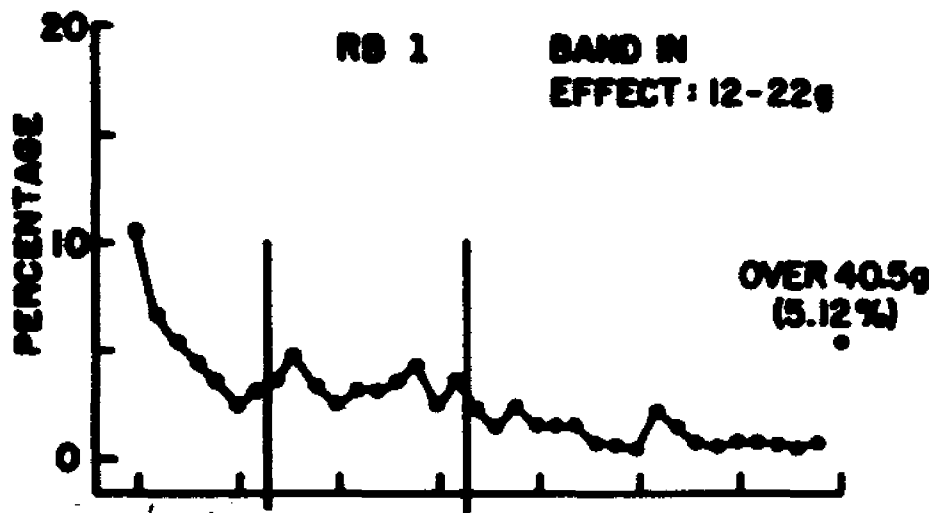


Figure 4

Peak force of response distributions for the Ss of group 1 during Phase II of Experiment 1. The band in effect for this condition was 14-20 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

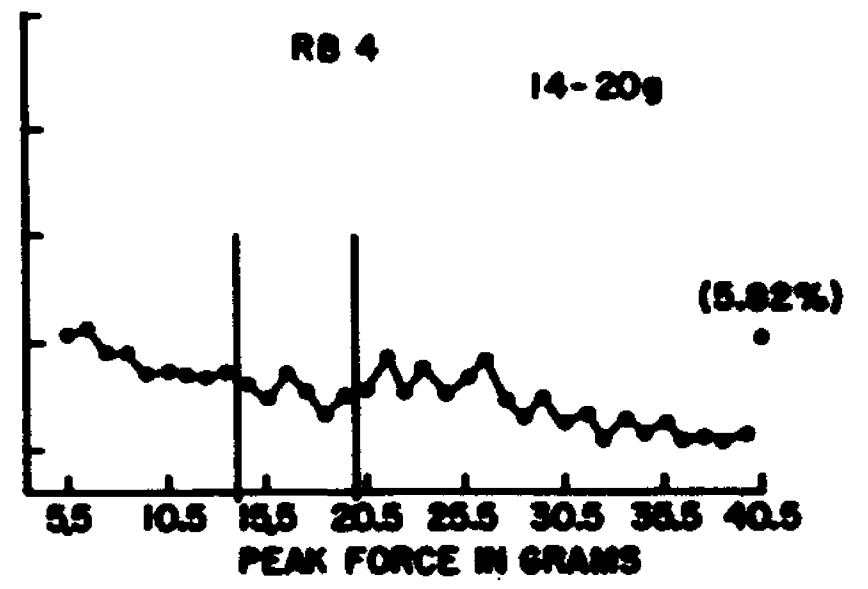
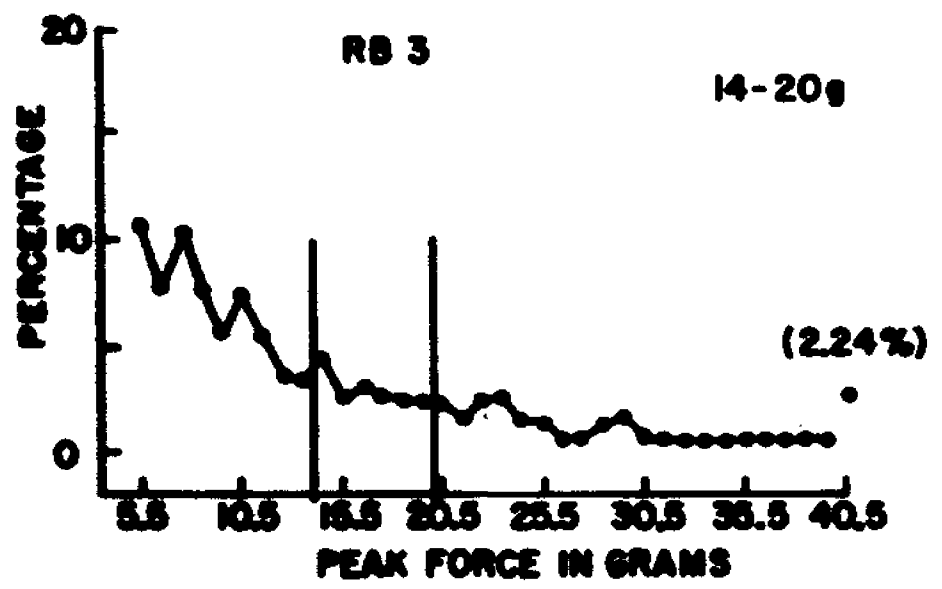
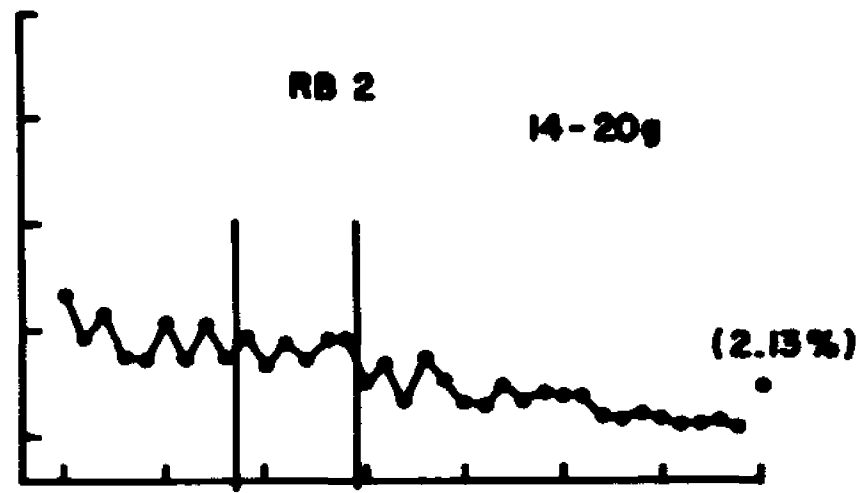
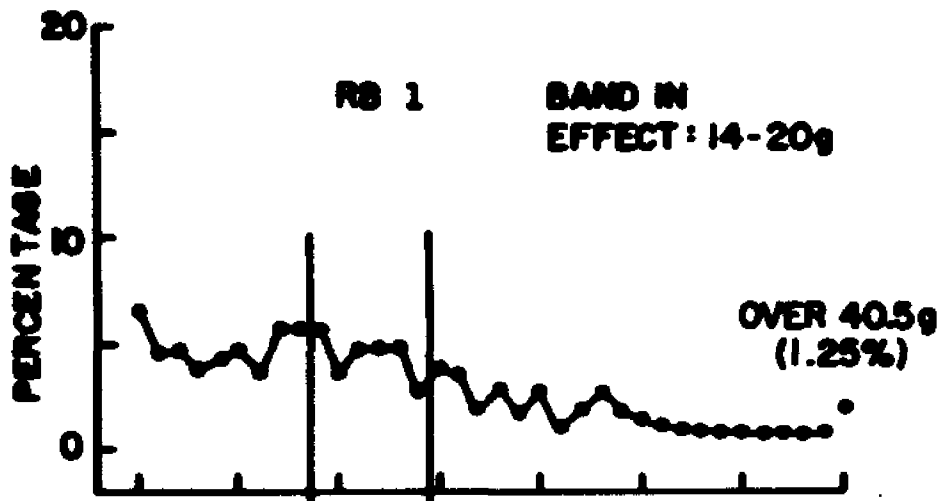


Figure 5

Peak force of response distributions for the Ss of group 1 during Phase III of Experiment 1. The band in effect for this condition was 15-19 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

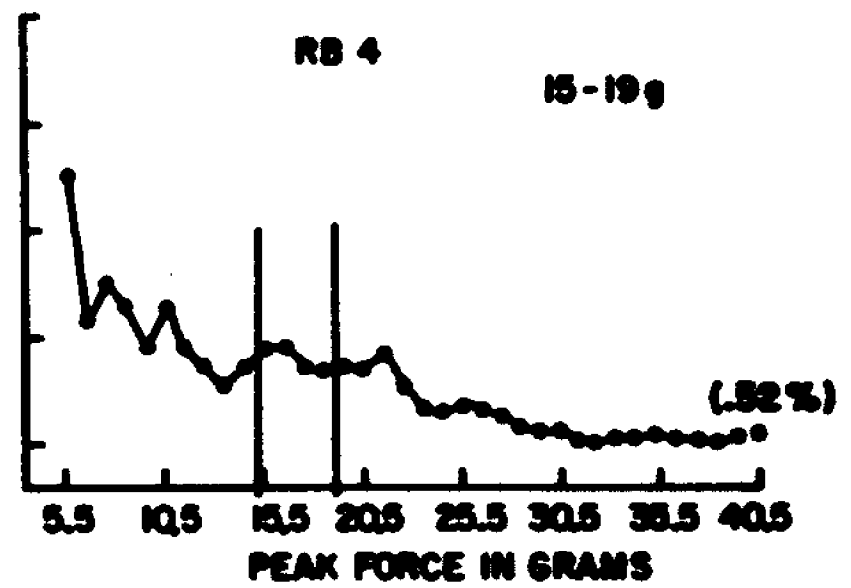
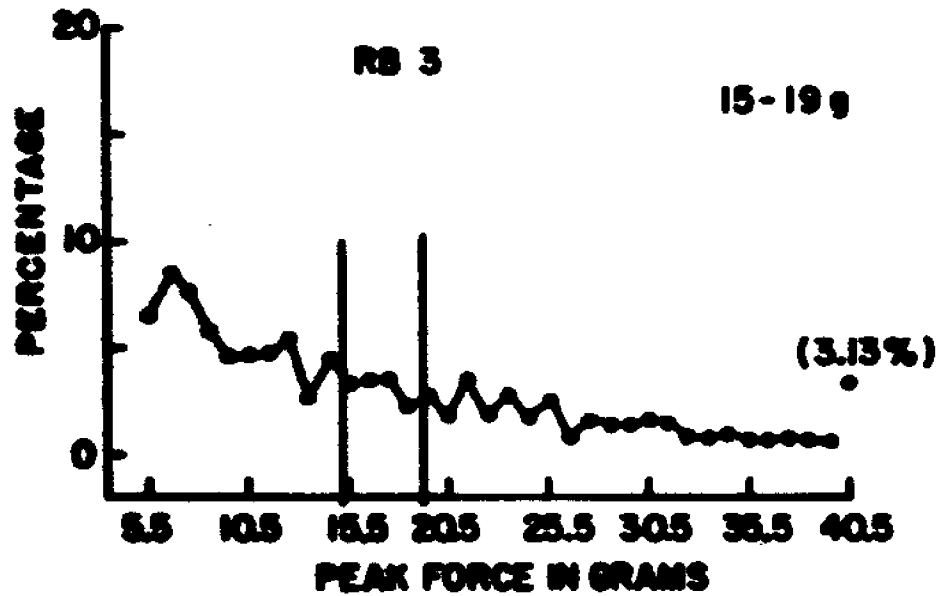
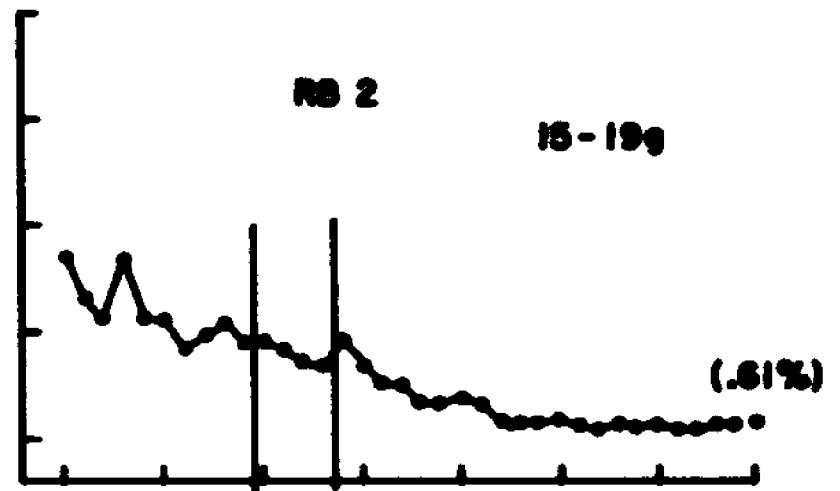
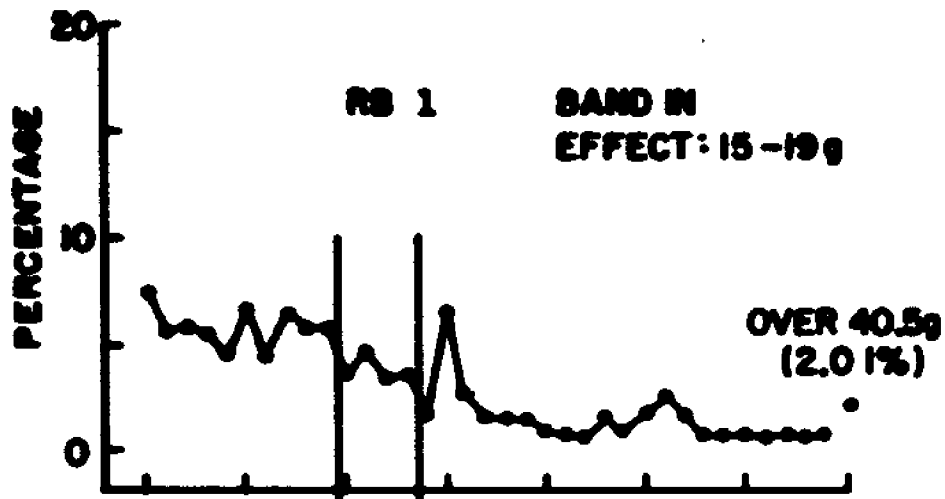


Figure 6

Peak force of response distributions for the Ss of group I, Phase IV, of Experiment 1. Ss RB 1 and 4 were run on extinction while Ss RB 2 and 3 were run on CRF.

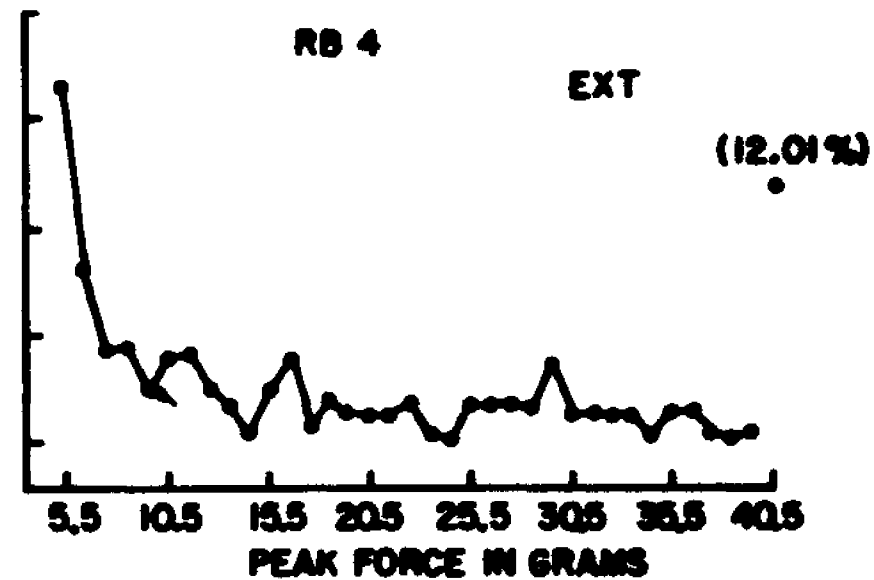
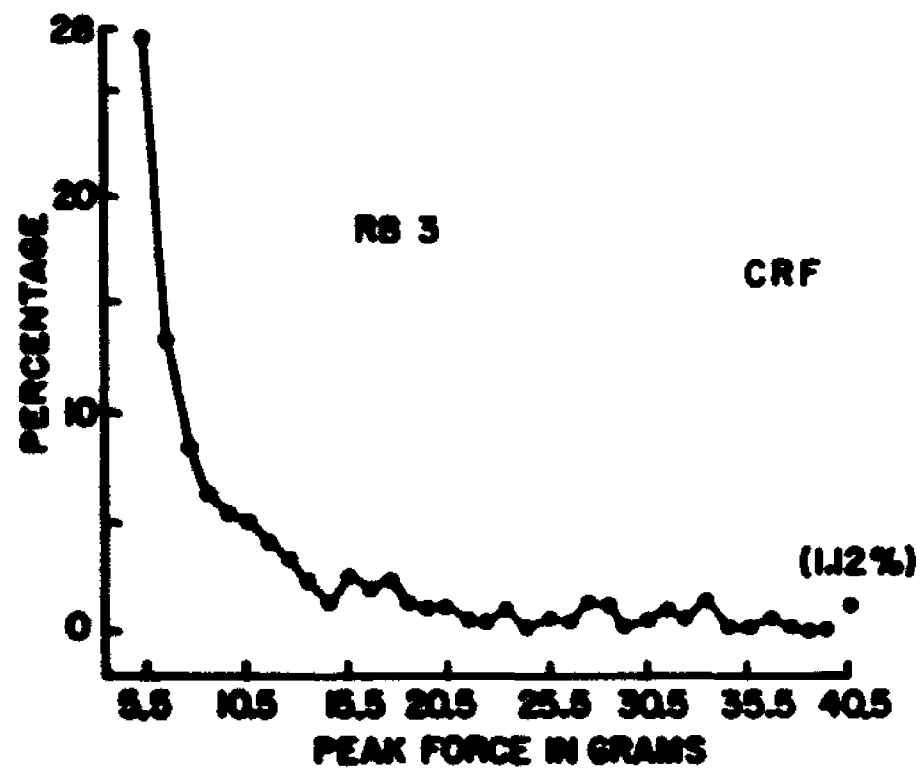
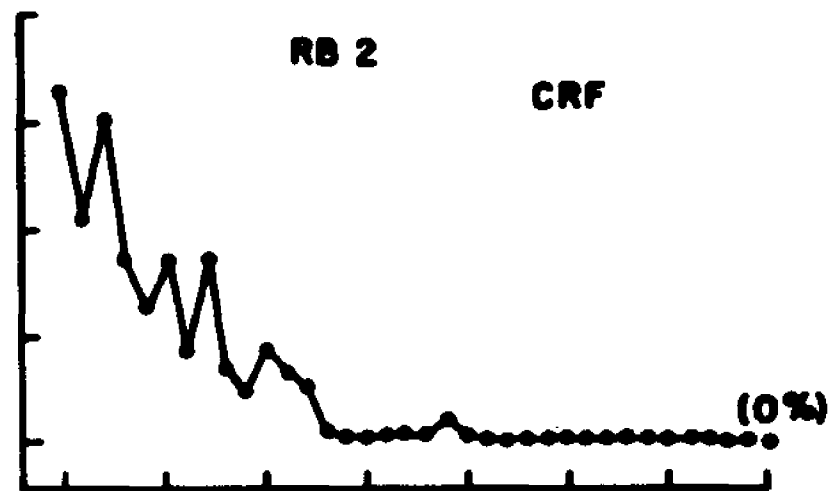
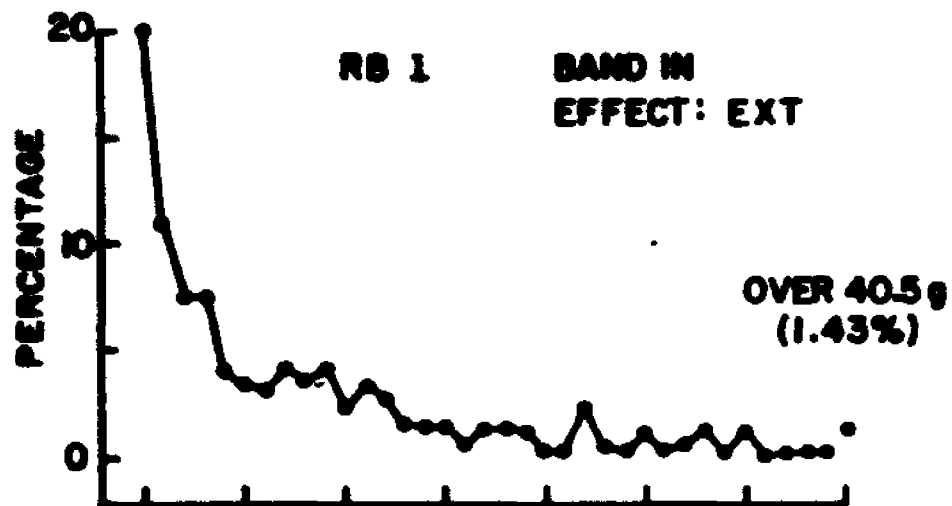


Figure 7

Peak force of response distributions for the Ss of group 2 during Phase I of Experiment 1. The band in effect for this condition was 15-19 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

