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THE EFFECT OF FORCE CRITERION AND VARIABLE INTERVAL SCHEDULE ON THE RATE, DURATION, AND PEAK FORCE OF RESPONSE DURING FINAL PERFORMANCE AND EXTINCTION IN RATS

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BY

NED G. BARBER

A dissertation submitted to the Graduate Faculty
in Psychology in partial completion of the
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Abstract

The Effect of Force Criterion and Variable Interval Schedule on the Rate and Peak Force of Response During Final Performance and Extinction in Rats

by

Ned G. Barber

Advisor: Professor Donald E. Mintz

The peak force of bar pressing emitted by rats has been shown to be differentiable by the imposition of elevated force criteria. Following the onset of extinction, response force has been found to increase and then decrease rapidly to a low level in a manner similar to response rate. The effect of two conditioning parameters, the level of the force criterion, and the amount of training undergone, on the emission of forces during extinction has never been methodically investigated.

Nine groups of rats were were trained to press a manipulandum with either 5, 15, or 25 grams of force in order to receive reinforcement. Three of the groups were run under CRF and a force criterion. The remaining six groups were run under a concurrent force criterion/VI schedule (VI 15, 30, 60) to provide for variation in the amount of responding that would be experienced during conditioning. Following conditioning, extinction was run for 10 days.

After conditioning the median peak forces for the 5g and 15g groups was found to above the level of the criterion they were trained with. The 25g groups were emitting forces close to but slightly below thier criterion level. Following the onset of extinction, the forces increased for all groups, with the largest increases shown by the CRF groups. The groups with low force criteria tended to exhibit larger increases in force at the onset of extinction. The tendency of the forces to decrease over the course of extinction was observed, but the rate of decrease appeared to be directly related to the level of force learned during training and to some degree inversely related to the schedule in effect during training.

... in loving memory of my mother,

Mildred Barber

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Skinner (1938) in discussing the measurement of behavior stated "...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 and the response immediately preceding it or in other words the response rate" (p58). This datum not withstanding, Skinner himself felt obliged to examine other properties of responding besides rate.

It has long been known that the reinforcement contingency imposed upon an organism influences many dimensions of operant responding besides rate, and that the final form of the behavior exhibited after a period of conditioning is dependent upon these contingencies. It is also clear that the changes in behavior to be expected following the onset of extinction are, at least to some degree, predicted by the conditions (including the contingencies) that prevailed during training. The specific purpose of the study described in this paper was to determine with some degree of precision the relationship between the training contingencies, the final behavior pattern resulting from continued exposure to those contingencies, and the sequence of changes in the behavior during the course of an extended extinction phase. The specific parameters of behavior measured throughout the experiment were the rate, and the peak force, or magnitude, of a lever pressing response emitted by rats. The goal of the research was to form a better understanding of the variables which shape responding and how these determine the central tendency, and the variability of overall populations of responses.

There are numerous studies in the literature which deal with parameters of responding other than rate. In general, the goal of these experiments has been to quantify the variability (or its inverse, the stereotypy) of the response dimension under analysis during conditioning and subsequent extinction. The studies tend to fall into one of two classes. Those that observed some response dimension while manipulating a reinforcement schedule, and those that attempted to control some response dimension by making reinforcement contingent upon the emission of responses whose values for that dimension met some criterion.The latter constitutes procedures conventionally identified as response differentiation.

The review of the literature which follows deals first with conditioning data and then with extinction data. Within the conditioning section, the non-response differentiation studies are dealt with first, then the response differentiation studies are presented with special focus on those studies involving response force as the response dimension under examination.

I. Conditioning

A. Non-Response Differentiation Studies

Early studies of the non-response differentiation type include that of Antonitis (1951) who measured the variability in the topography of a nose-poking response along a 50 cm horizontaol strip during continuous food reinforcement with rats. Variability was shown to decrease during training, increase during extinction, and decrease to its lowest value during retraining.