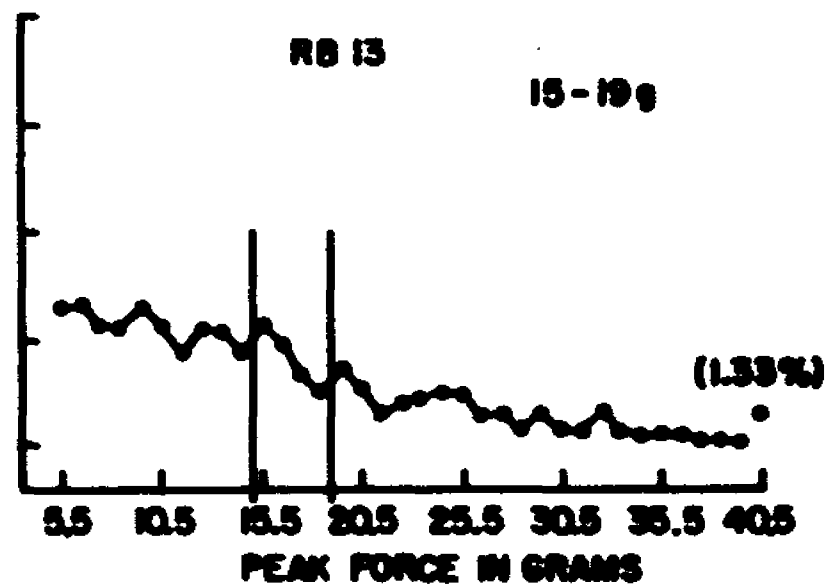
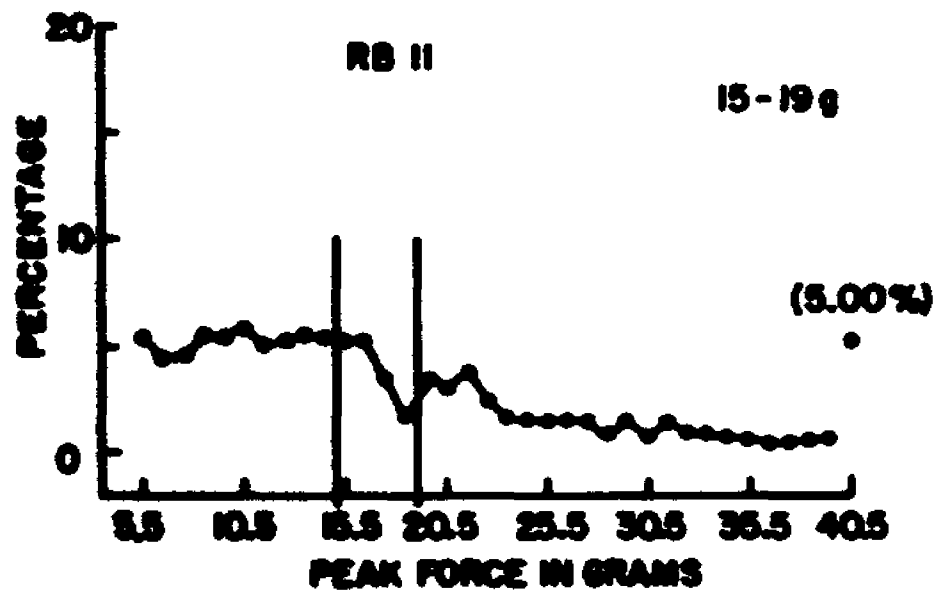
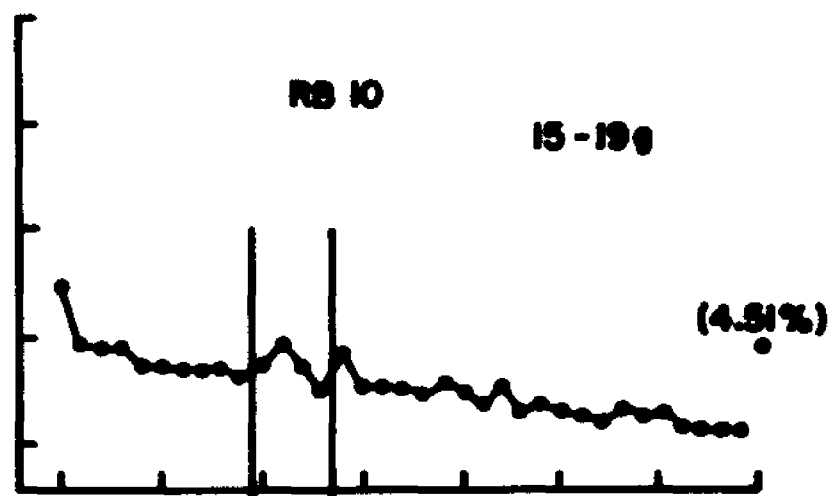
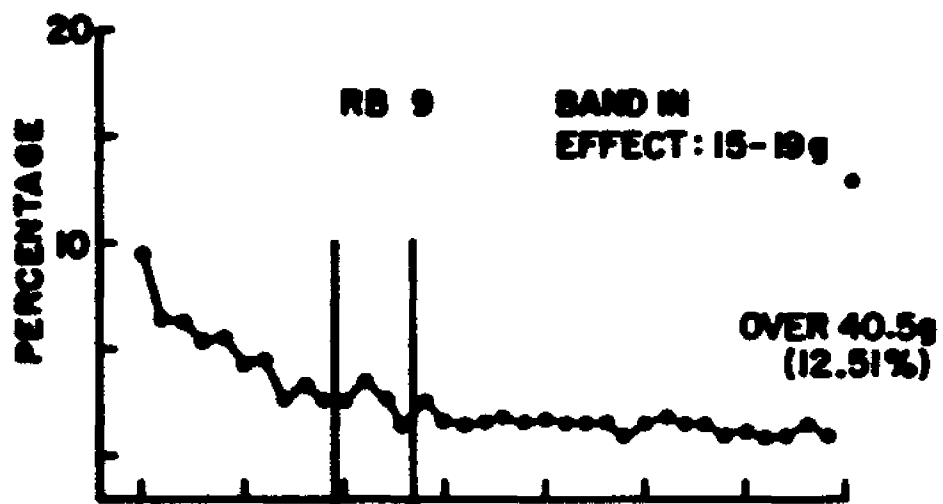


Figure 8

Peak force of response distributions for the Ss of group 2 during Phase II of Experiment 1. The band in effect for this condition was 14-20 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

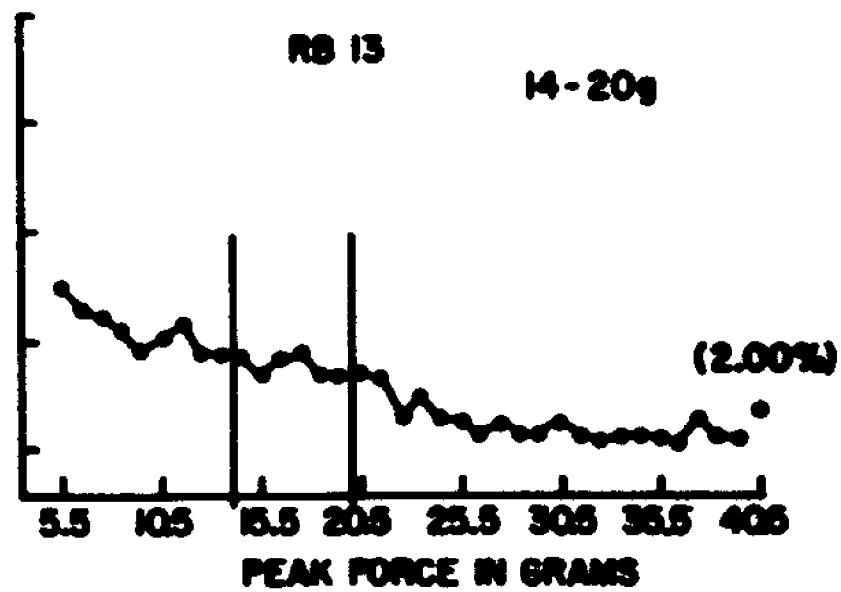
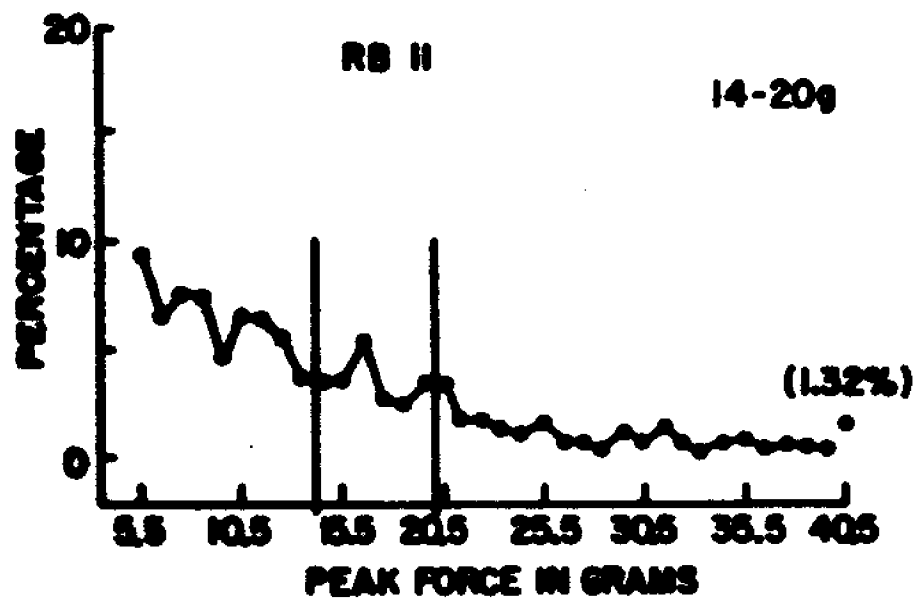
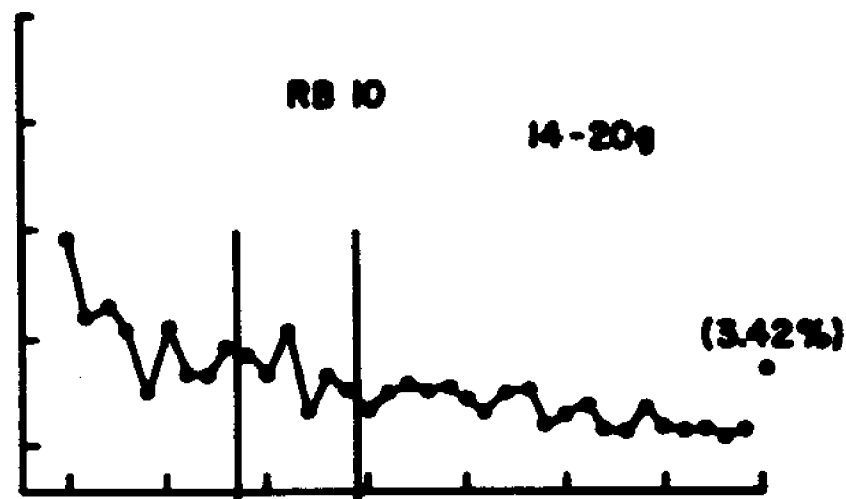
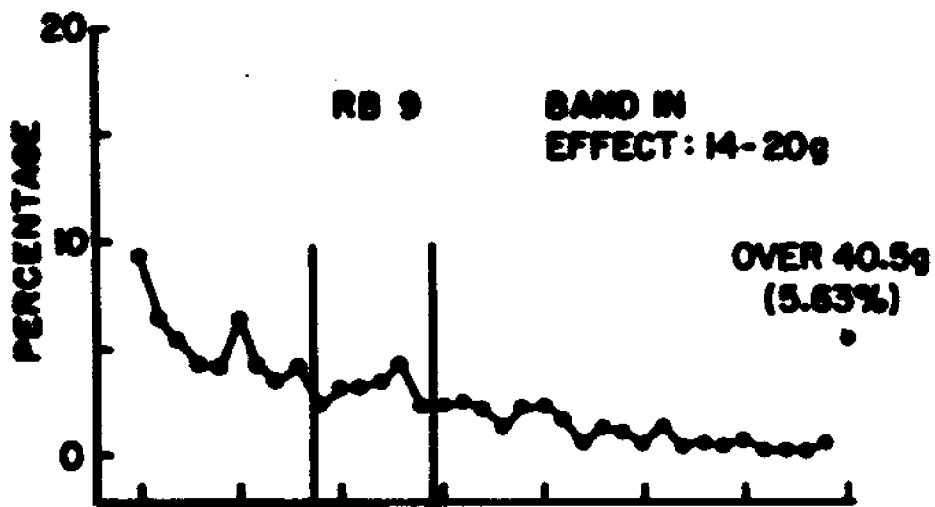


Figure 9

Peak force of response distributions for the Ss of group 2 during Phase III of Experiment 1. The band in effect for this condition was 12-22 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

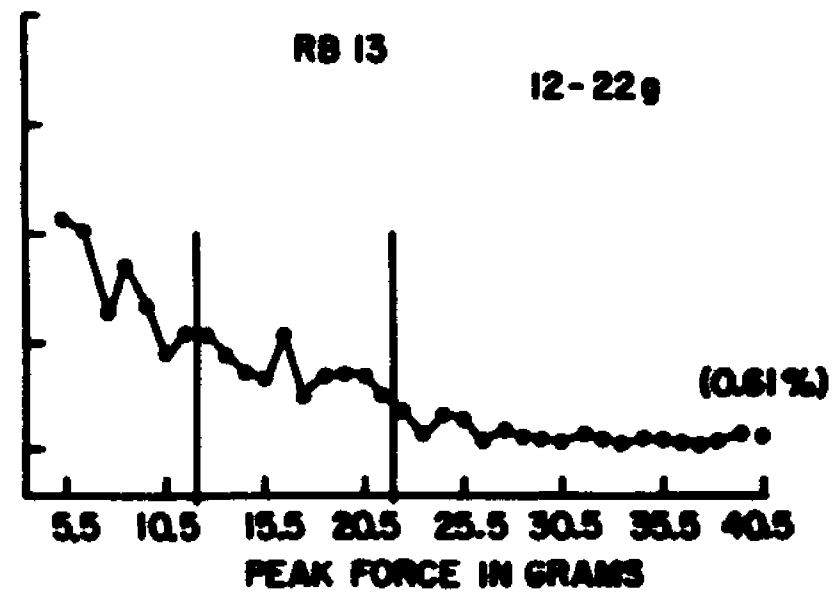
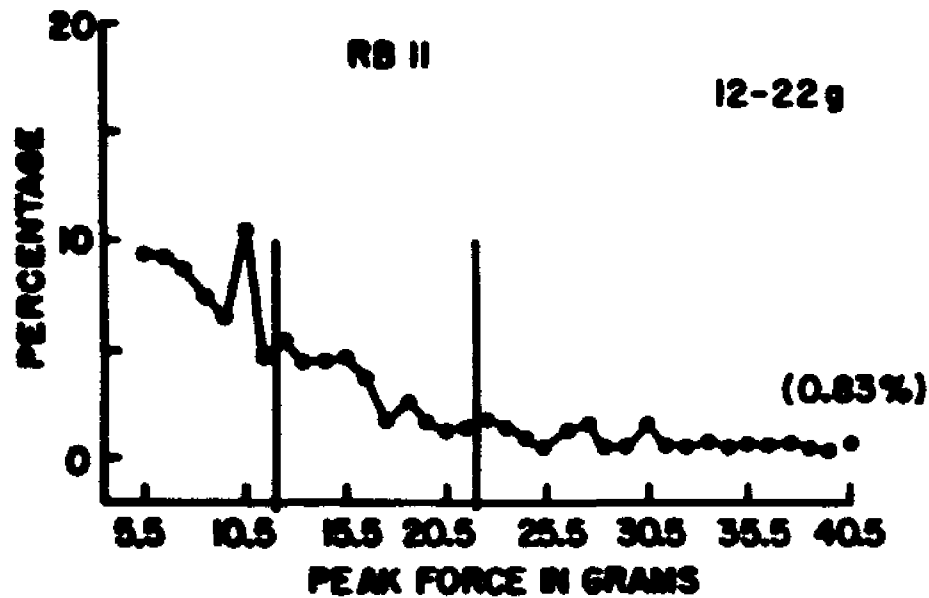
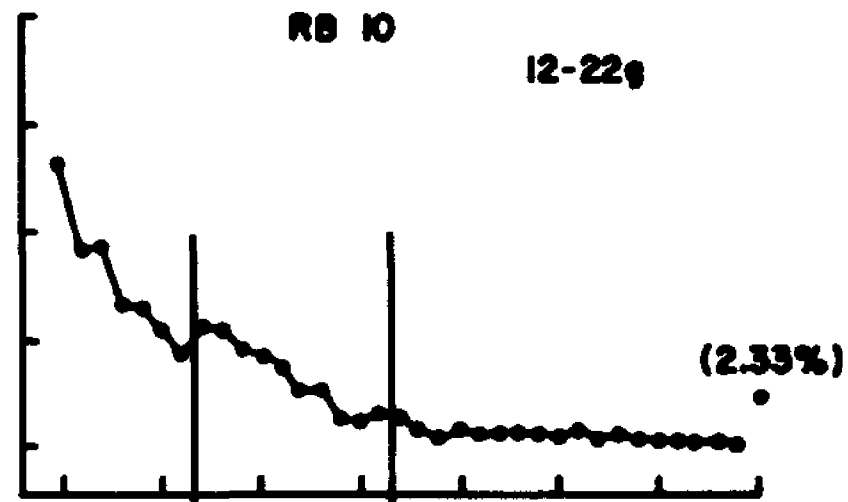
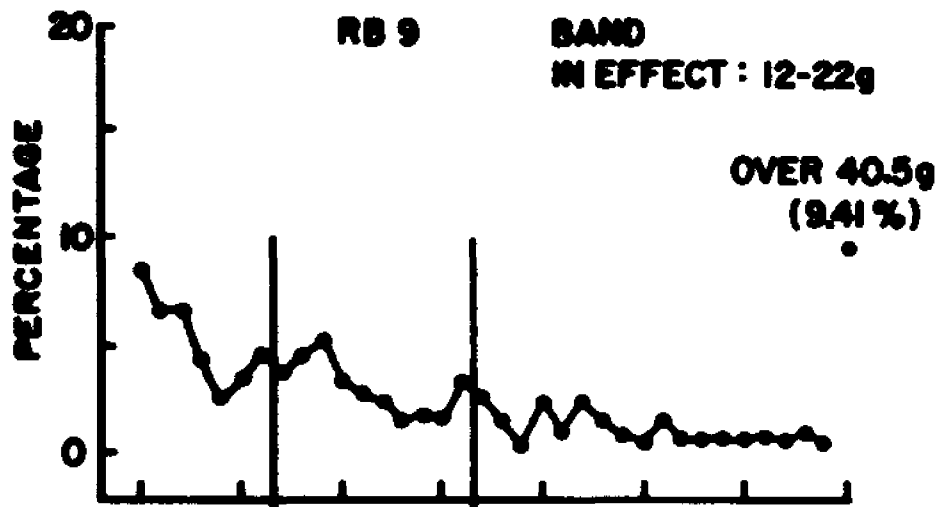


Figure 10

Peak force of response distributions for the Ss of group II, Phase IV, of Experiment 1. Ss RB 10 and 13 were run on extinction while Ss RB 9 and 11 were run on CRF.

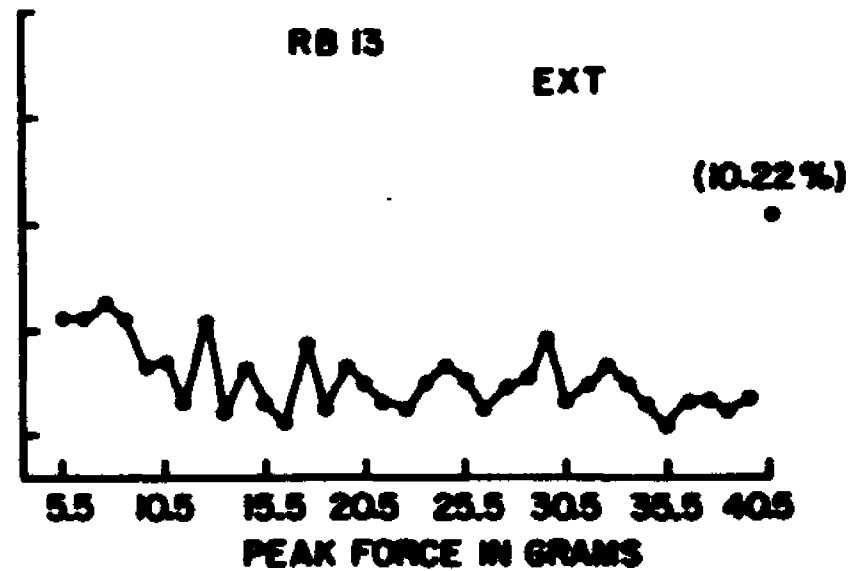
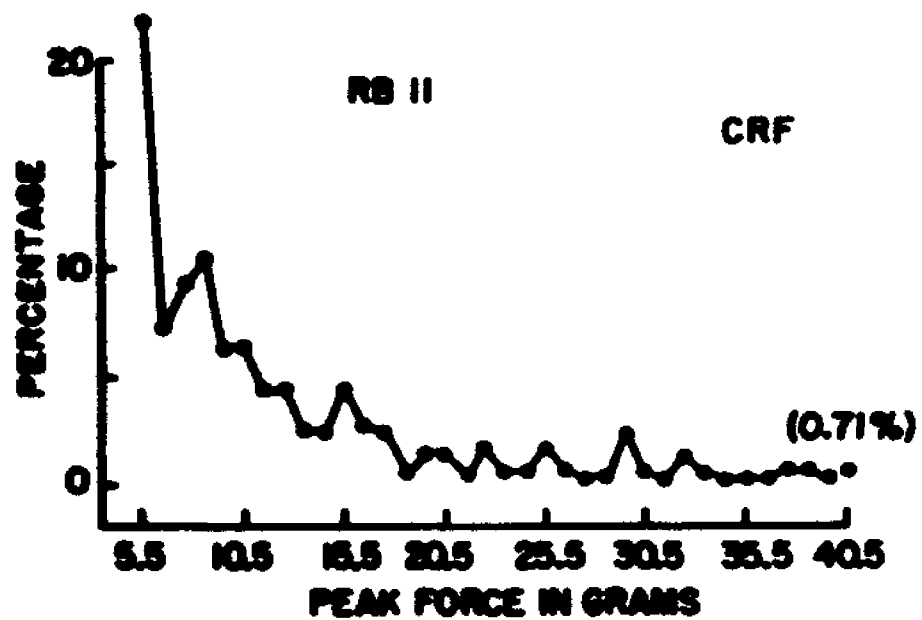
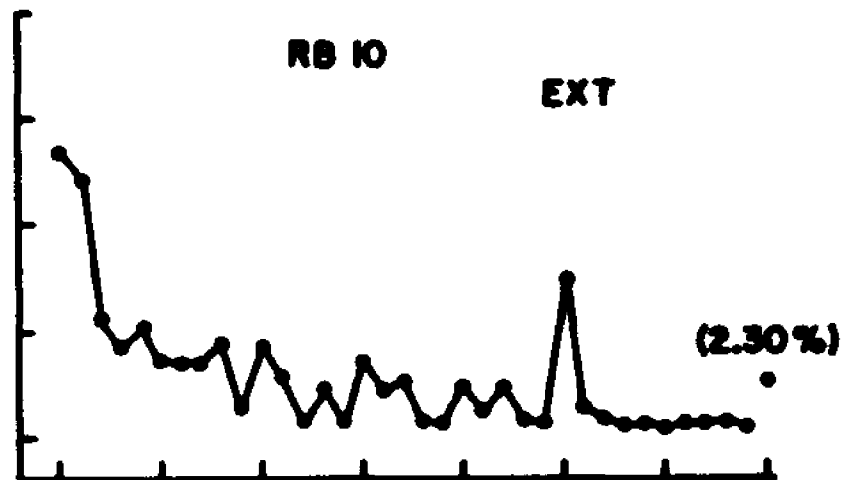
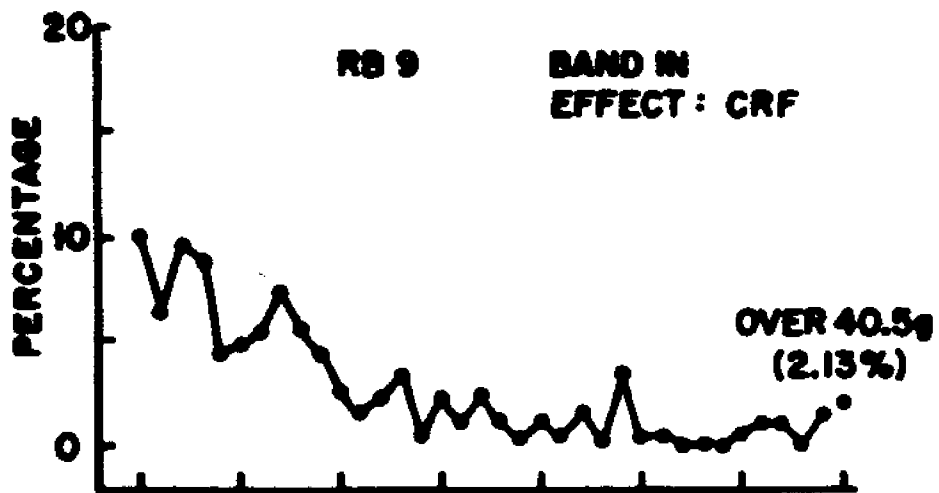


Figure 11

Peak force of response distributions for the Ss of group 3 during Phase I of Experiment 1. The band in effect for this condition was 18-28 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

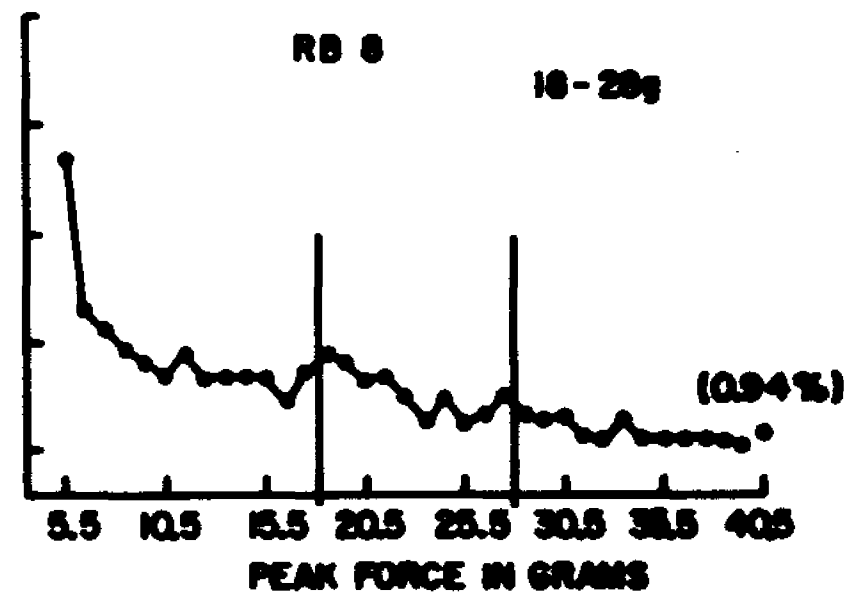
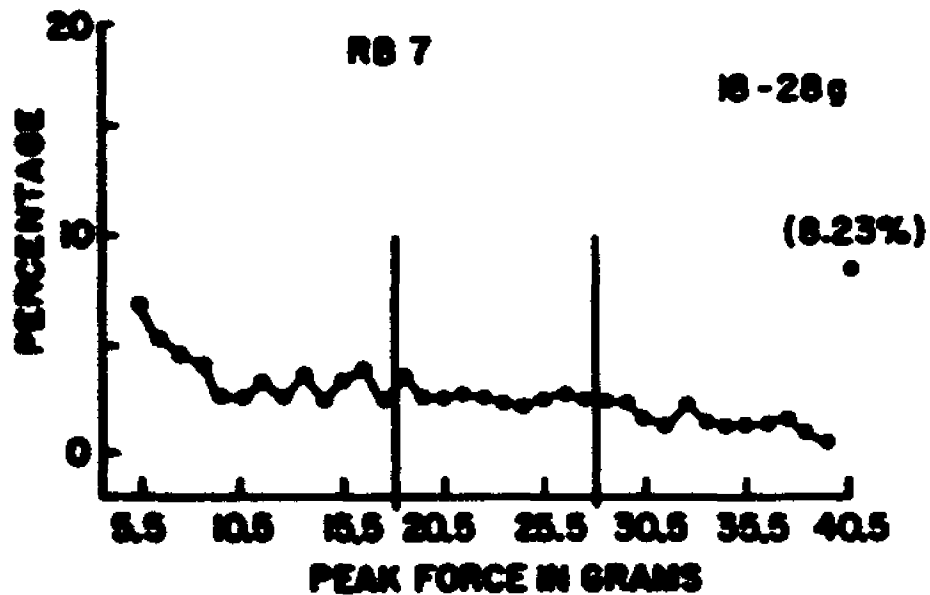
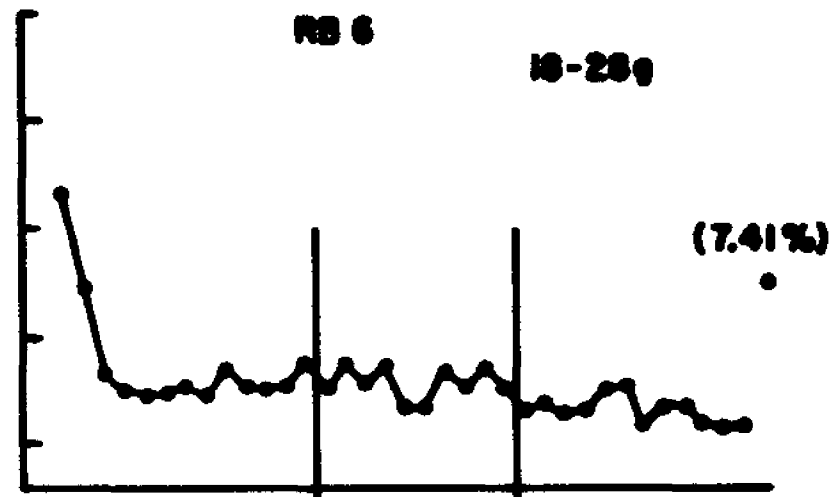
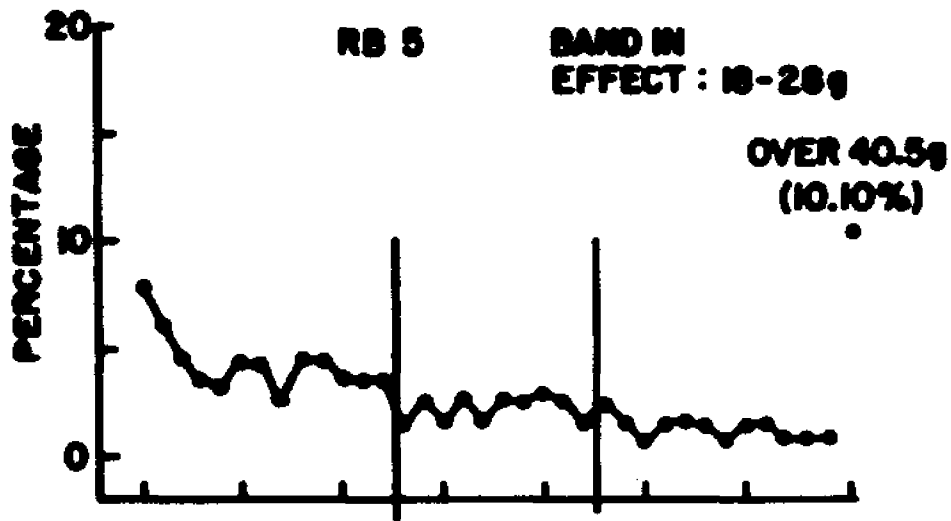


Figure 12

Peak force of response distributions for the Ss of group 3 during Phase II of Experiment 1. The band in effect for this condition was 20-26 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

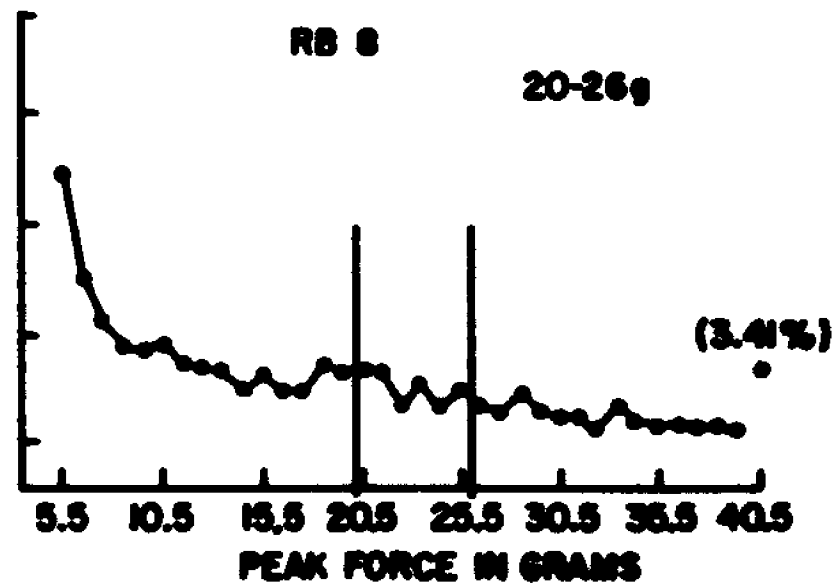
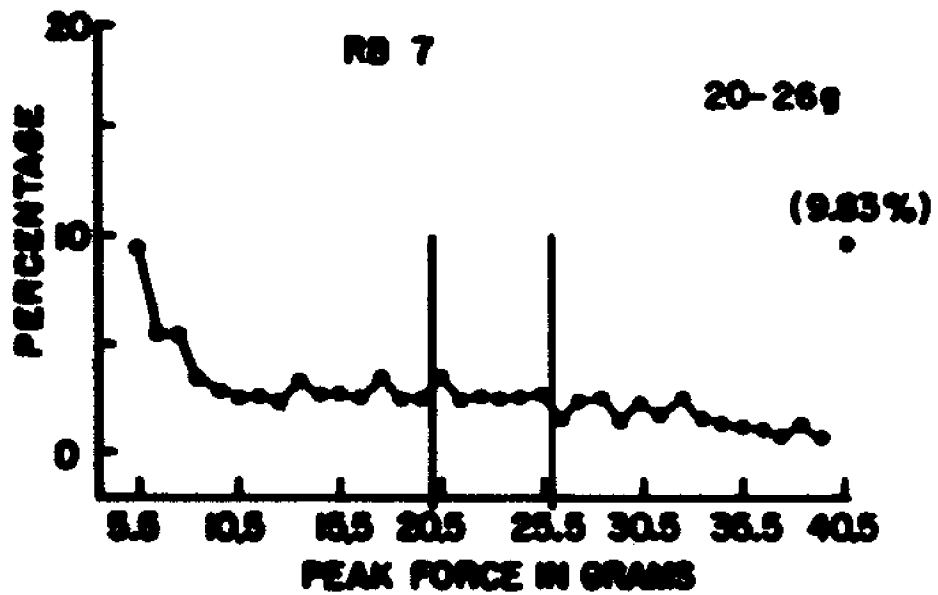
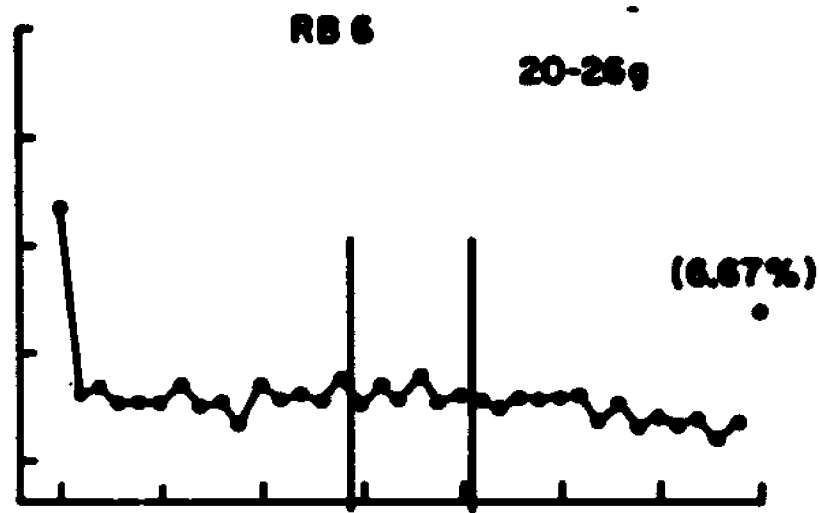
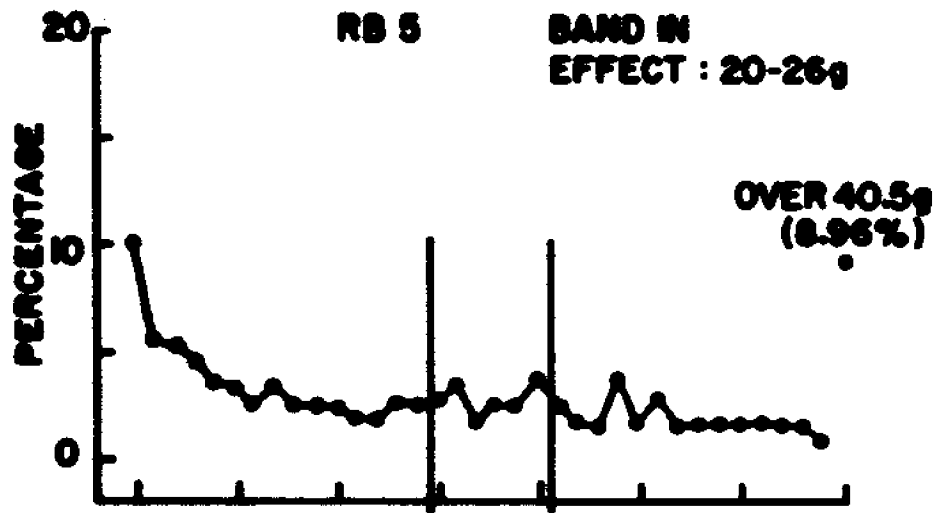


Figure 13

Peak force of response distributions for the Ss of group 3 during Phase III of Experiment 1. The band in effect for this condition was 22-24 g. In-band responses were reinforced 100 percent of the time. The distributions reflect the mean of the last three days of running during the specified Phase.

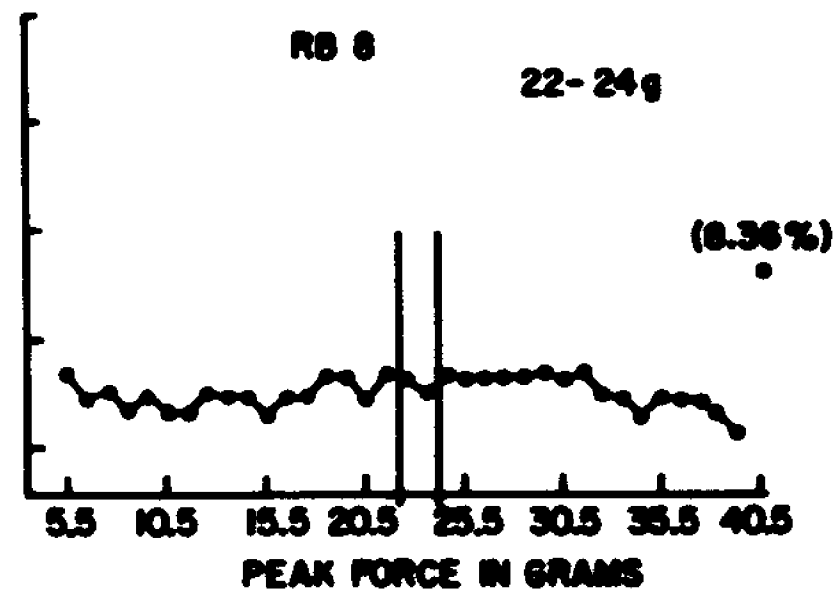
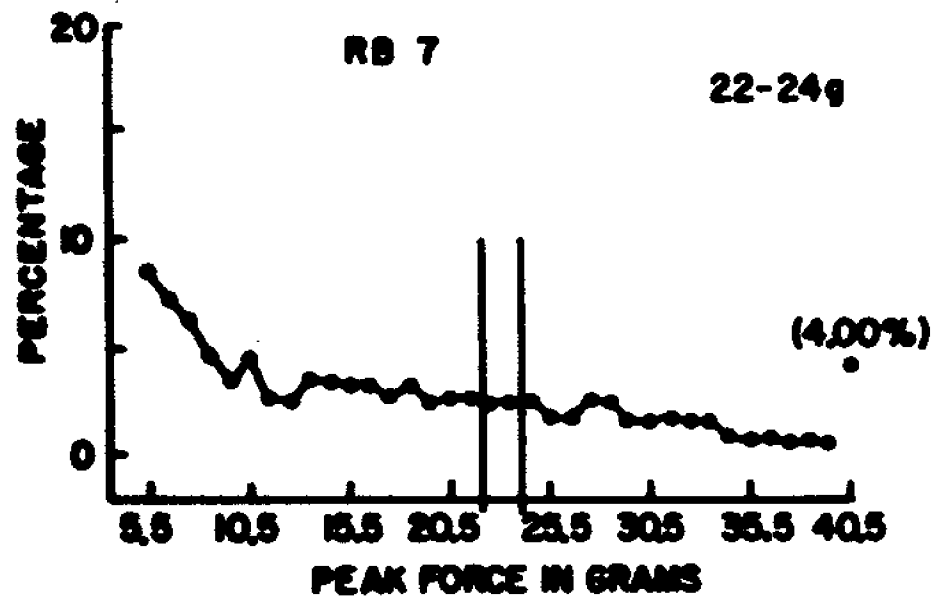
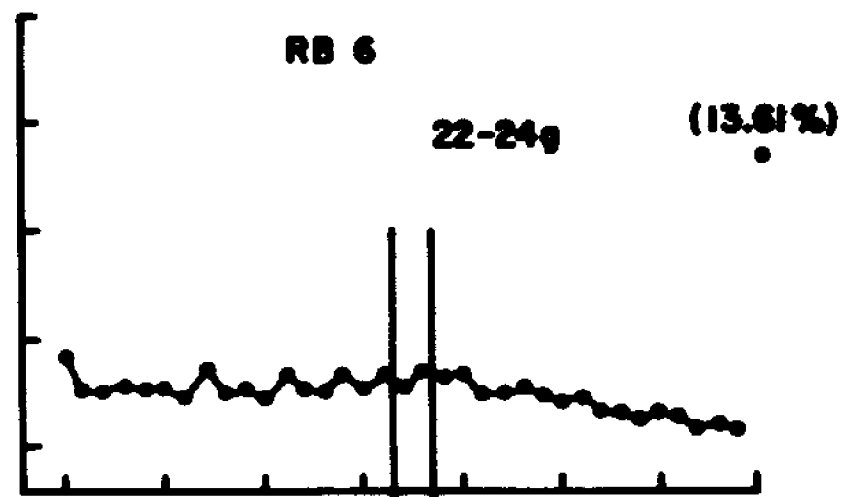
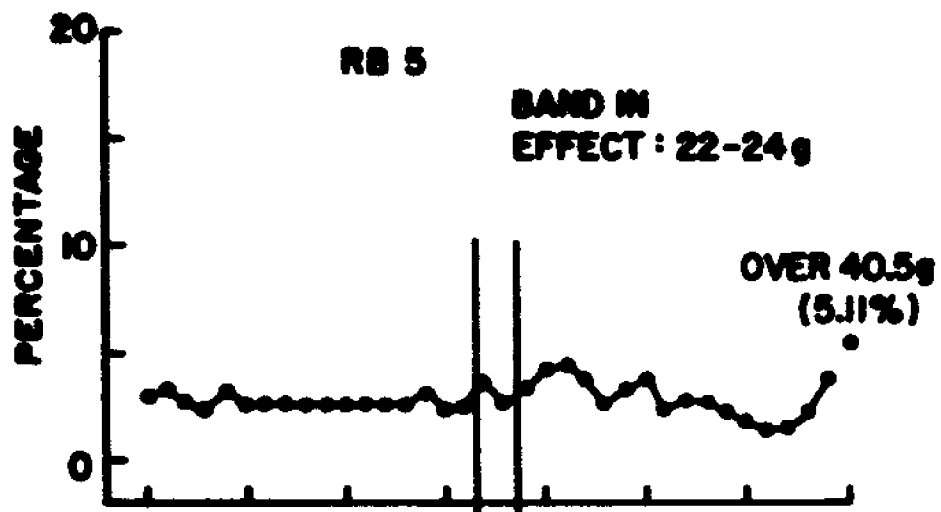


Figure 14

Peak force of response distributions for the Ss of group 3, Phase IV, of Experiment 1. Ss RB 6 and 7 were run on extinction while Ss RB 5 and 8 were run on CRF.