In a study similar to Antonitis', but incorporating another variable, Herrnstein (1961) examined the distribution of pecking location on a 10-inch wide key when pigeons were run under Continuous Reinforcement (CRF) and 3 min. Variable Interval Schedules of reinforcement. He found that the variability of peck locus was much lower under the VI. Since the animal always moves away from the key to eat and thus will have greater probability of changing position on its return, he examined seperately those VI responses immediately following reinforcement. While representing a small proportion of the overall behavior, they did in fact have a similarly low level of variability. Thus it appears that the reduced variability is the result of the intermittant schedule itself. Unable to explain his findings, Herrnstein concludes that a " significant but unexplored principle may be involved".

Eckerman and Lanson, (1969) extended the work of Herrnstein in a more extensive study which included CRF, and VI as well as Fixed Interval (FI) schedules. Their data regarding the distributions of response locus on a 10 inch pecking key are in agreement with the earlier reports of reduced variability following extensive CRF training, but they found increased variability relative to CRF levels under the intermittant schedules. They speculate that the reason for this discrepancy between their data and that of Herrnstein had to do with differences in the amount of CRF training allowed; their animals having has roughly twice as many CRF reinforcements prior to imposition of the intermittent schedule, as in the Herrnstein study..

Notterman (1959) examined the force of responses during lever pressing by rats during several stages of a typical operant conditioning experiment. Forces were quite variable and relatively high during the preconditioning phase, but progressively decreased in intensity and variability over the course of training with CRF. Both mean force and variability increased over the conditioning level during extinction.

Extending this line of investigation to include the effects of a light on-light off discrimination, Notterman and Block (1960) recorded the force exerted against the bar by rats learning the discrimination. They found that the forces applied to the bar were reliably higher during the S Delta (stimulus correlated extinction) periods, though the response rate was substantially lower in comparison with the S Discriminative (stimulus correlated reinforcement) periods. Their analysis concludes that this phenomenon is the result of extinction effects during S Delta which caused more forceful responses to be produced. Notterman and Mintz (1965,ch 5) extended this work, by running a similar study in which they employed several degrees of difference between the discriminative stimuli. They also found that the response force was higher during S Delta, but there appeared to be no effect upon response force due to the varying discrimination task.

Mintz (1962) recorded the force of lever pressing responses by rats being run on a Fixed Ratio 12 schedule, and looked at the mean peak force of the responses at each of the 12 points in the FR cycle. He found a systematic increase in force as the animals progressed through the cycle. The possibility was raised that the force level at any point in the cycle could represent a discriminable cue to the organism giving information about incremental reinforcement probability.

Millenson and Hurwitz (1961A) measured the durations of bar press responses (they referred to them as press-release IRT's) and found nearly normal distributions after substantial (>3000 reinforcements) CRF training. Following the onset of extinction the peak of the response duration distributions was shifted upwards and the variability of the durations was increased.

In a separate study, Millenson and Hurwitz (1961B) looked at durations of bar press responses with several different schedules of reinforcement in effect. Fixed Interval (FI) schedules ranging from 30 seconds to 4 minutes in length all produced longer durations and greater variability than did CRF, but there was no systematic difference in the response durations observed among the different schedules. In a second experiment, they showed that extended exposure to a 1 minute FI produced no change in median durations for 3 rats over a period of 60 days of training. In a third experiment they imposed a constant probability of reinforcement for each response and again found longer durations than under CRF, with an inverted U-shaped function relating response duration with probability. Longest duration were observed in the vicinity of a 0.1 probability of reinforcement. Their final experiment involved a Fixed Ratio (FR) schedule with a length of 5, and showed no tendency for duration to change during the sequence of 5 responses preceding reinforcement. This is interesting in light of Notterman & Mintz's (1965) later findings that force as well as duration tend to increase during an FR cycle, particularly with longer FR's. The shortness of the FR 5 used by Millenson may have masked this effect. Furthermore even when within ratio changes in response duration have been shown, the entire population tends to be well below CRF levels (Notterman-Mintz).