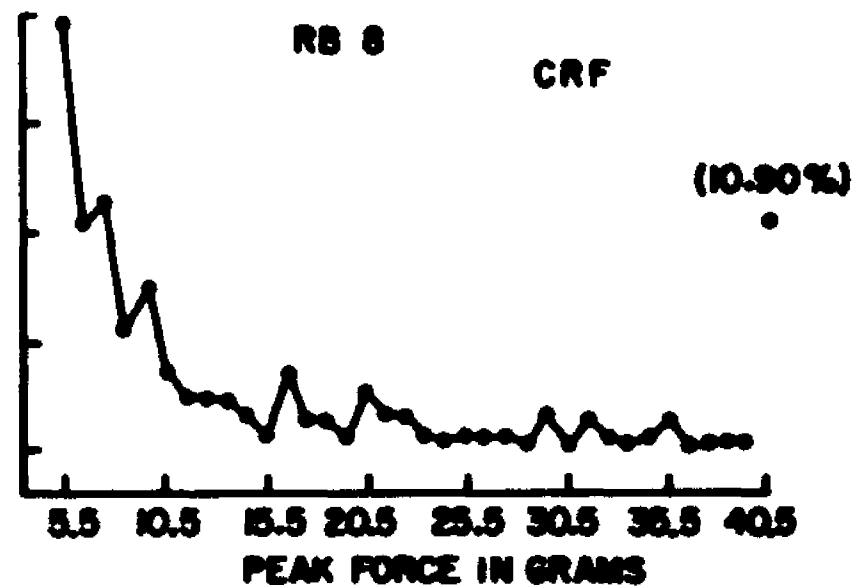
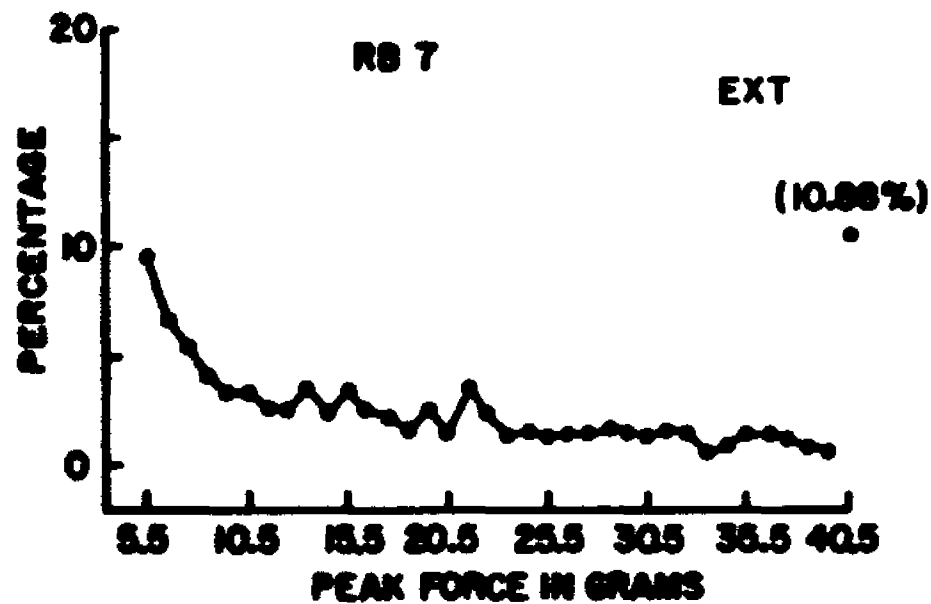
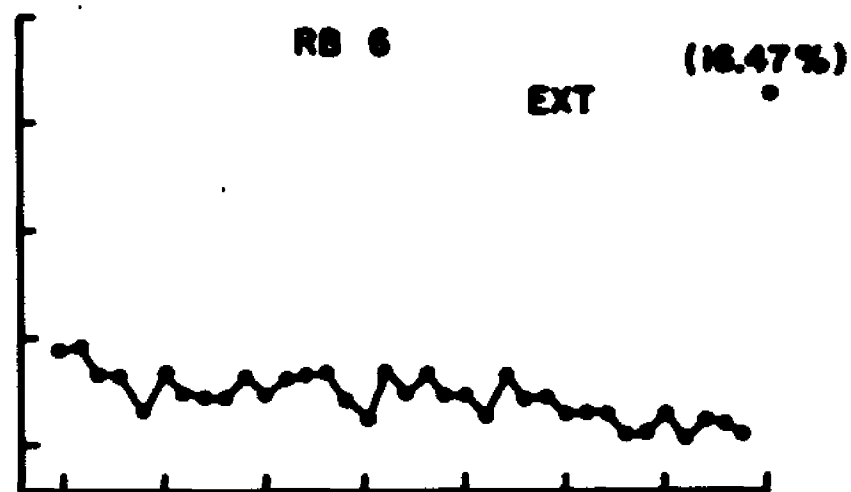
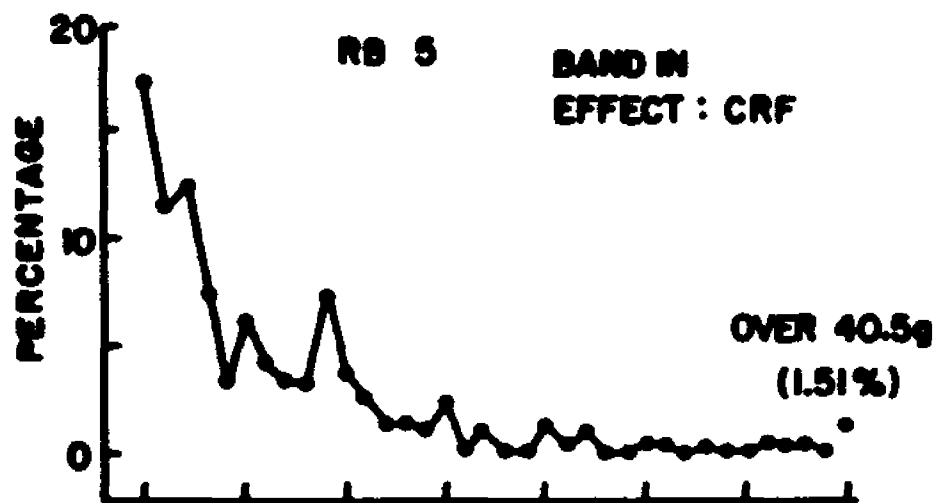


Figure 15

Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 1 of Experiment 1. Phases I, II, and III are displayed. The appropriate band in effect is indicated on the figure. Each data point is based on the mean of the last three days of each Phase.

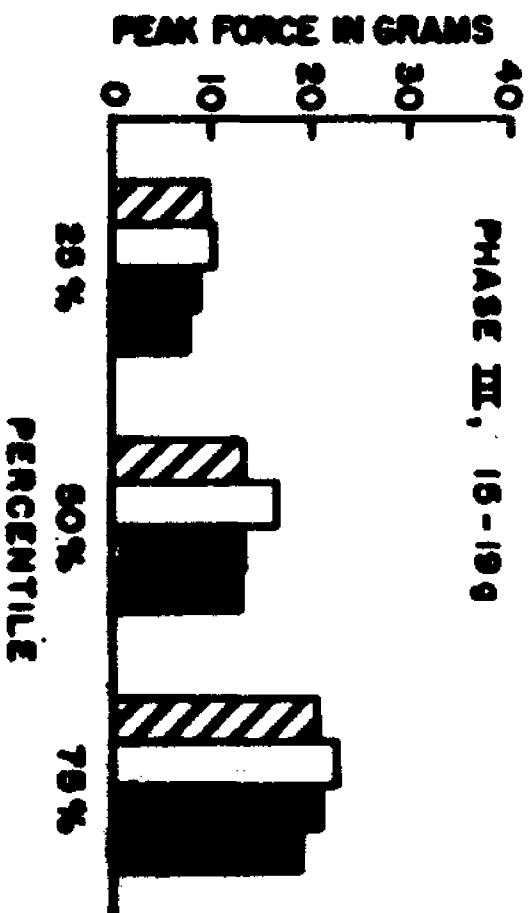
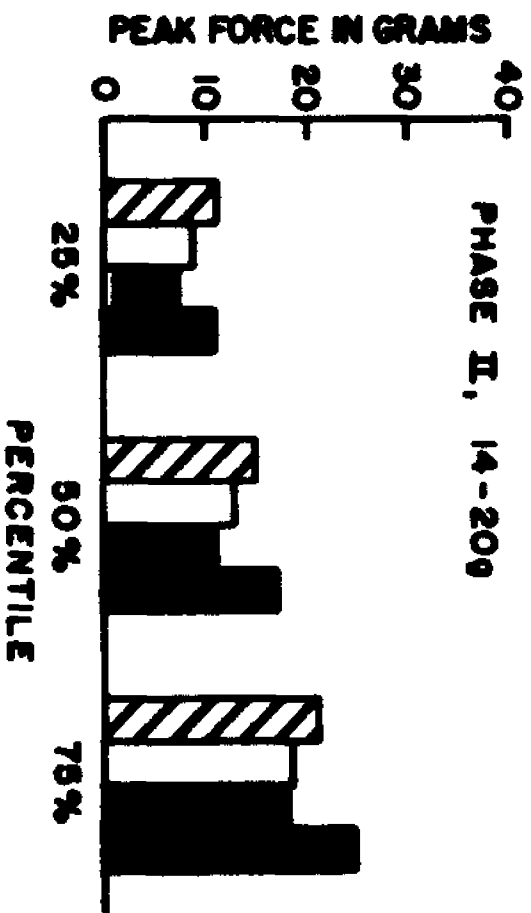
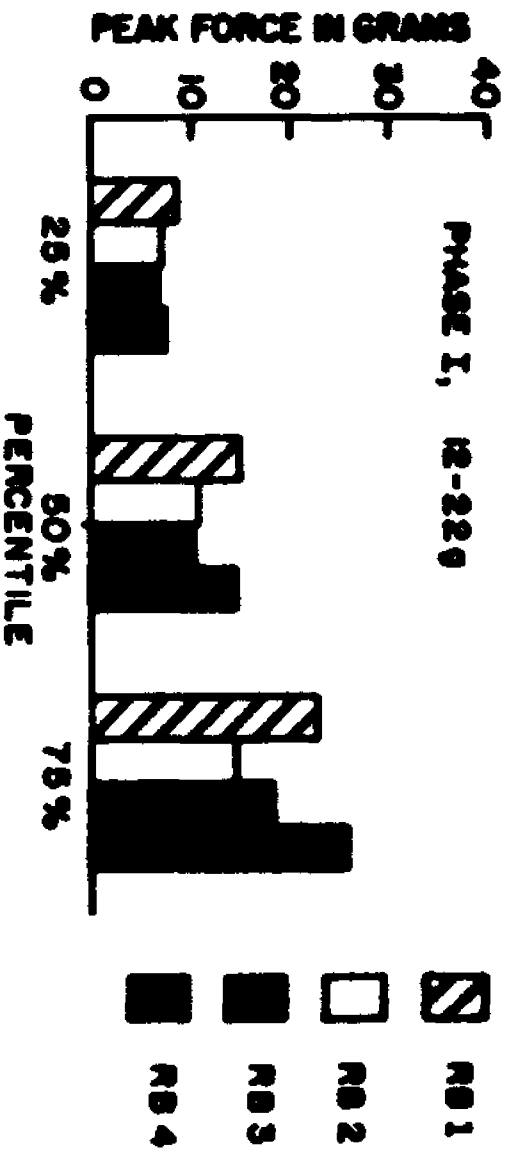


Figure 16

Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 2 of Experiment 1. Phases I, II and III are displayed. The appropriate band in effect is indicated on the figure. Each data point is based on the mean of the last three days of each Phase.

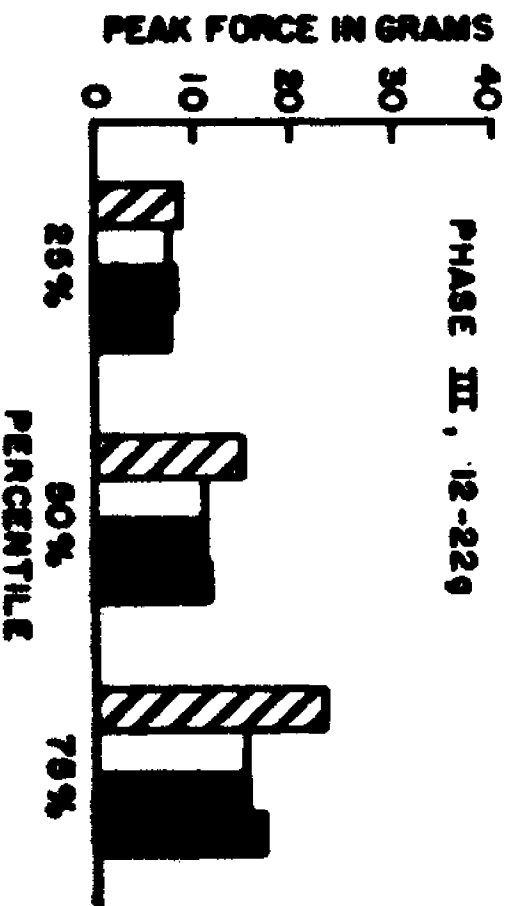
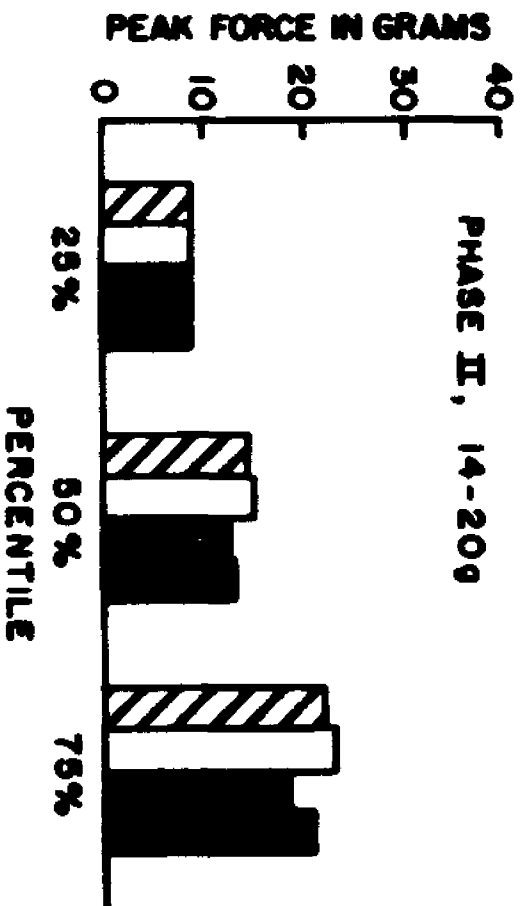
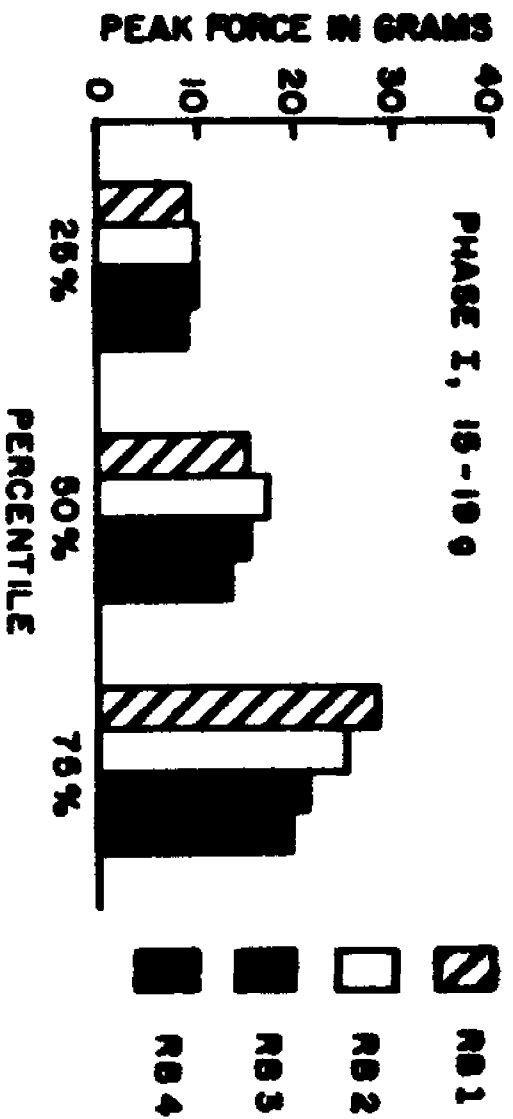


Figure 17

Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of group 3 of Experiment 1. Phases I, II and III are displayed. The appropriate band in effect is indicated on the figure. Each data point is based on the mean of the last three days of each Phase.

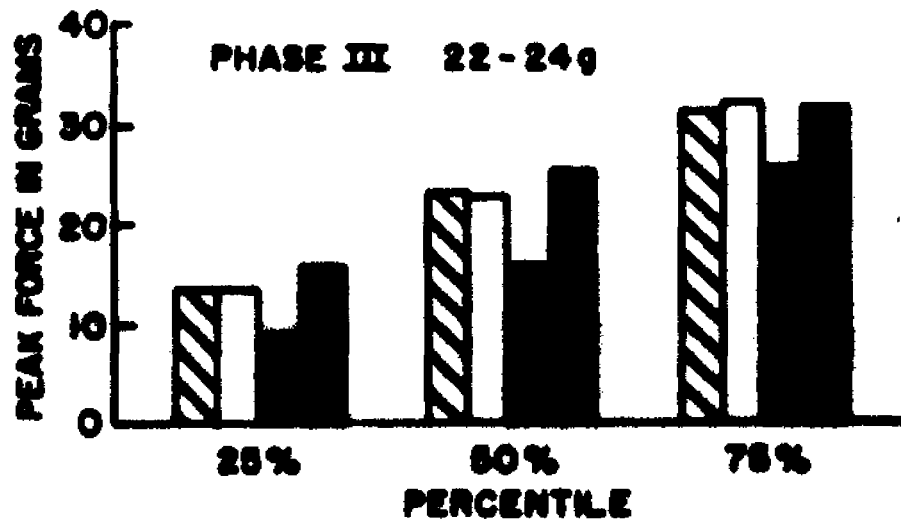
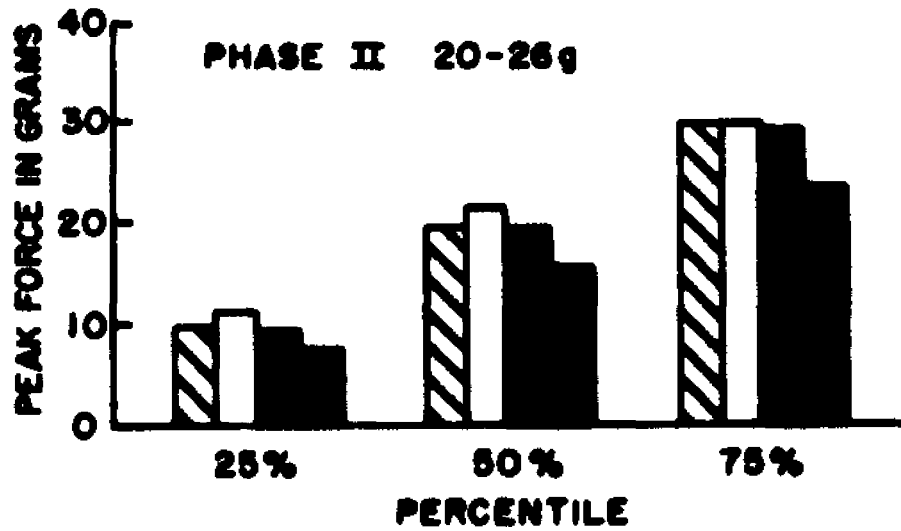
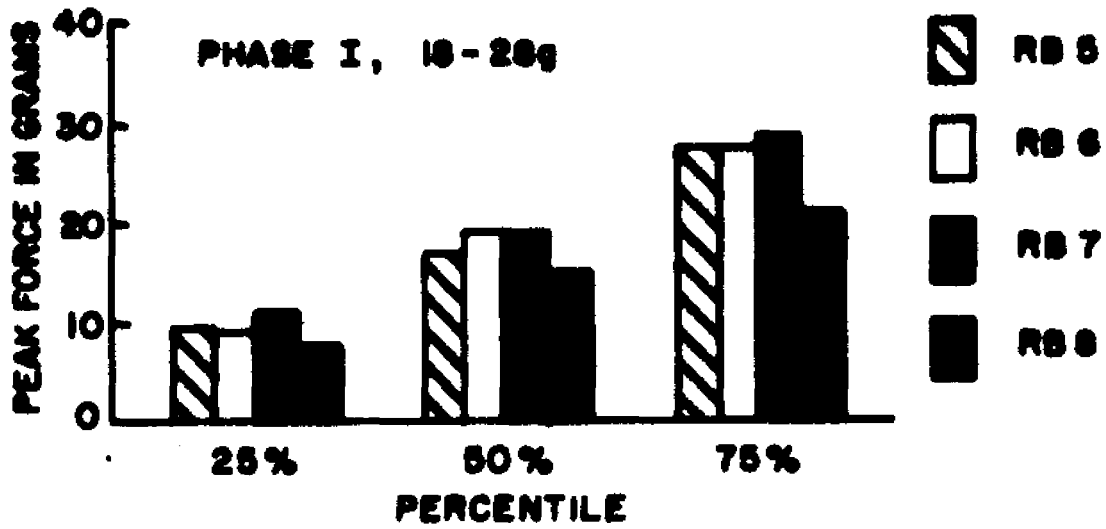


Figure 18

Mean peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of groups 1, 2 and 3 of Experiment 1. Phases I, II and III are displayed. The appropriate band in effect is indicated on the figure. Each data point is based on the mean of the four Ss in each group.

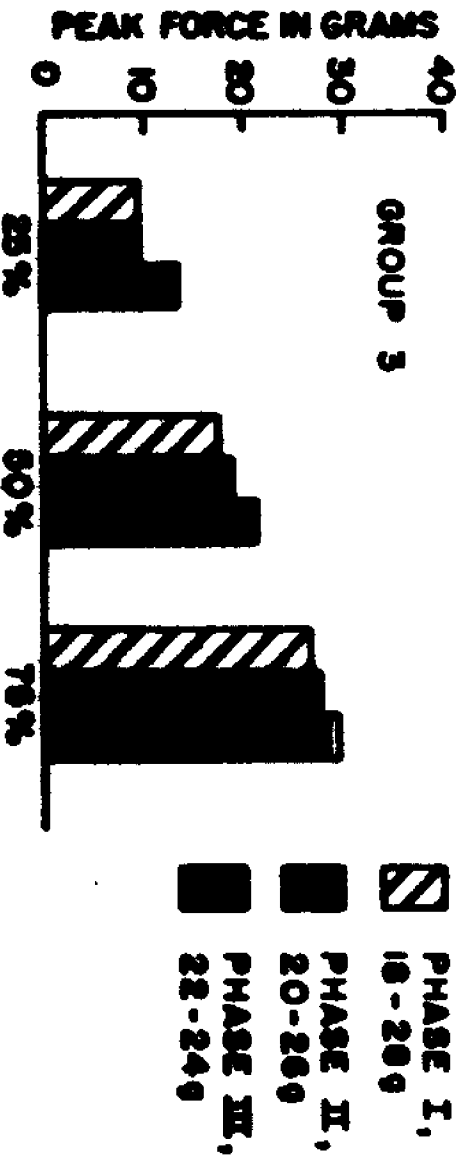
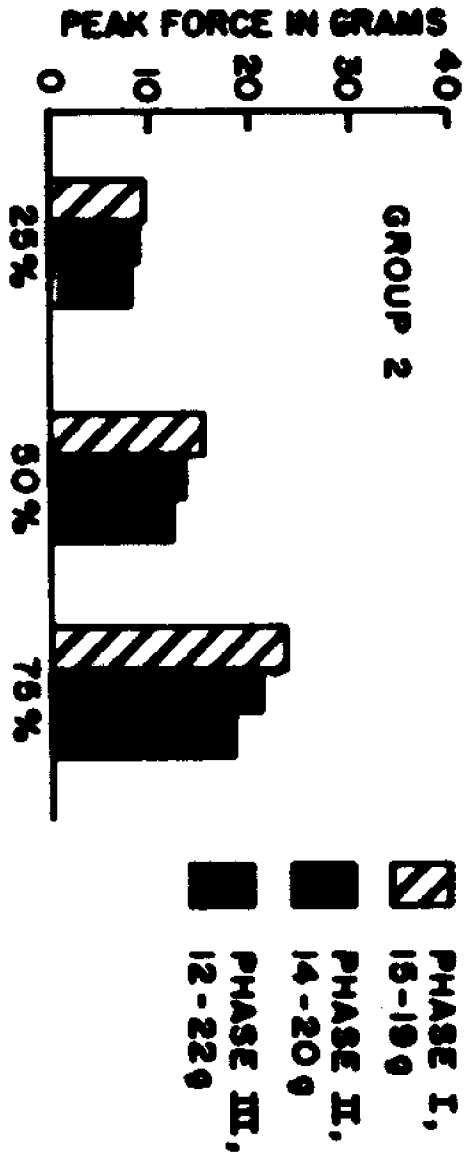
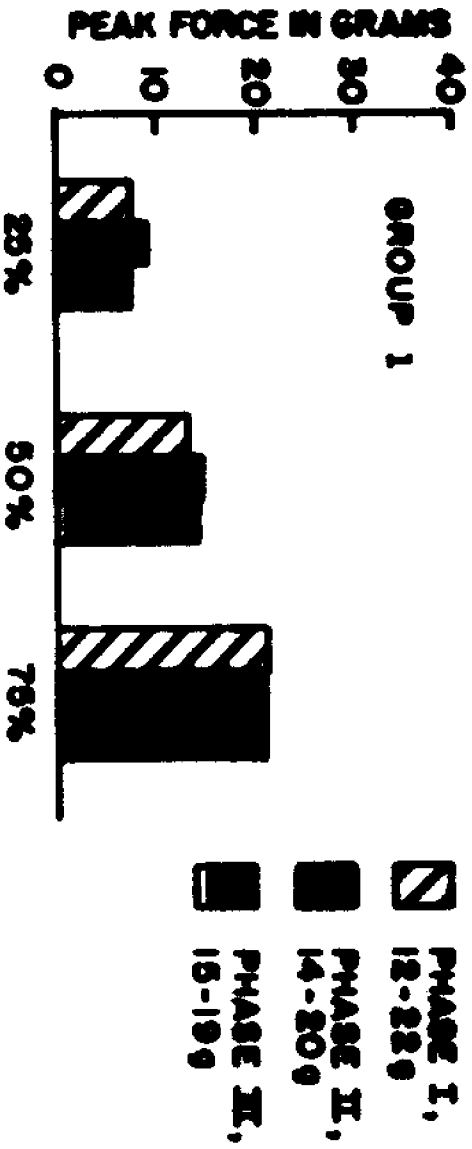


Figure 19

Peak force of response values in grams at the 25th, 50th and 75th percentiles for the Ss of groups 1, 2 and 3 of Experiment 1. Phase IV, the CRF or Extinction condition is displayed. Each data point is based on the mean of the last three days of Phase IV.

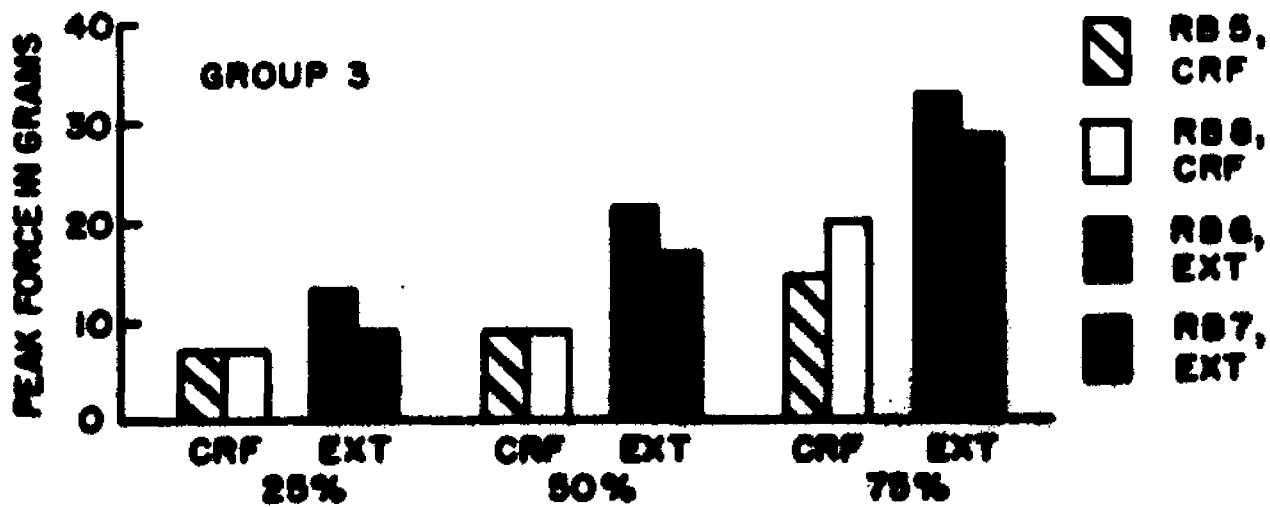
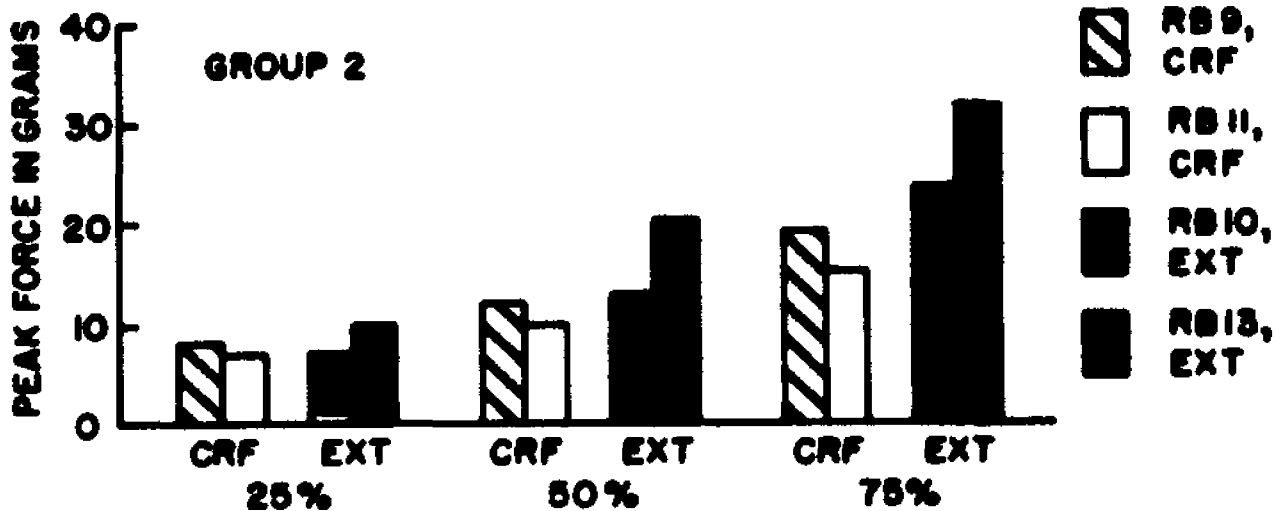
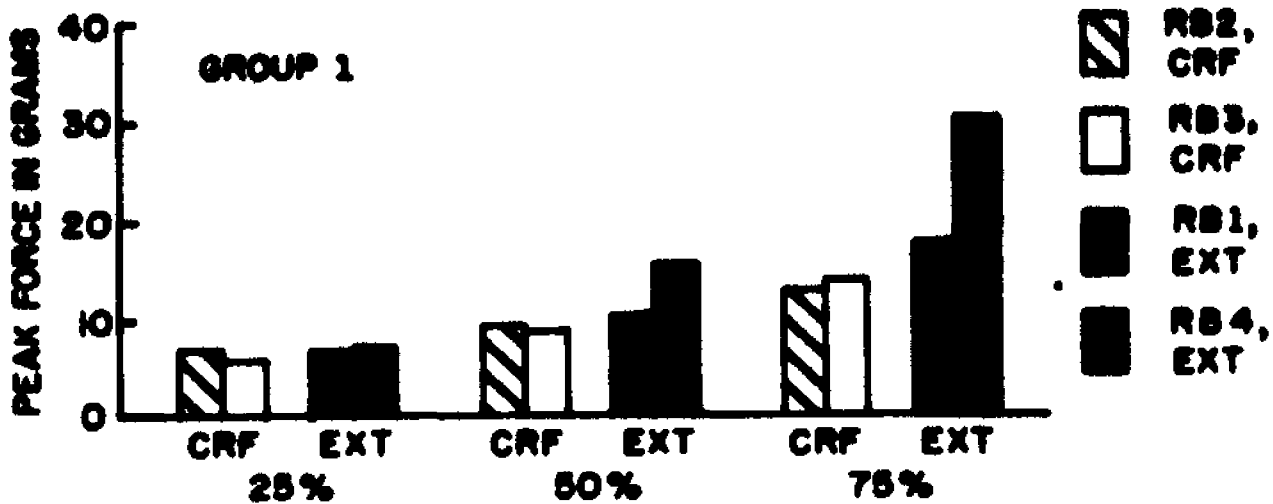


Figure 20

The mean rate of responding in responses per minute as a function of the mean percentage of in-band responses for groups 1, 2 and 3 of Experiment 1. Data from Phases I, II and III as well as the CRF data from Phase IV is represented.

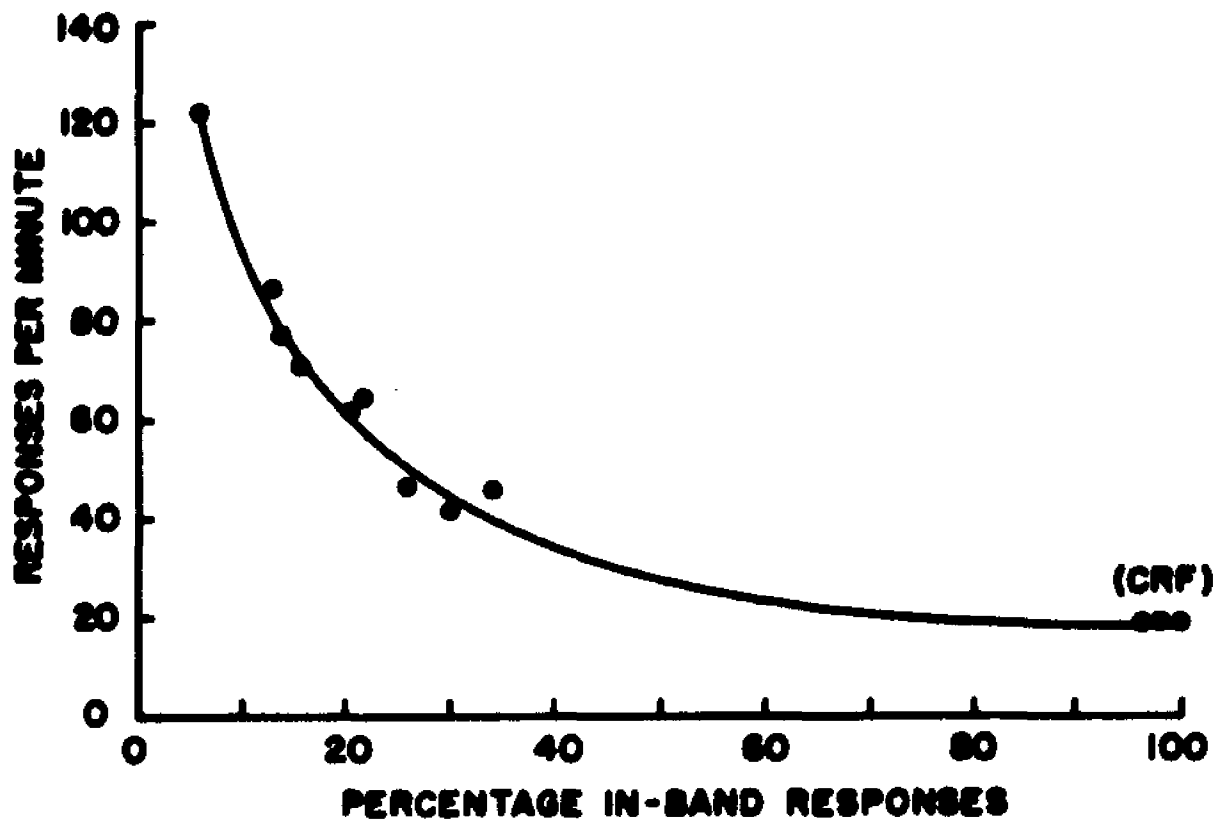


Figure 21

Mean percentage of in-band responses as a function of sessions for the Ss of groups 1 and 2 of Experiment 2. Both Phase I and Phase II are displayed. The appropriate reinforcement ratio is indicated on the figure.

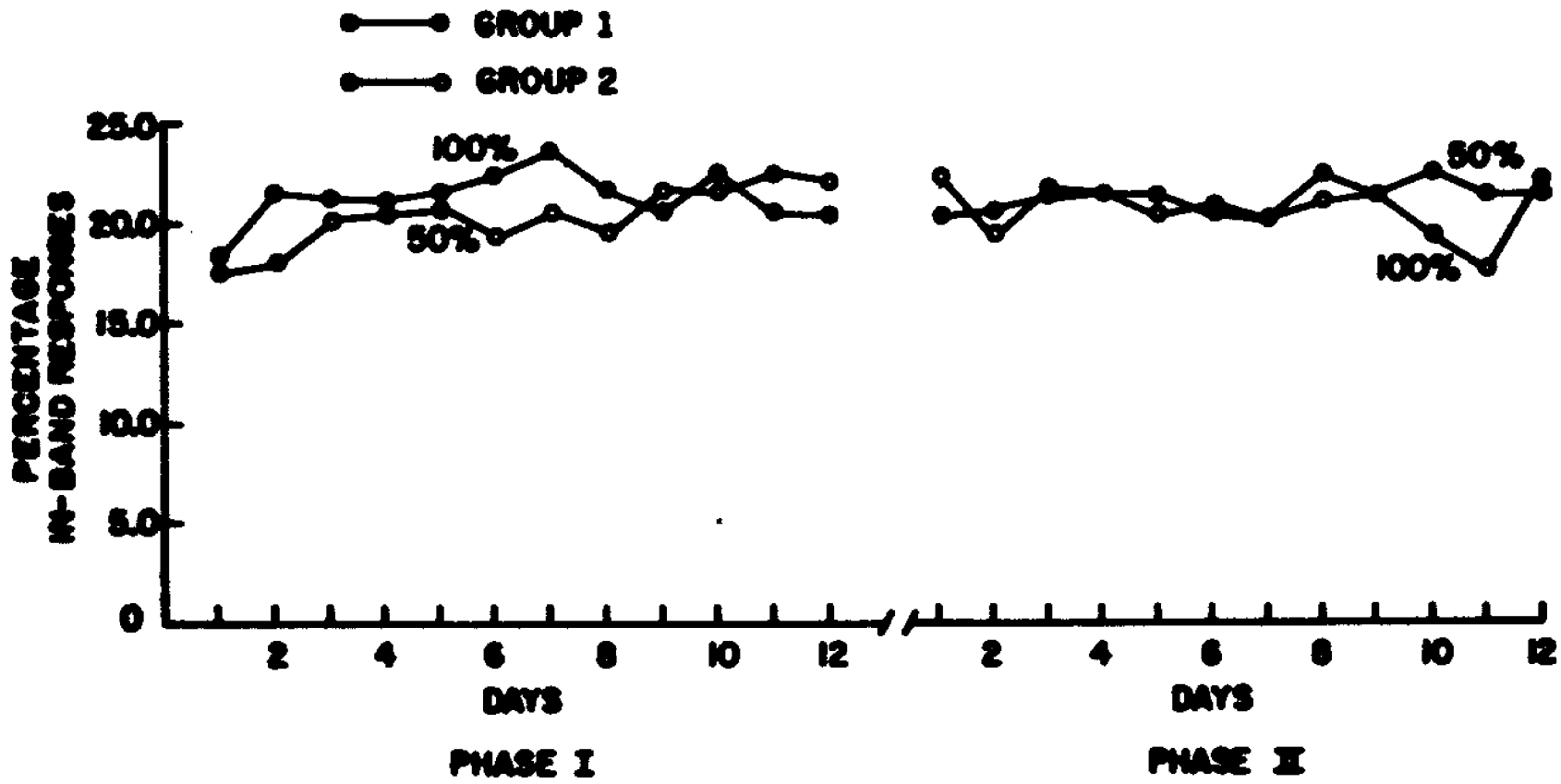


Figure 22

Mean responses per minute as a function of sessions for the Ss of groups 1 and 2 of Experiment 2. Both Phase I and Phase II are displayed. The appropriate reinforcement ratio is indicated on the Figure.

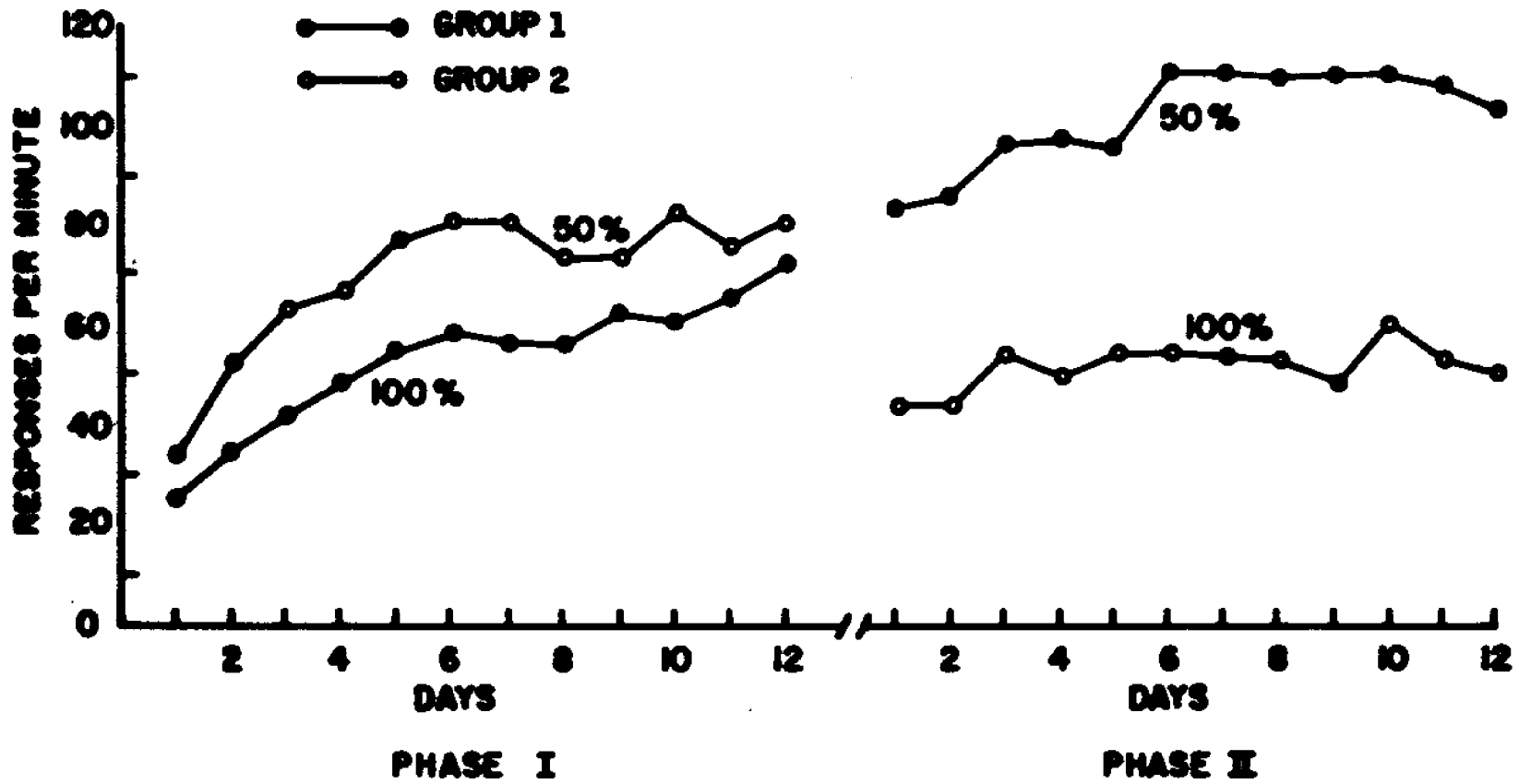


Figure 23

Mean reinforcements per minute as a function of sessions for the Ss of groups 1 and 2 of Experiment 2. Both Phase I and Phase II are displayed. The appropriate reinforcement ratio is indicated on the Figure.