Margulies (1961) also studied response durations and found that they tended to be high during operant level, decreased to a low asymptote during training, and were high again during extinction. The distributions of duration in the very earliest part of extinction were similar to those observed during the final stages of conditioning. This was followed by a rapid increase in both the level and variability of duration which led ultimately to distributions resembling those of operant level.

B. Response Differentiation Studies

The second type of study, that in which the response parameter of interest is part of a reinforcement contingency, is typified by the work of Herrick (1964). Rats were trained to press a lever which could have a maximum displacement of approximately 45 degrees from its resting position. Reinforcement was made contingent upon the maximum displacement for any response falling within certain predefined limits. A CRF schedule was employed so that every press with the required displacement resulted in a reinforcement. The apparatus was designed in such a way that the force required to depress the lever was constant throughout the excursion so that the dimension being reinforced, displacement, was not correlated with a force requirement. As would be expected, the variability of the displacements decreased during training. Additionally, there appeared to be a tendency to displace the lever just enough to pass the minimum requirement of the required displacement range. The modes of the displacement distributions fell in close proximity to the low-displacement end of the so called "reinforcement zones." Herrick explains this as a manifestation of a least-effort mechanism, and he points out that this tendency is likely to be related to the absolute effort required by the response. Thus, a low-effort reinforcement range may produce responding throughout its limits, while a high-effort reinforcement range will yield responses near its low limit. The issue may be related to the concept of "response cost", the sum total of factors mitigating against response emissions.

C. Response Force - General Considerations

Studies in which the force of response is included as part of a reinforcement contingency, can be traced back to B. F. Skinner's work in The Behavior of Organisms (1938). Skinner arranged for the reinforcer to be delivered only if a rat pressed a lever with a force exceeding a minimum requirement. It is ambiguous whether Skinner's animals were being trained to exceed a minimum force, or a minimum displacement, or some combination of the two, since the movement of the lever was proportional to the applied force. Nonetheless, the studies reported an increase in the mean force of the responses emitted when reinforcement was made contingent upon higher forces. He states that "when responses are differentially reinforced with respect to their intensity, the relative frequency of strong responses immediately increases." (p 314)

A substantial amount of work has been done along these lines by many researchers in the more than 40 years since Skinner's initial investigations. Since these studies are obviously most relevant to this paper, I shall combine my review of them with a discussion of the rationale underlying studies of response force and a definition of the necessary terminology.

D. Defining Response Force

Notterman and Mintz (1965) in their comprehensive research monograph entitled Dynamics of Response address the definition of response force as follows:

> "There is a striking parallel between the defining operations of 'force' in physics and 'operant' in psychology. The former is defined in terms of its effect upon the state of rest or motion of matter (Hodgeman, 1943). Whenever the state of rest or motion of an object changes, the presence of an unbalancing force is inferred. The 'operant', as we have seen, is defined in terms of the effect of motor behavior upon some specific object in the environment." (p 4)

They go on to say "Hence, it is possible to redefine operant behavior as behavior that is tantamount to the organismic emission of forces." They then present a review of a number of behavioral indices of energy expenditure and their mathematical relationships. Finally they conclude "In short, and as Trotter (1956) has noted, the best index of energy expenditure during motor behavior is the time integral of force of response, a dimension we henceforth refer to as effort." (p 7)

Throughout Dynamics of Response the data they present in many of their experiments are mean peak force as well as mean effort for responses recorded under a given condition or contingency. As Mintz, Samuels and Barber (1970) point out "they provide considerable empirical evidence that the peak force of response is highly correlated with the time integral of force, and is thus a conveniently measured alternative index of energy expenditure."