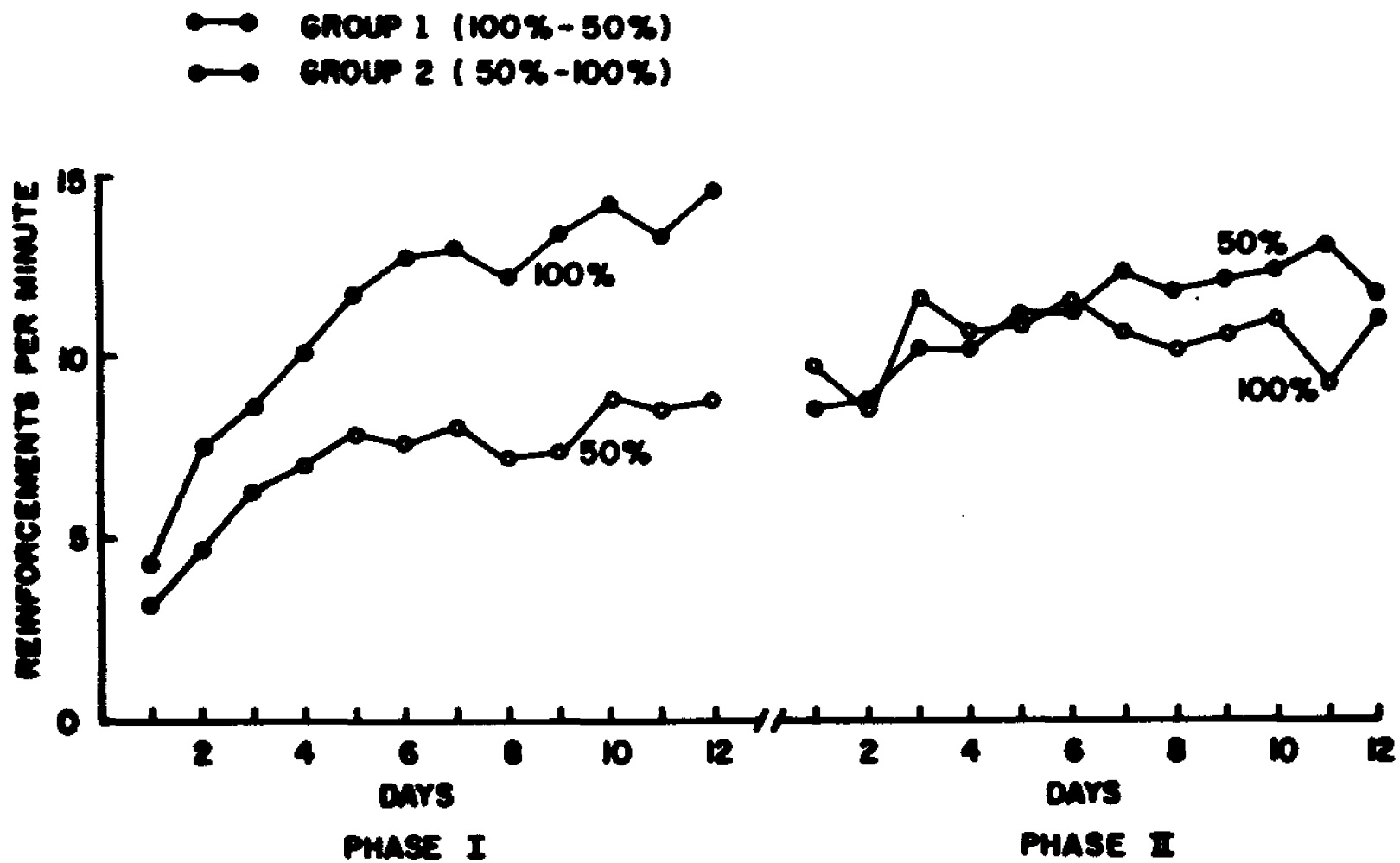


Figure 24

Peak force of response distributions for R 1 and R 3 of group 1, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

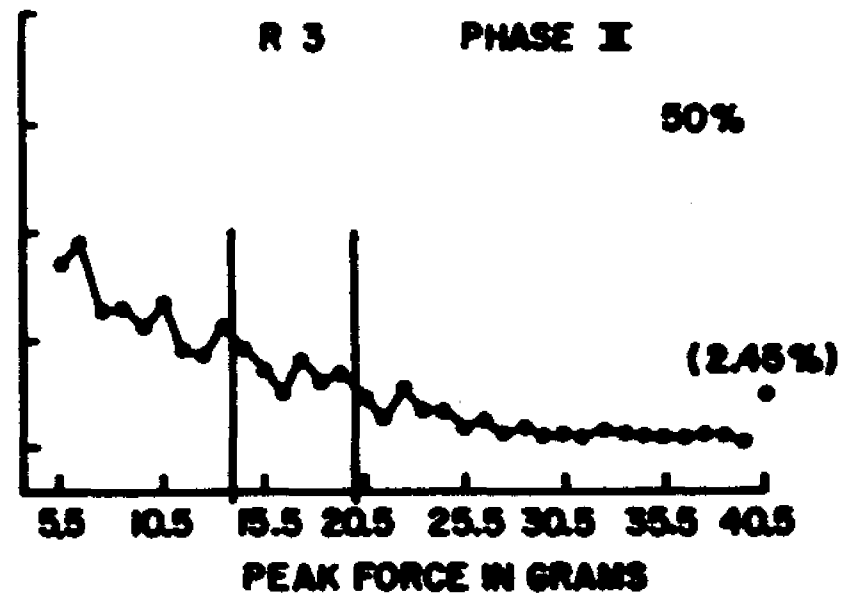
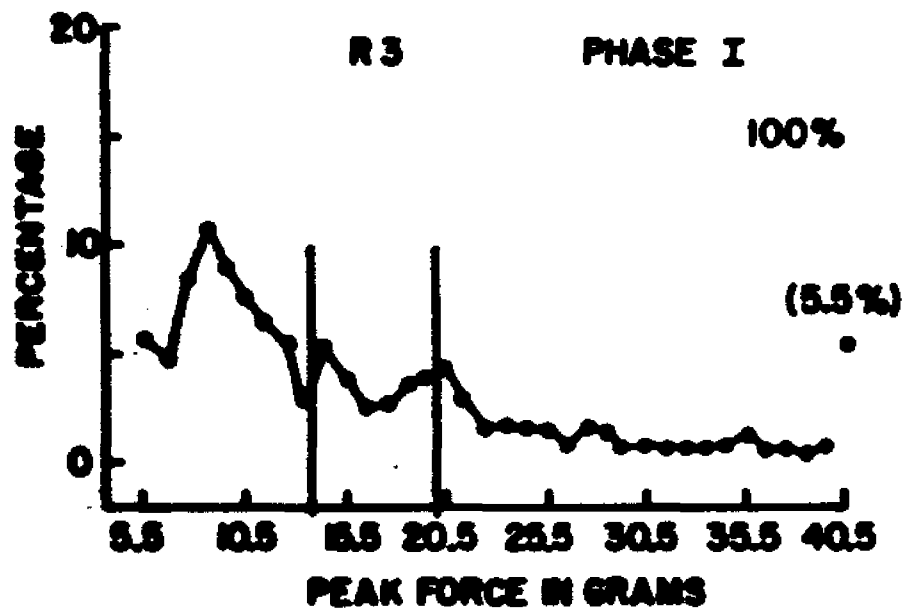
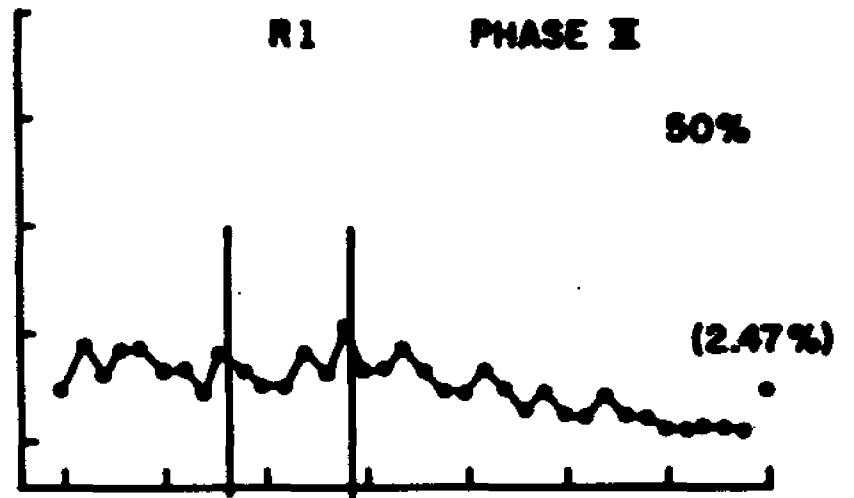
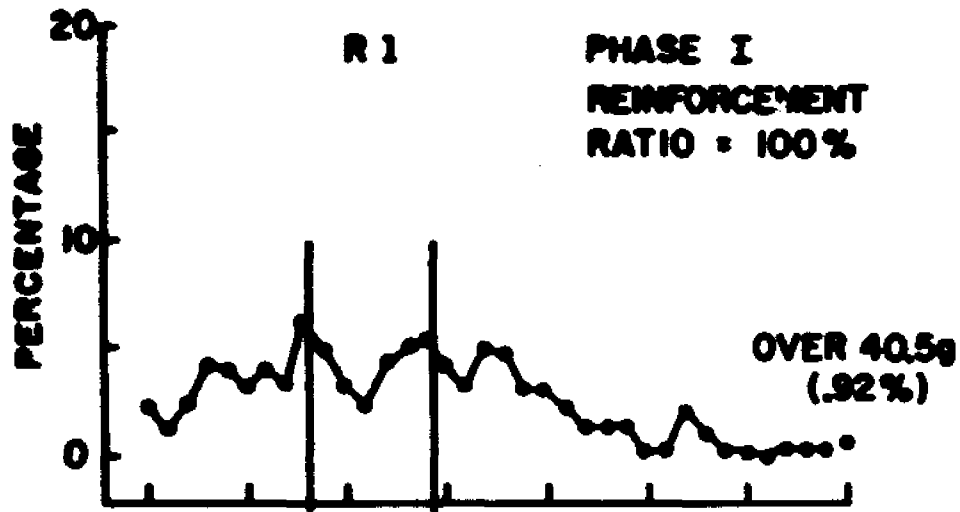


Figure 25

Peak force of response distributions for R 5 and R 7 of group 1, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

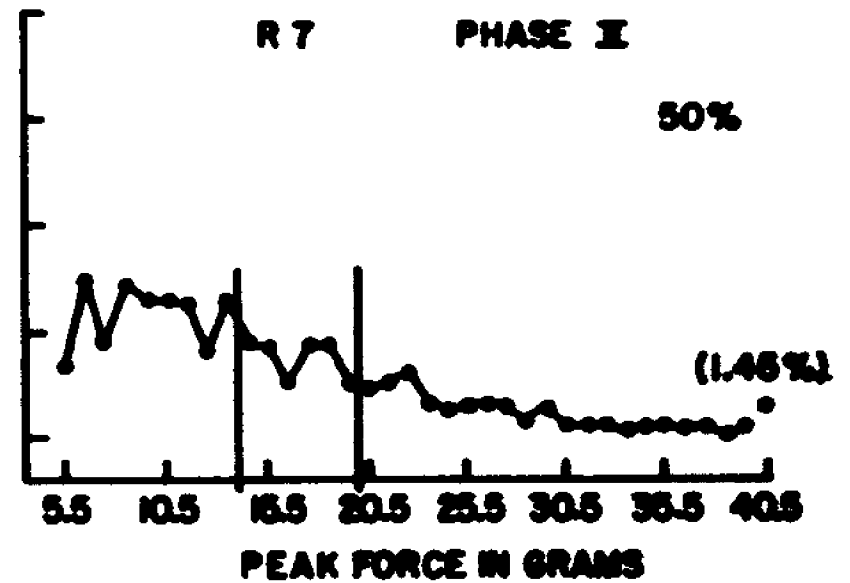
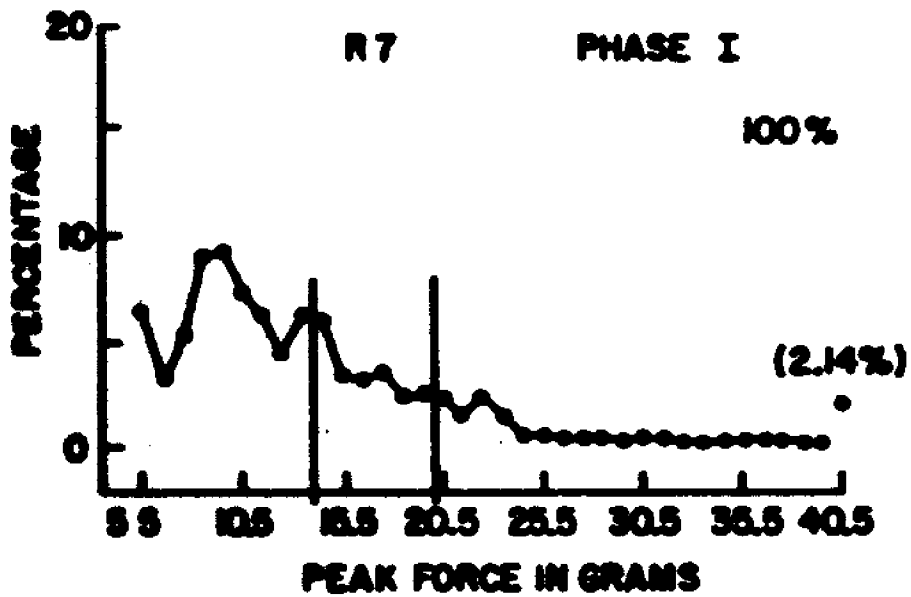
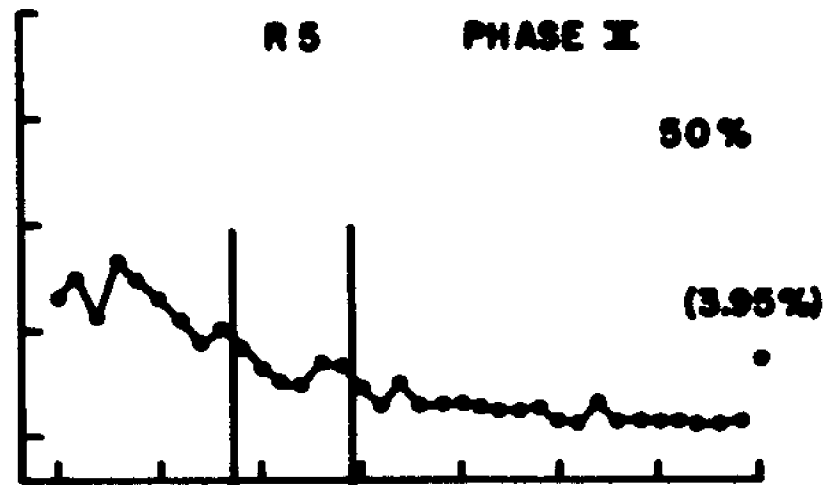
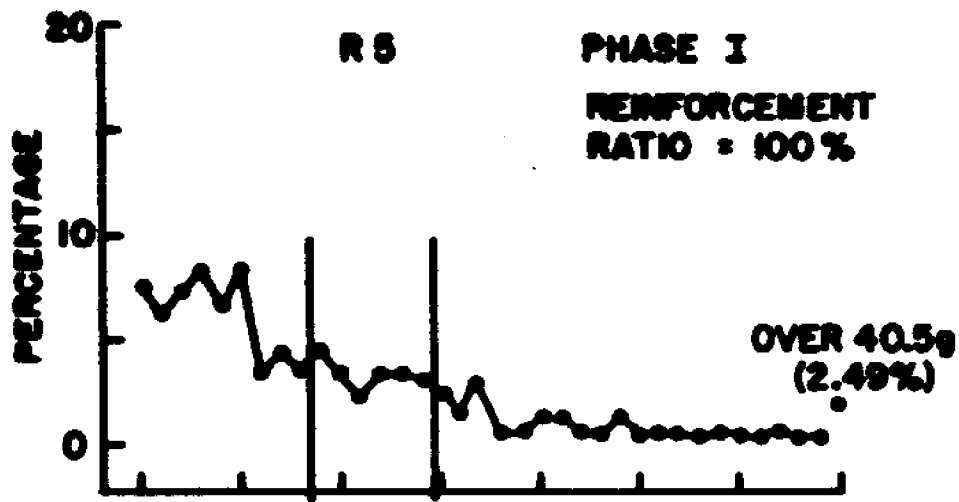


Figure 26

Peak force of response distributions for R 9 and R 11 of group 1, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

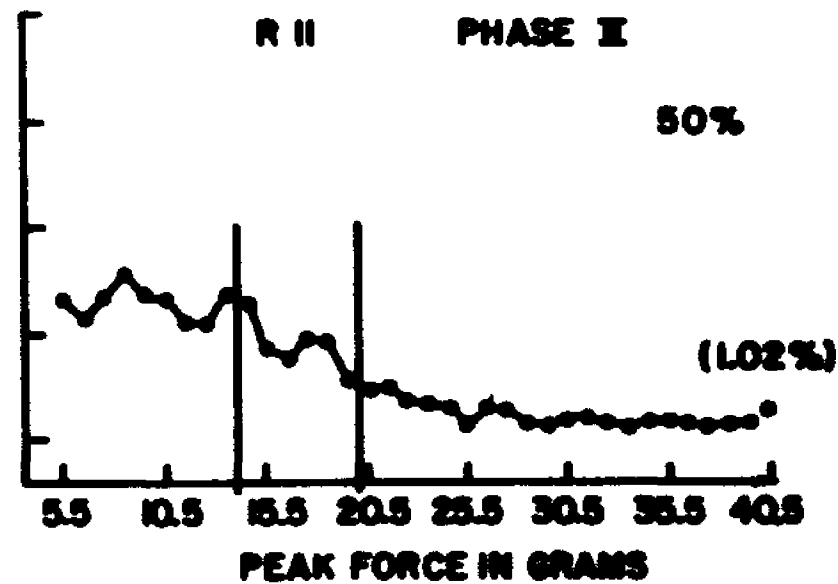
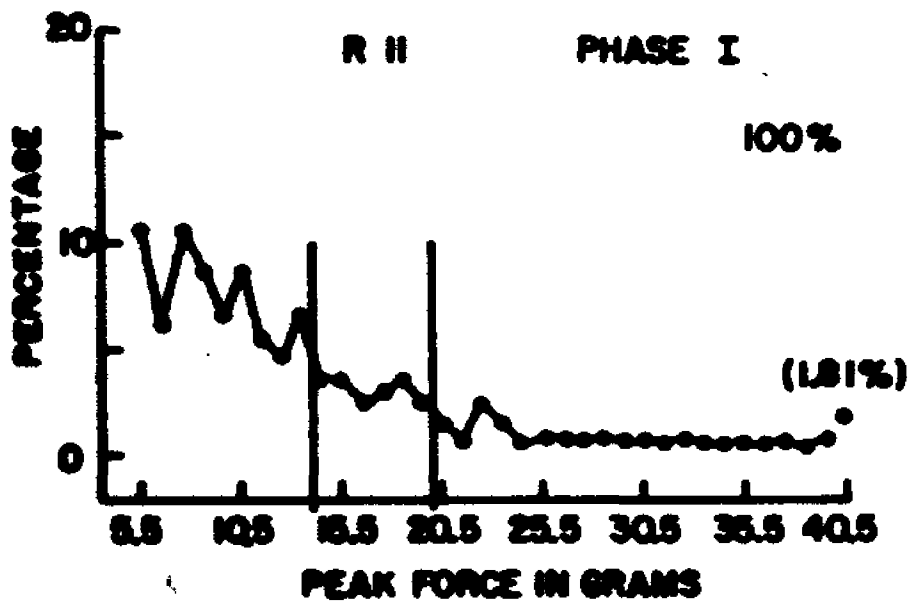
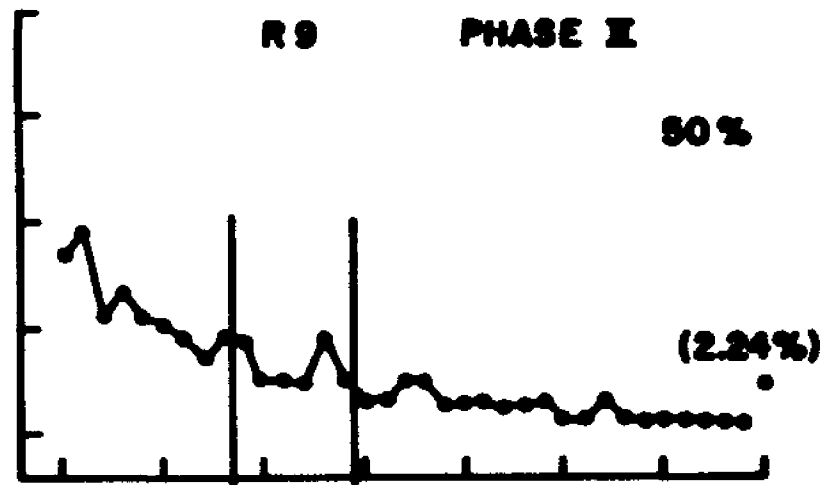
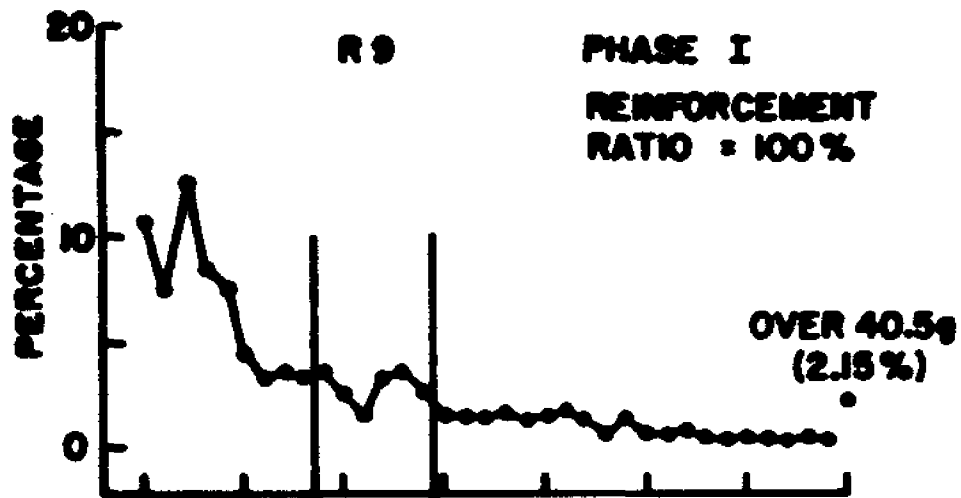


Figure 27

Peak force of response distributions for R 2 and R 4 of group 2, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