E. Defining Reinforcement Criterion

Another issue raised by Notterman and Mintz (1965) is the distinction between a response threshold and a reinforcement criterion. They point out that conditioned response strength, the quantitative measure of conditioning, is not necessarily related to magnitude of response force, or frequency of response, but rather to the degree with which the emitted responses comply with whatever magnitude or frequency requirement is in effect. Thus, either high-or-low rate or high-or-low force could represent high response strength. In the case of force, they see an implication that the "proportion of criterion responses" is a suitable index of conditioned response strength.

Their use of the term "criterion responses" is based upon a distinction that they make between two classes of behavior. Their overall class of "responses" is best defined as those behaviors which meet the general topographic and intensive requirements to qualify as the dependent variable under analysis. Thus, for behavior to qualify as a bar press response, it must be directed at the bar, and must have sufficient magnitude to exceed some minimum force threshold. The sub-class "criterion responses" is those behaviors meeting the requirements for classification as a response plus a further requirement determining eligibility for reinforcement: this requirement is the reinfocement criterion, in the present case, a specific force exerted on the bar. Thus, there is a dual definition of mutually exclusive sub-classes; criterion responses and non-criterion responses, which together sum to the overall class, responses. Mintz et al (1976) elaborated on the dual definition with respect to response threshold and reinforcement criterion as follows: "The former defines the generic response class, in a sense a reinforcement independent redefinition of the operant; the latter defines the reinforcement-eligible subclass of the independently defined response."

This dual definition is necessitated by a paradox described by Mintz et al. (1976) which develops when a response is to be differentiated. If one adheres to Skinner's original definition of the operant as "a unit of behavior defined by a contingency of reinforcement...A class of responses, all members of which are equally effective in achieving reinforcement under a given set of conditions", then differentiation is impossible. As mintz et al. point out,

> "The difficulties in such a definition arise from the requirement to redefine the behavior of interest when the procedure calls for selective reinforcement of some new or different range of behaviors. If responses with peak forces exceeding 5 g are reinforced in one phase of a study and those exceeding 20 g are reinforced in another, a comparison of the behaviors is confounded by the redefinition of the operant of interest. In the latter case, "behaviors" in the 5 to 20 g range are no longer members of the operant class that identifies the dependent variable in the analysis." (p387)

Mintz et al cited as an illustration of this paradox a study by Chung (1965) on the differentiation of key pecking behavior in pigeons, in which different forces were required to operate a pecking key in different phases of the experiment. In one condition a key peck with a magnitude of 50 gram operated the key and thus qualified as a response and contributed to rate. In another condition a 50 gram peck did not operate the key and thus was not a response and made no contribution to overall rate. As Mintz et al stated it, "Rate changes were as susceptible to changes in the experimenters measuring behavior as to changes in the pigeon's key pecking behavior." In effect, what is really changing in such a situation is the set of sampling rules used to sample the overall population of behaviors, and thus there is inherent confounding of the results. To prevent such confounding, it is necessary to maintain a uniform sampling procedure independent of the imposition of criteria or other influences on behavior. In the case under consideration what was needed was a separate measure of all key pecks, regardless of their force.

F. Response Force as a Behavioral Measure

Response force has several advantages over most traditional choices as a behavioral measure. It is, as we have just indicated, a reasonably good index of organismic energy output. It can be used as a reinforcement criterion by itself or in conjunction with various schedules of reinforcement, and it will not be intrinsicly confounded by the presence of the schedule itself as would, for example, response rate. In fact, one should be able to measure independently the simultaneous effects on rate and force of schedules and criteria in a parametric study.

Response force exists as a continuum with an essentially infinite number of values. Rate can be thought of as a continuous variable, but rate is a property of a sequence of responses, not of an individual response. Even inter response time is dependent on the occurrence of at least two responses for its determination. Force is unique to, and totally determined within the limits of, the specific response being examined. It is a property of the momentary behavior unlike rate, which has no momentary value where rate is defined by the occurence of two or more discrete events in time.