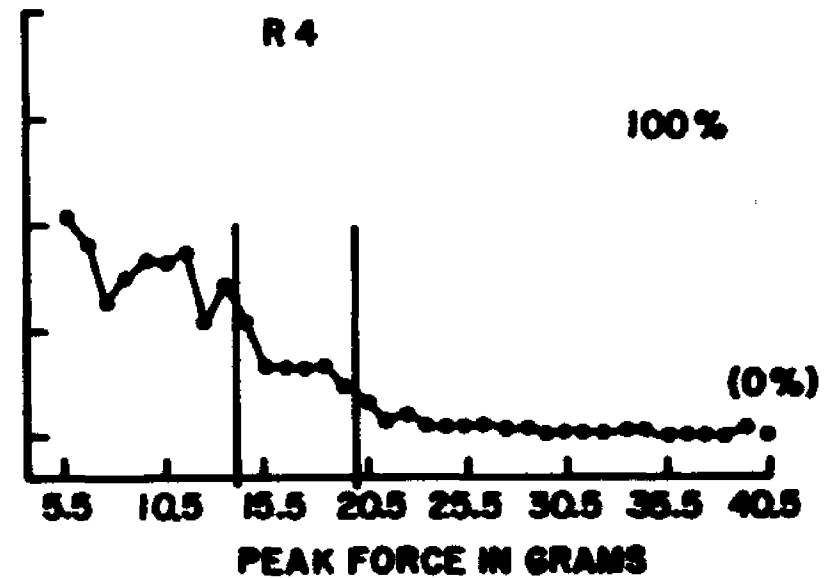
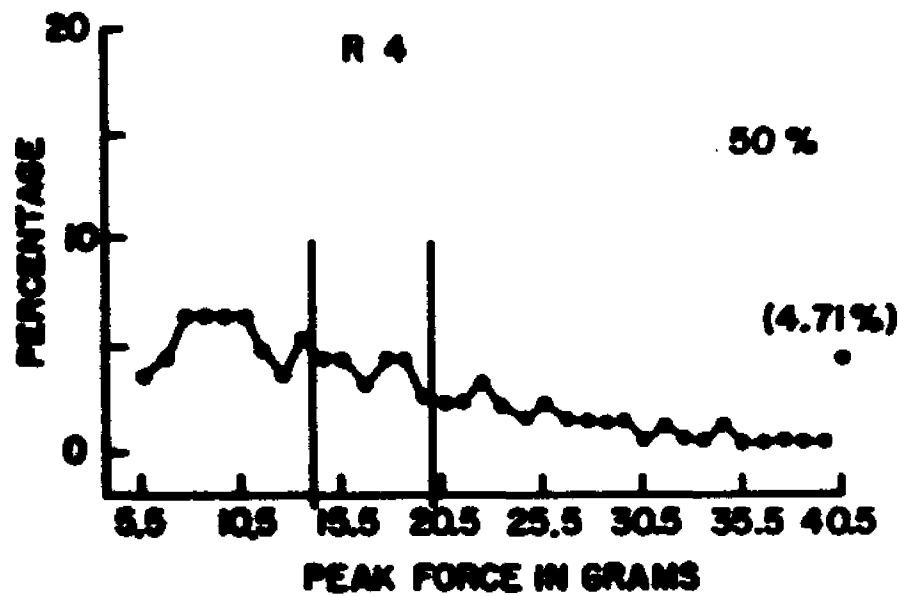
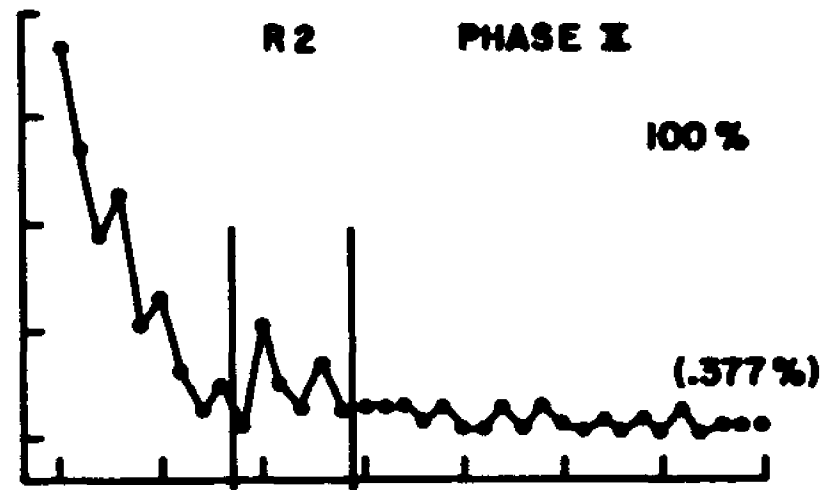
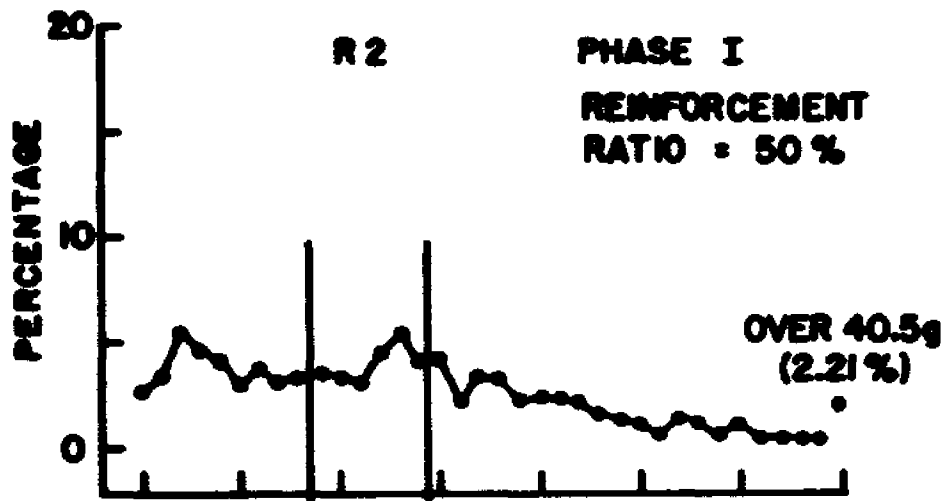


Figure 28

Peak force of response distributions for R 6 and R 8 of group 2, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

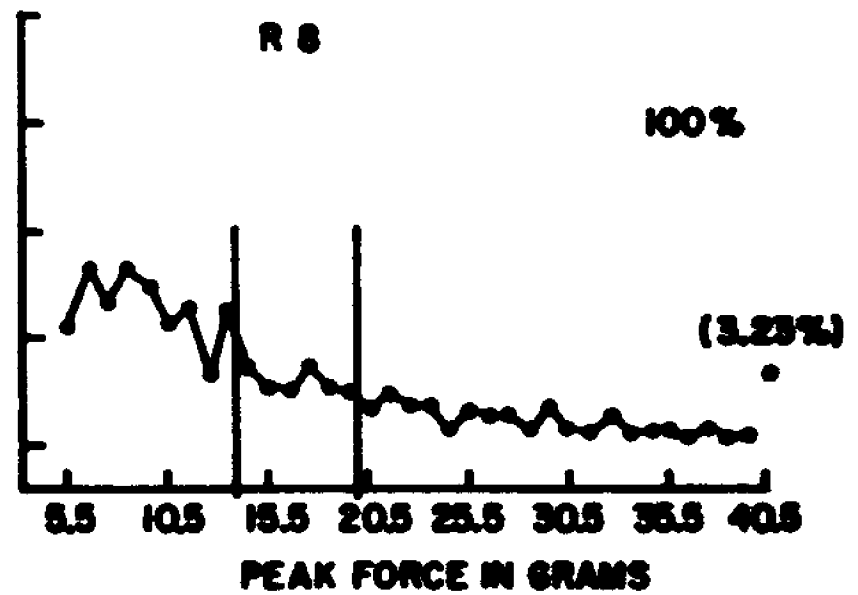
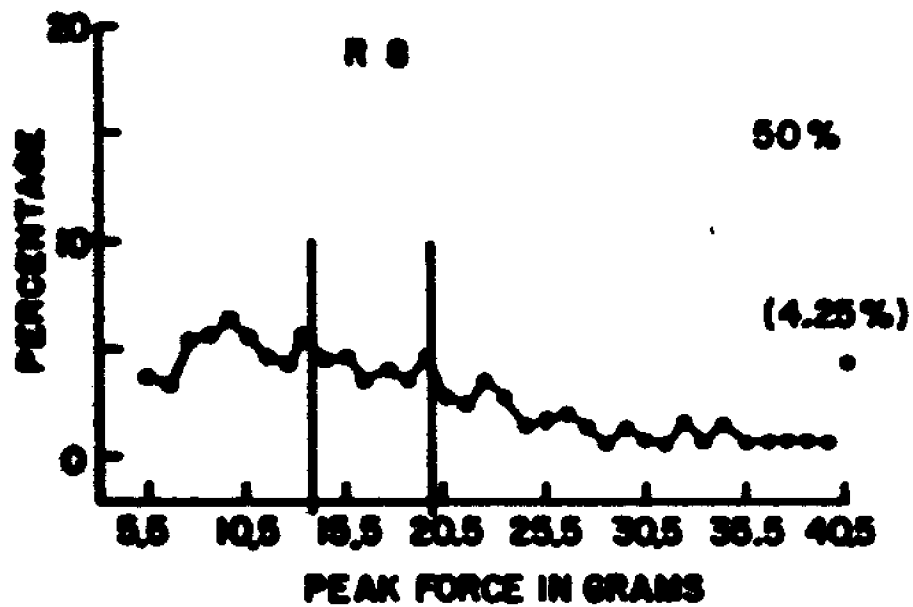
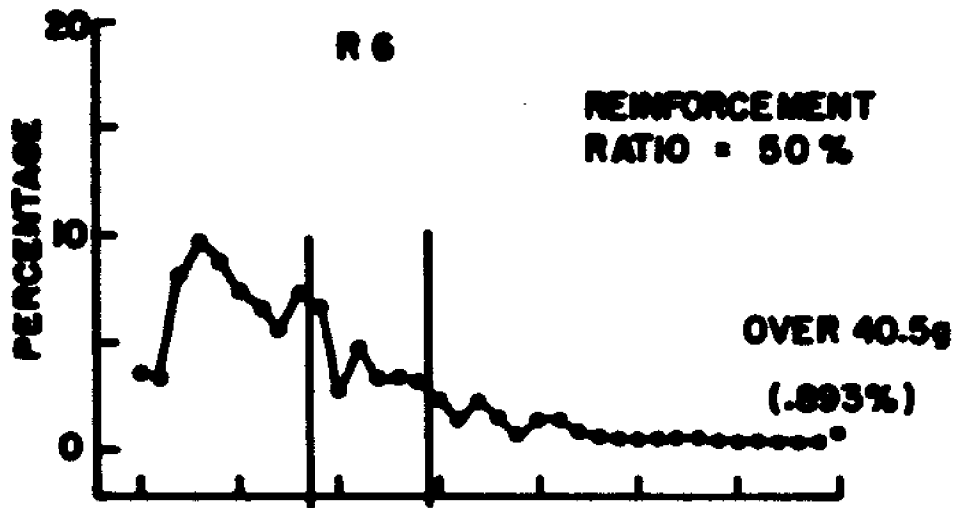


Figure 29

Peak force of response distributions for R 10 and R 12 of group 2, Experiment 2. Both Phase I and Phase II are displayed. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Each data point is the mean of the last three days of each Phase.

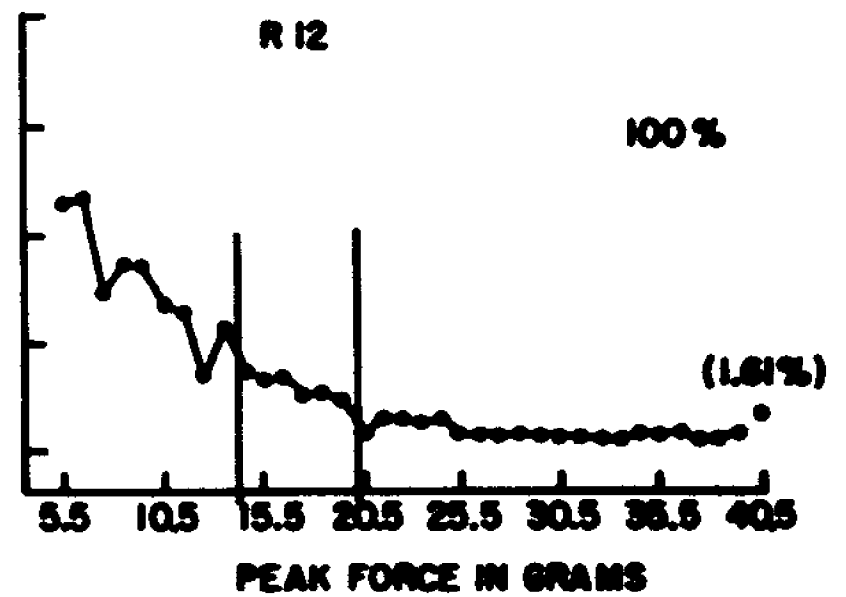
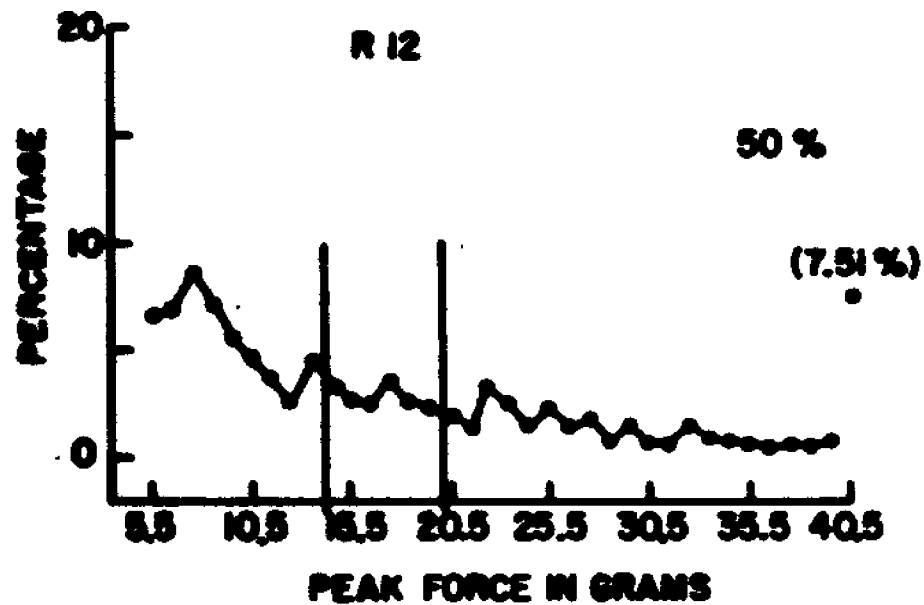
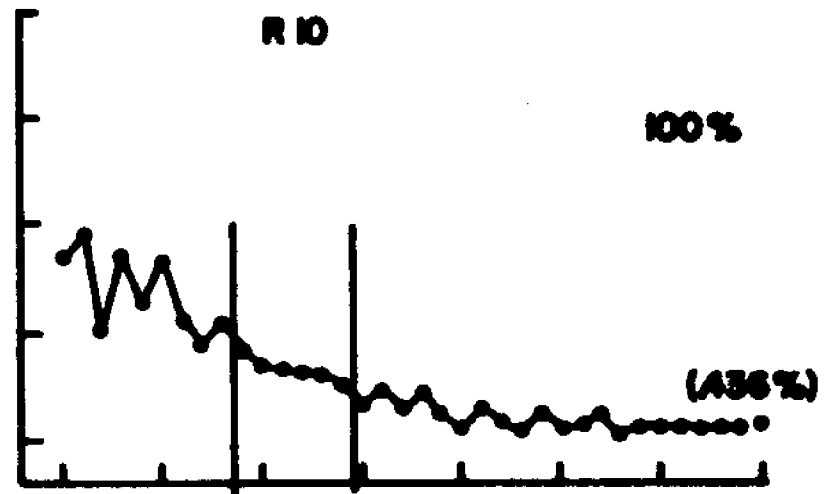
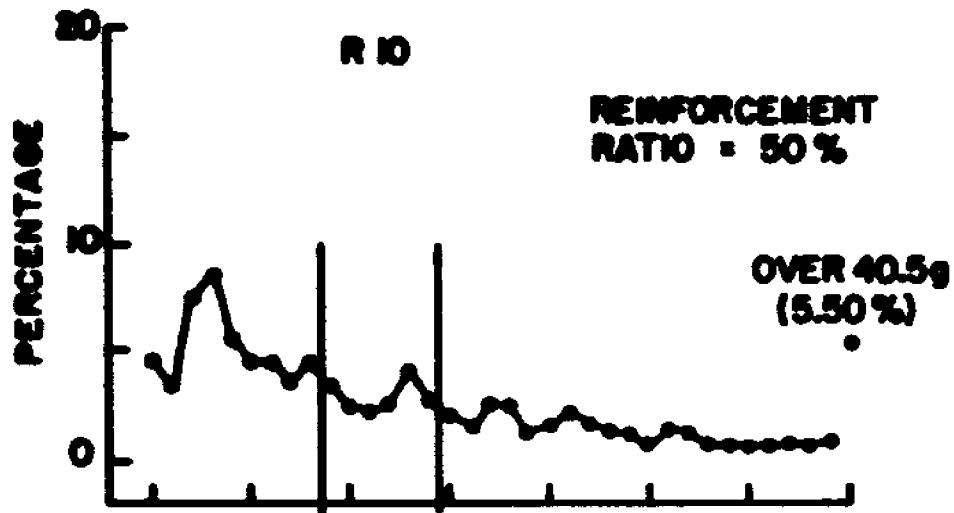
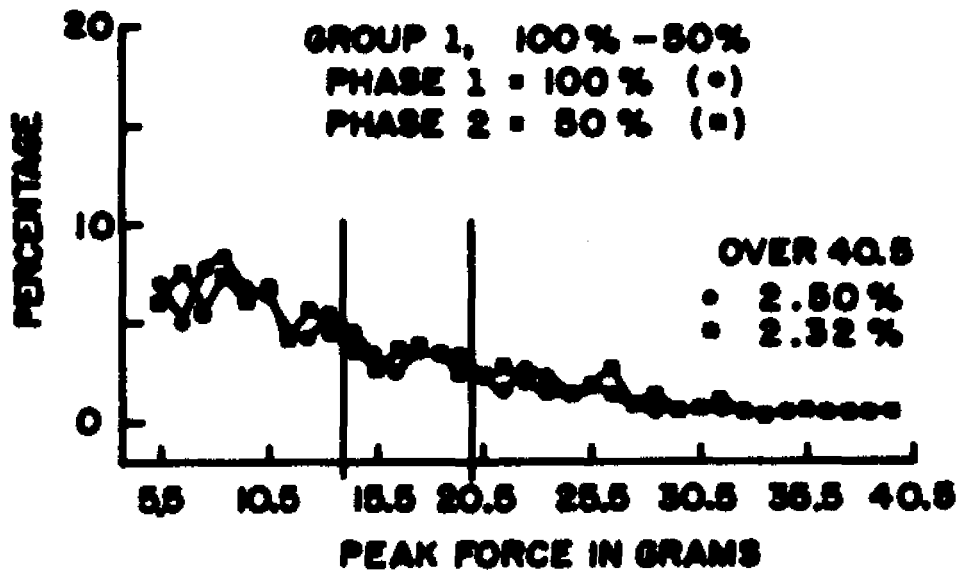


Figure 30

Mean peak force of response distributions for groups 1 and 2 of Experiment 2. Each data point is the mean of the six Ss of each group.



• = OVERLAPPING POINTS

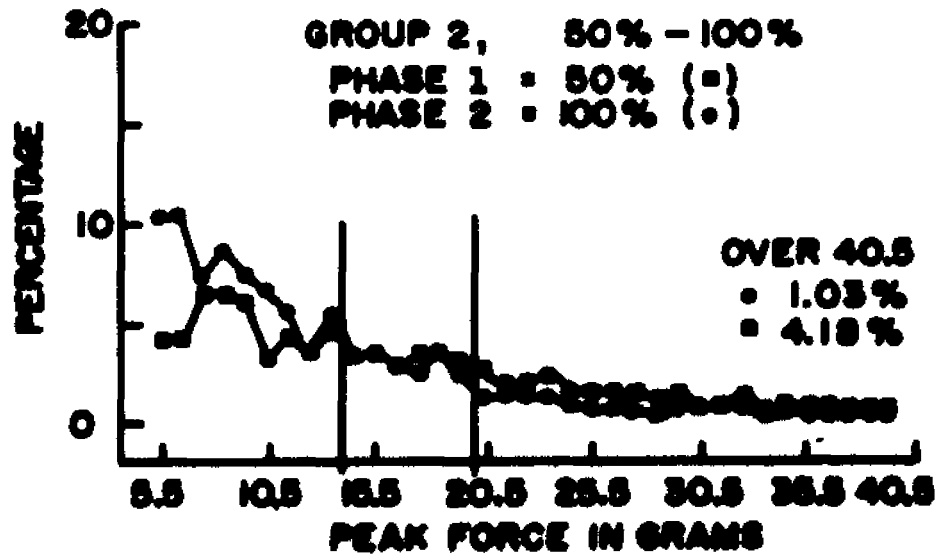


Figure 31

Below, in-band and above band percentages for R 1 and R 3 of group 1 for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived from the individual S peak force of response frequency distributions.

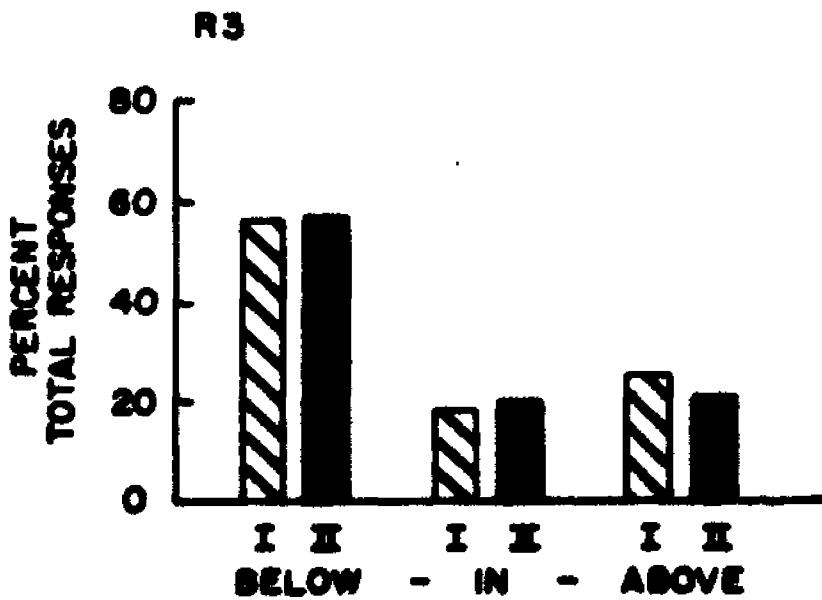
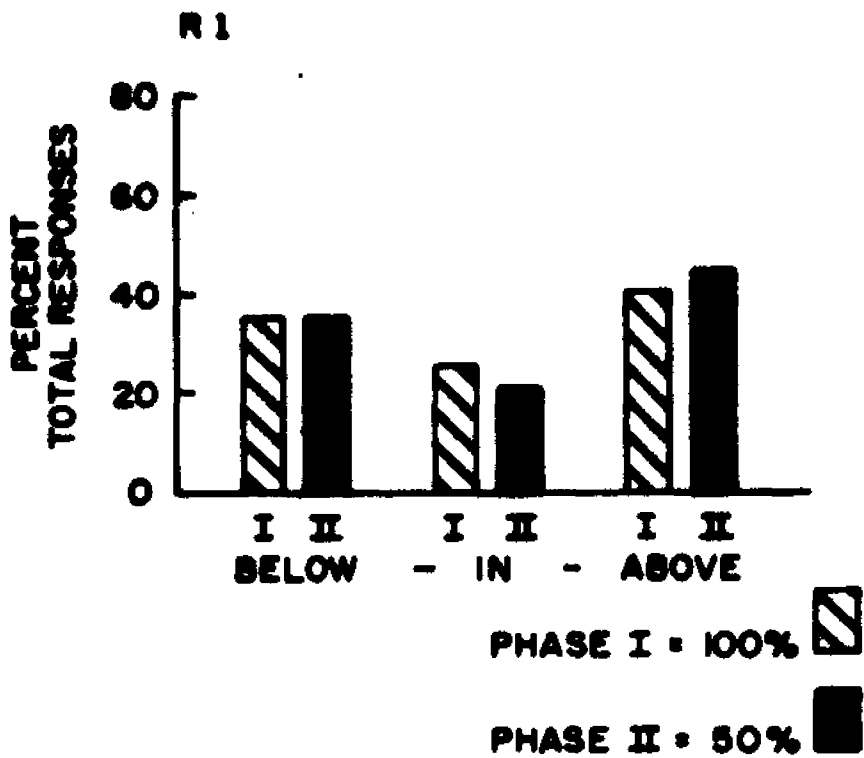


Figure 32

Below, in-band and above band percentages for R 5 and R 7 of group I for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived from the individual S peak force of response frequency distributions.