Other properties of behaviors that are measured along a single continuum have been studied, in particular the location (or locus) of responses along a linear operandum. The major difference between locus of response and force of response as response continua is that changes of locus generally require substantial expenditure of effort (e.g. repositioning, changes in posture) while changes in force would generally require minimal changes in behavior other than the changes in the measured dimension itself. The amount of effort required by changes in locus may not be proportional to the magnitude of the change. The relationship is likely to be a step function since a range of responses could be emmitted with no movement from a given position, while a large movement might be required to emit a response just slightly out of range. Response force is by definition,well correlated with effort, and changes in the two would also be inherently synchronous. In addition, the behavior involved in delivering a peck or nose press at one end of a key does not simultaneously include the behaviors required to deliver a peck at the other end, or for that matter, at any other locus. The behavior of exerting a 25 gram force on a lever does include the behavior of exerting a 5 gram force, as well as all the intermediate forces up to 25 grams. Essentially, force of response represents a true continuum of behavior, while locus represents a range of discrete behaviors at locations along a physical continuum.

G. Response Force Differentiation Studies

Notterman and Mintz (1962,1965) examined the ability of rats to produce response populations meeting a variety of force criteria up to 16 grams. Initial experiments showed that force distributions were shifted upward when a minimum force criterion was imposed, and that the distributions tended to peak well above the actual criterion level. In further studies not only was the organism required to keep the force of response above a minimum, but a maximum force criterion was also imposed. In essence, this produced what the authors refer to as a "band" of reinforcable responses (analogous to Herrick's zone of reinforcement in his earlier attempts to differentiate displacment). The imposition of the upper limit was found to lower the peak force of response produced by organisms exposed to it, compared to organisms reinforced without the upper limit. In addition, the frequency distributions for the animals run with the force band peaked at the lower limit of the band, not well above the lower limit as was the case when the upper limit did not exist.

As a further extension of this band technique, a dual band paradigm was developed where two non overlapping force bands were exteroceptively cued by the on or off state of a stimulus light. The results of this study clearly demonstrated that rats were capable of learning to emit different magnitudes of response force related to different stimulus conditions.

More recently, Samuels (1973) reported a series of studies in which a constant probability schedule was superimposed upon a band reinforcement contingency. In this situation, responses which meet the force band criterion are then subject to a given probability of reinforcement. The bands used varied in terms of both minimum force and maximum force defining the band and the probability of reinforcement for responses meeting the band criterion. The probabilities investigated were 100% and 50%. Results suggested that with the probability of reinforcement at 100%, as the force criterion became more stringent, (e.g. narrower force band), the overall rate of responding increased, but the percentage of responses meeting the criterion decreased. Samuels speculated that an inverse relationship exists between accuracy and rate of response. When the probability component of the contingency was manipulated, the data showed that animals shifted from 100% to 50% manifested no reliable change in forces emmited, while animals started on 50% and then shifted to 100% increased the percentage of low force responses. This was evidenced by downward shifts in the frequency distributions of force for these groups. The accuracy of responding was not effected by changes in the probability of reinforcement imposed in these studies.

Birch (1964) examined the behavior of a monkey exposed to both force and displacement bands in a sequential differentiation study. Two force bands were used, 740g - 790g and 790g - 840g and a total of eight displacement bands were used each with a width of 5 degrees arc. Each session consisted of a period of force differentiation training followed by a period of displacement differentiation training. In addition to the band criteria, a Multiple Fixed Ratio Extinction schedule was in effect during the training. A stimulus light was used to cue the condition in effect. When the light was on, an FR 4 (only within band responses applied) was in effect. The light stayed out for 45 seconds after reinforcement during which time, extinction was in effect. In addition, any within band responses during that period postponed the ligh onset by an additional 45 seconds.

While Birch defined responses as those presses meeting the respective force or displacement criteria, he also recorded presses which failed to meet his criteria but were within the sensitivity range of his apparatus. These non-criterion presses were termed errors. By recording both classes of behavior he was able to show that during both force and displacement differentiation, the first response in each FR 4 sequence was much more likely to be an error (not meet the band criterion) than the subsequent responses.

In addition, his data showed that the subjects response force peaked near the bottom band limit after training on the low band. The force distributions initially peaked below the bottom of the band following the shift to training on the high band, but shifted into the band limits over the course of training. The displacement distributions also peaked within the required bands after training had occurred. The subject produced these distributions despite the fact that for both force and displacement consitions, in band responses during the 45 seconds following each reinforcement prolonged the light-off (extinction) period.

Notterman and Mintz (1965) ran a study with rats in which the amount of food reinforcement delivered was proportional to peak force of response. They varied the ratio of food to force that was programmed as the contingency, or what they termed "specified gain". At a given specified gain, the animal has a choice of making a smaller number of high force responses or a larger number of low force responses to get the same absolute amount of food reinforcement. His "actual gain", the ratio of the average amount of food earned per response to the mean response force will be greater for the case where the smaller number of high force responses are emitted. When the transition from CRF to the proportional reinforcement was made, animals did not achieve actual gains as high as the specified gain. As the specified gain was lowered, however, they did tend to hold actual gain constant, and thus the discrepancy between the two gains grew smaller. In short, though the animals did not exert more force to increase reinforcement rate when presented with the opportunity, they did exert more force to maintain overall reinforcement rate when changes in the contingency tended to lower the rate of reinforcement.

Filion, Fowler and Notterman (1969B) investigated both positive reinforcement and punishment where the magnitude of both stimuli was made proportional to force of response. They found a relationship between the probability of shock and the mean peak force of response when both the shock probability and the magnitude of food reinforcement were proportional to the force of a given response. When the shock probabilities ranged from 10% to 50% there was no effect, but when the probabilities ranged from 20% to 100%, there was a significant reduction in forces.

Filion, Fowler and Notterman (1970A) repeated the earlier proportional reinforcement work of Notterman and Mintz (1965), but used effort as the variable controlling amount of reinforcement. The findings are in line with those discussed previously, namely that the rats did not take advantage of the opportunity to exert more effort per response in return for more reinforcement. A decrease in the number of responses below the minimum reinforcement criterion during training indicated a tendency to minimize effort expenditure that failed to produce reinforcement, a result consistent with a least-effort analysis. Effort appeared to have no real advantages over peak force as either a measure of behavior, or as the basis of a reinforcement contingency.

Filion, Fowler and Notterman (1971) examined the motivational issues of force proportional reinforcement by running rats with 3 levels of prefeeding and then discontinuing the prefeeding. Their findings essentially were that following termination of prefeeding, the animals made up the deficit in intake by increasing their rate of reinforcement, but that this was achieved entirely through increases in response rate, not through increased forces.

Filion, Fowler and Notterman (1970B) also looked at prefeeding effects on force-band discriminations in rats.

Using a "wide" (8g) force band, no significant differences were found for either mean peak force or percentage in band as a function of amount prefed. Rate of responding was influenced slightly, but the relationship was non-monotonic. Following a transition to a narrow (4g) force band, the expected reductions in accuracy were observed, as indicated by lower percentages of within band responses. The final reinforcement rate, however, was not substantially lower, the difference having been made up by fairly large increases in overall rate.

Notterman and Mintz (1965) investigated the characteristics of responses maintained under other forms of intermittant reinforcement using interval and ratio schedules. In addition they imposed various reinforcement criteria based upon effort (as previously defined) in order to determine what interactions might exist between the two aspects of the overall contingency. They point out that the general assumption of response strength being greater under intermittant reinforcement than under CRF is based upon measures of resistance to extinction and response rate. " The degree of conformity of the conditioned behavior to the reinforcement criterion ", they go on to say, "may have as appropriate a place in the concept of response strength as does the frequency and temporal distribution of responses."