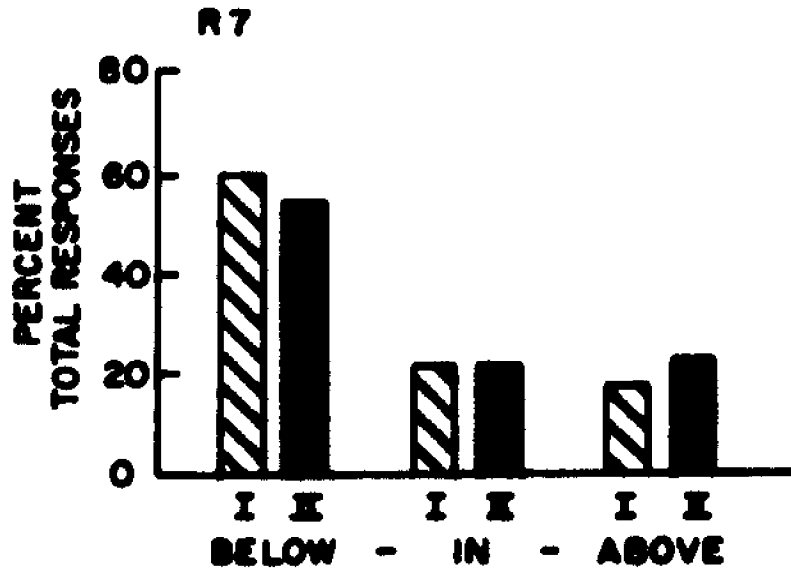
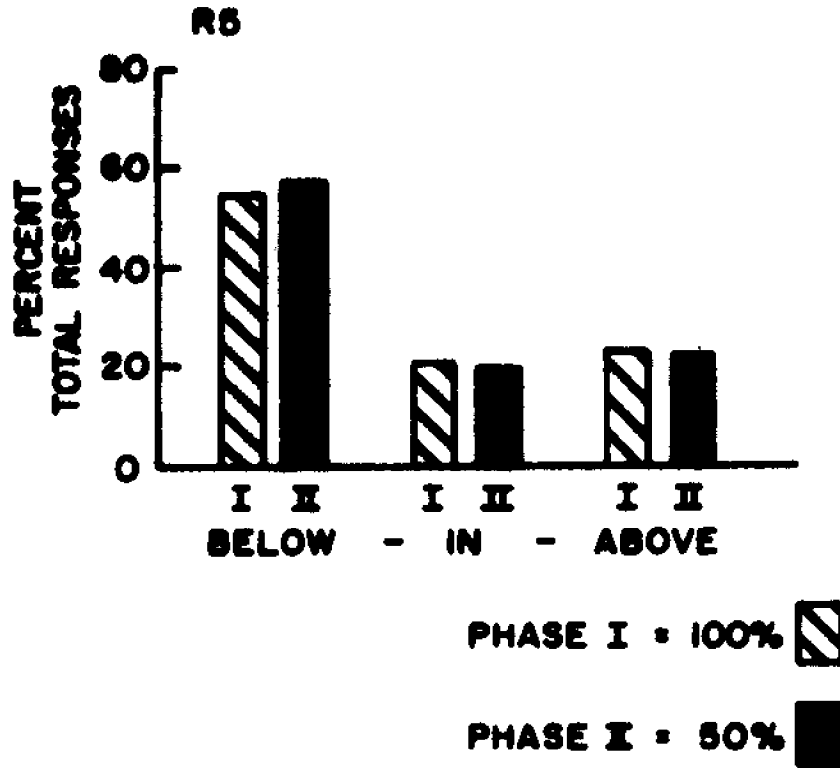


Figure 33

Below, in-band and above band percentages for R9 and R11 of group 1 for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived from the individual S peak force of response frequency distributions.

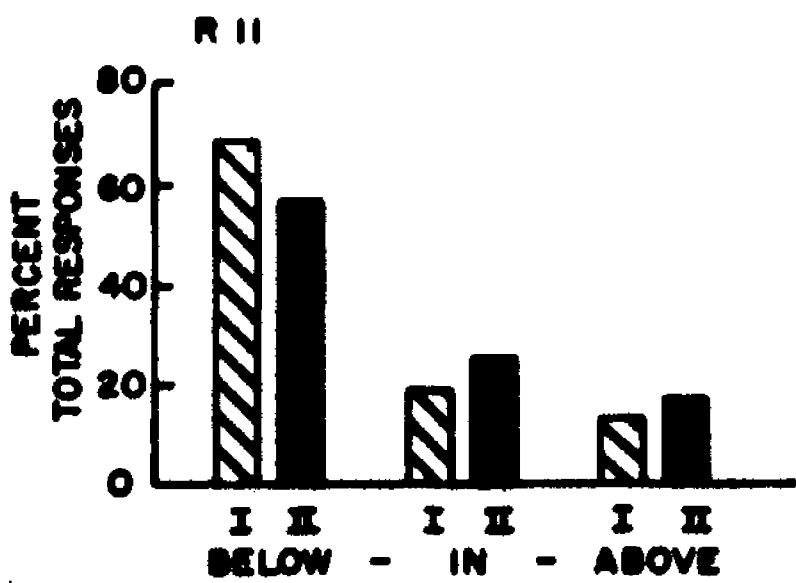
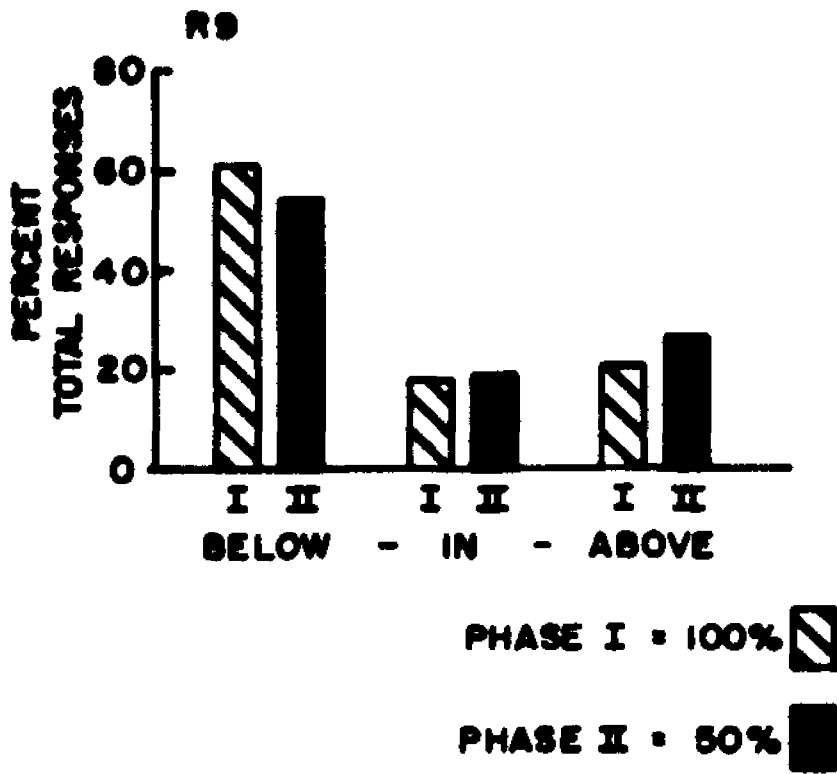


Figure 34

Below, in-band and above band percentages for R 2 and R 4 of group 2 for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figures. Data is derived from the individual S peak force of response frequency distributions.

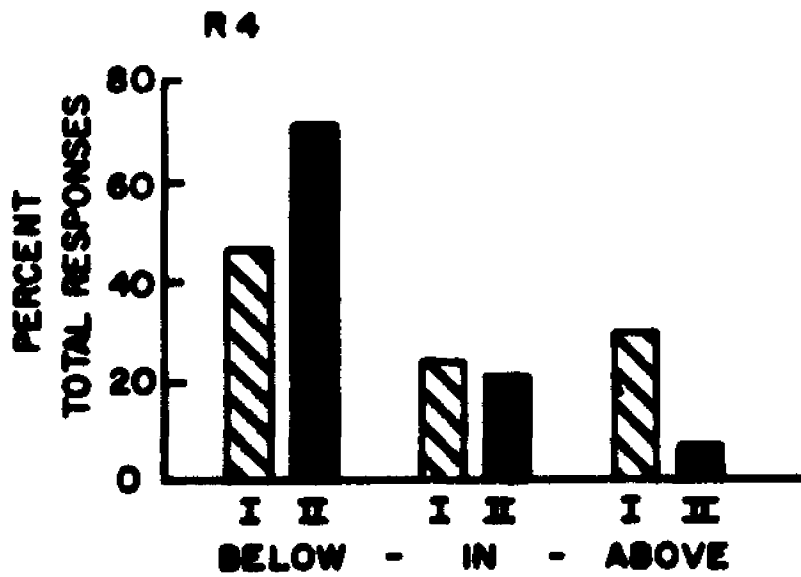
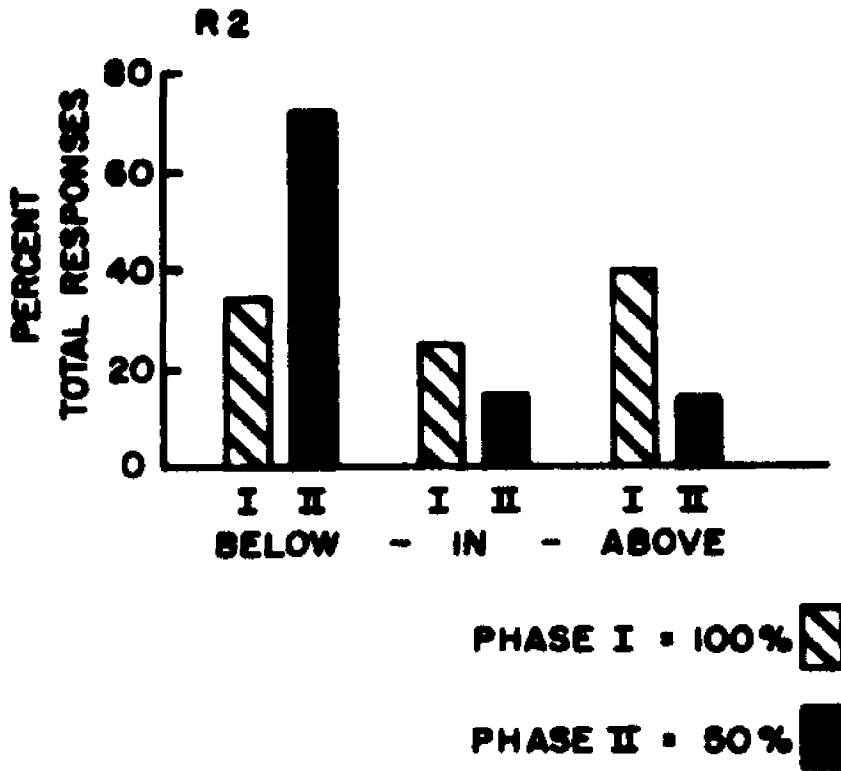


Figure 35

Below, in-band and above band percentages for R 6 and R 8 of group 2 for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived from the individual S peak force of response frequency distributions.

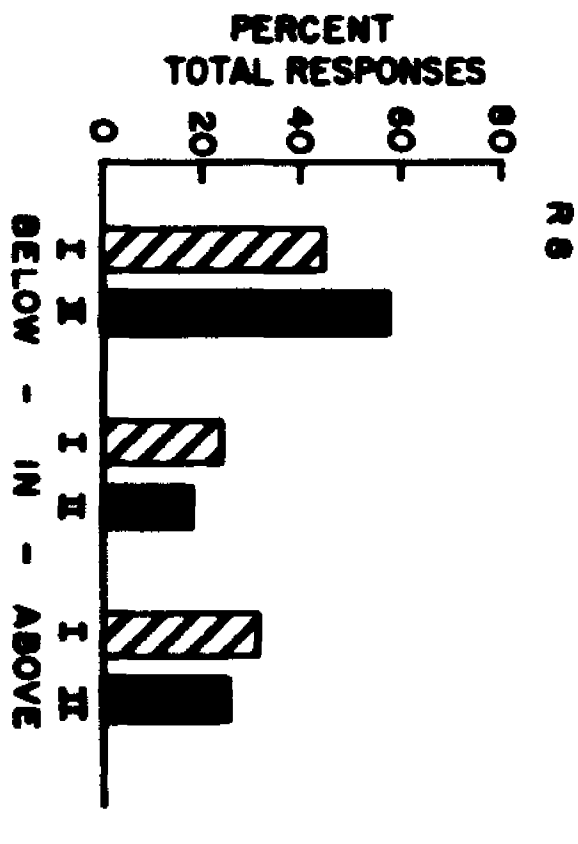
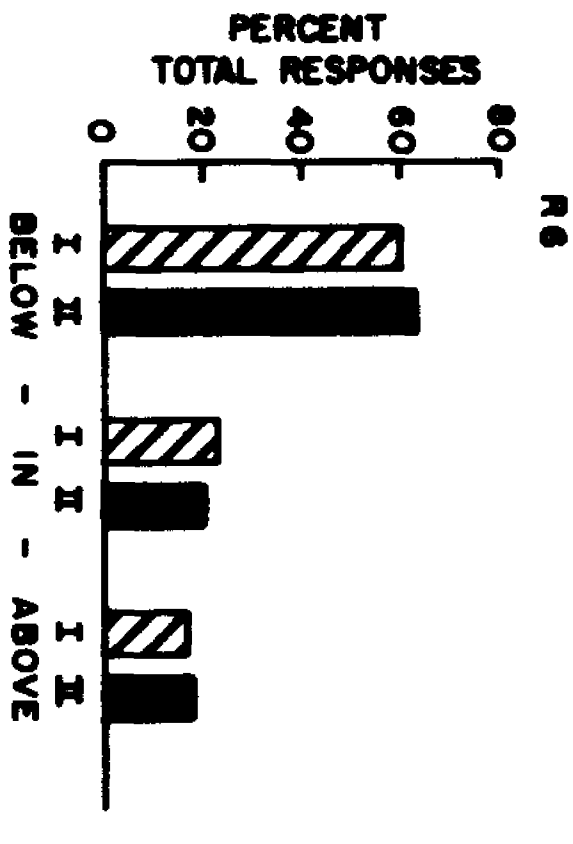


Figure 36

Below, in-band and above band percentages for R 10 and R 12 of group 2 for both Phase I and Phase II of Experiment 2. The band in effect was 14-20 g during all conditions of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived from the individual S peak force of response frequency distributions.

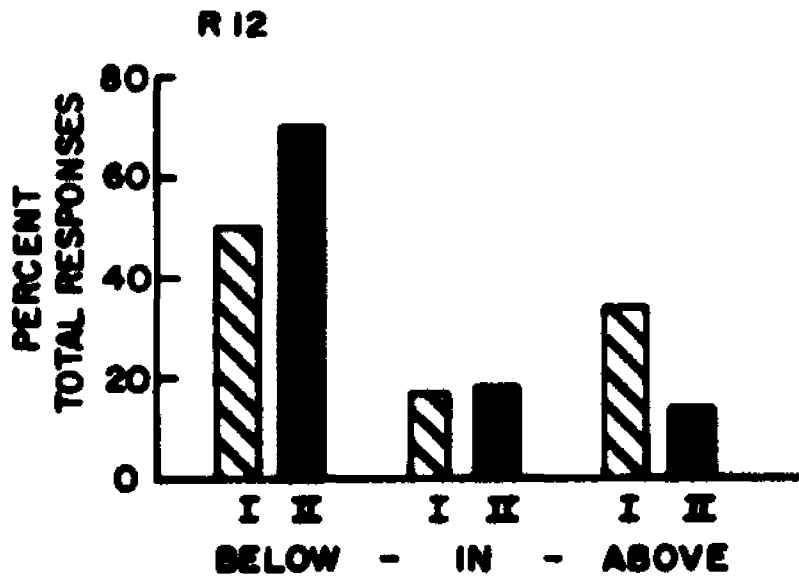
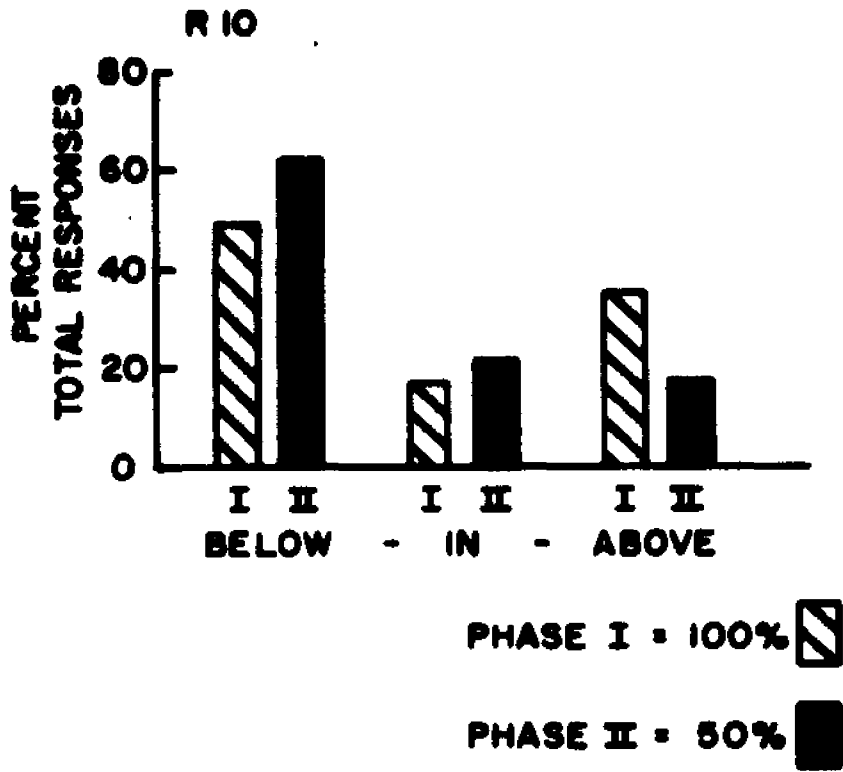
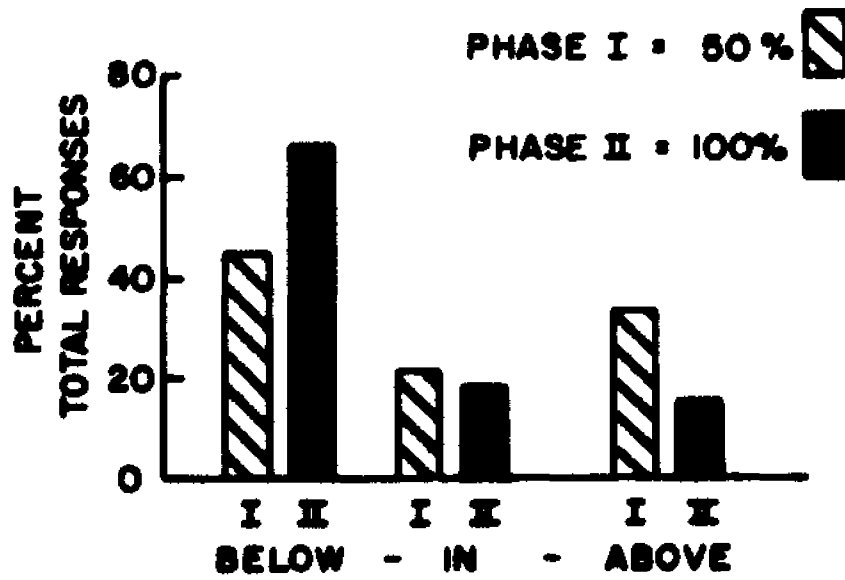
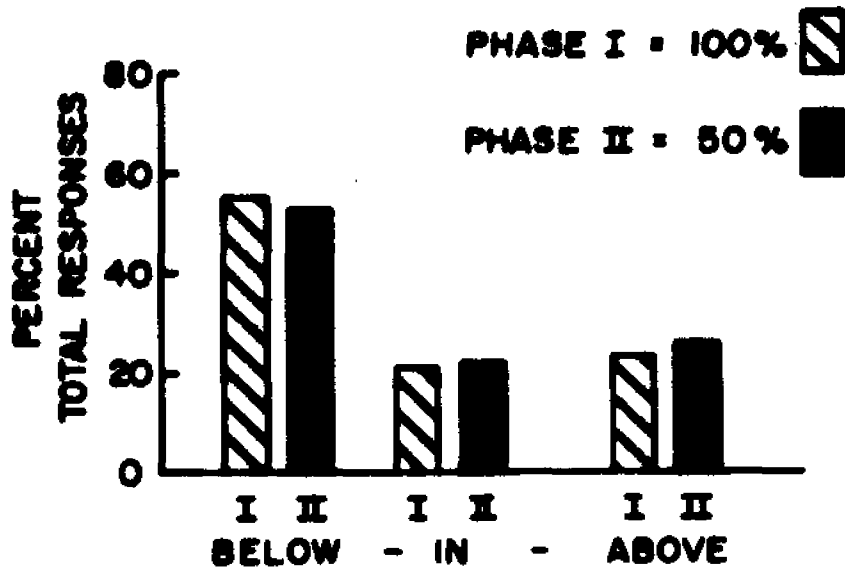


Figure 37

Mean below, in-band and above band percentages for the Ss of groups 1 and 2 for both Phase I and Phase II of Experiment 2. The appropriate reinforcement ratio is indicated on the figure. Data is derived for the individual below, in-band and above band percentages.



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