Their data show that under a combined fixed ratio-minimum effort schedule (one where only responses exceeding the effort criterion count towards the ratio) the rats overall effort per reinforcement is significantly greater than the theoretical minimum (defined as the minimum effort per response multiplied by the ratio), and this discrepancy increases as a monotonic negatively accelerated function of ratio length. That this elevation was due to the presence of the ratio contingency is clear from the fact that the rats run on threshold criterion yielded overall effort figures well below the theoretical minimum values which would have been required by the ratio contingency. The mean effort per response, on the other hand, was well above the criterion for all subjects in both the threshold and elevated criterion groups, while the percentage of responses meeting the elevated criterion was approximately 50%. These measures did not vary significantly as the ratio was lengthened. Thus it appears that the increased overall effort exerted by the animals with elevated effort criteria compared to the animals on threshold criterion, resulted from changes in the number of responses as well as increased effortfulness of individual responses. The increase in overall effort observed for longer ratios was primarily due to the increased numbers of responses.

When a similar approach was taken with fixed interval and variable interval schedules the results showed that longer fixed intervals generated greater overall effort and that this was entirely attributable to a greater number of responses being emmitted, no increase in mean effort being observed. The data for variable interval schedules was limited, but one finding emerged, namely that on VI, the animals persisted in a tendency to emit more effortful responses just prior to reinforcement than following it. As time of reinforcement is not discriminable, the effect must be interpreted as effort elevation relating to remoteness from prior reinforcement.

Mintz, Samuels and Barber (1976) used VI schedules to study the effects of increasing force criteria or imposing a force band criterion on rate of response and mean force of response. Their findings are summarized as follows: When a new criterion required a variation of behavior that was previously relatively rare, increases in absolute rate are likely. When the new criterion required a variation that was previously frequent, absolute rate will remain constant or decrease. In essence ,if the criterion being newly imposed requires that the organism emit a specific response which it was emitting infrequently prior to the imposition of the criterion the organism does not learn that response variant but rather will increase its overall rate of responding. Given that the desired response variant was at least present with some frequency greater than zero in the previous response population this will have the effect of increasing the rate of emmision of that response variant in direct proportion to the increase in overall rate. While not an energy efficient approach, such a change in behavior does provide an immediate degree of conformity to the new contingency and tends to maintain the reinforcement rate.

H. Human Force Differentiation Studies

The human organism has not been overlooked in the research on response force. In an early study of force differentiation in human subjects, Murphey (1943) used a modified pin-ball machine to assess human subject's ability to adapt their behavior as he imposed upper and lower force limits. His results revealed that as he narrowed what he called the "tolerated range" (analogous to what we have defined as a force band) the percentage of reinforced responses initially decreased, but that the decrease was reversed after continued training. It was clear that the subjects compensated for the change in the reinforcement contingency which resulted in more of their responses falling outside of the reinforced range, (and fewer of their responses being reinforced) by increasing the accuracy of their responding. This reduction in variability was visible in the response distributions they were generating, and was the mechanism by which the percentage of reinforced responses was increased to its original value.

A close analog of response force was examined by Hefferline and Keenan (1961) who measured human electromyographic (EMG) potentials in a study of amplitude differentiation. The response differentiated was a small thumb contraction and the reinforcement was the removal of white noise which masked a baseline music signal in the subjects earphones. For a response to qualify for reinforcement, the EMG potentials had to fall between a lower and an uppper limit. Subjects initially emitted responses with amplitudes far in excess of that required for reinforcement, but these high amplitude responses soon dropped out and the response rate of responses meeting the criterion was maximized. A slight tendency to respond with slightly greater amplitude than necessary was maintained throughout the conditioning period.

Mintz and Notterman (1965) examined the relationship between absolute force level and response variability when human subjects were asked to emit responses at several different force levels. The different levels ranged fron

25g to 200g and were exteroceptively cued by stimulus lamps in front of the Ss. Their results showed that while the absolute variability increased at higher force levels, the relative variability, or more specifically the ratio of the standard deviation to the force level being reinforced, declined.

Filion, Fowler and Notterman (1969A) continued the study of response force and human psychophysics in a study which analyzed Weber ratios produced during a cued multiple criterion paradigm. Human subjects were required to emit one of five forces cued by an array of signal lamps, and were given digital feedback of the force in grams that they had just emitted immediately following the termination of the response. Weber ratios were determined for subjects run under normal conditions, reduced cutaneous feedback conditions (produced by injections of xylocaine), and reduced exteroceptive feedback conditions where a click was substituted for the digital indication as a signal that the force had been within a small range around the target. The ratio of the standard deviations to the target values were here assumed to be a close analog to the more familiar ratio of the difference threshold to the point of subjective equality. The curves show that both types of feedback manipulations increase the Weber ratios by about 20%. As an additional experiment, a monkey was run on the click only condition for comparison. The monkey Weber ratios were about 50% higher than the human's under the same conditions.

Mintz, Samuels, Barber, and Grossman (1971) attempted to assess te contribution of cutaneous feedback to response precision by varying the diameter of the surface that the human subjects pressed on, thus affecting the pressure applied to the skin for a fixed force. A smaller surface would yield a greater change in pressure for small variations in force than a larger surface, and thus might improve accuracy. The results showed no such effect, but the possibility that the 200 g target force was already in the range where proprioceptive and not cutaneous sensation was the primary feedback was suggested as an explanation, and the need for a similar study using much lower target forces was apparent.

Schwartz and Mintz (1980) applied the band paradigm in a study with human subjects, in which both a high force band, starting at 240g and a low force band, startng at 120g were used. The width of the bands was sytematically reduced from an initial value of 80g to 40g, 20g, and finally 10g, and then returned to 80g. The narrower bandwidths produced downward shifts in the central tendency of the force distributions, with a slight tendency towards reduced variability, but the percent of responses in band was also lower. This indicated that the subjects were only able to partially compensate for the more stringent criteria by increasing their accuracy and precision. Response variability was found to be lower with the low force band than with the high force band at comparable band widths, and this agreed with the earlier findings of Mintz and Notterman (1965).

II. Extinction Studies

A. Non Response Force Studies

Historically, extinction has been shown to produce abrupt but transient changes in behavior. Skinner (1938) defined extinction of operant, or what he calls type R, responses as follows: "Extinction of a conditioned reflex of type R occurs when the response is no longer followed by the reinforcing stimulus."(p74) He describes the effects of extinction as follows: "When the first response to the lever fails to supply the stimulus for the next member of the usual chain, the response is elicited again immediately, and a high rate of elicitation is maintained for a short time. This is soon interrupted and the rate subsequently undergoes an extensive fluctuation."(p74)

Skinner also looked at the force of responses during extinction following differentiation of a high force response. He reports an initial rise in force, followed by a decrease to a low value. In addition, he states that when differentiation training "is maintained for periods on the order of 10-15 days, the decline in force is much delayed."

Skinner tended to equate the non-reinforcement of sub-criterion responses during training with intermittent or irregular reinforcement. With regard to rate changes in extinction, he states "those after prolonged differentiation are still of the magnitude to be expected from irregular reinforcement."

Skinner showed no data relating extinction effects following intermittent reinforcement. Hilgard and Marquis (1961) in Conditioning and Learning discuss the issue of extinction and the effortfulness of the response. They cite several studies which they claim support the assumption that a response requiring greater effort will extinguish more quickly than one requiring less effort. A typical experiment used a weighted bar as a means of controlling effortfulness. They point out, quite correctly, that a problem exists with regard to partial responses, those presses not strong enough to trigger the recording and/or reinforcing apparatus. The question is, they state, should these responses be counted during extinction. This is equivalent to the problem discussed earlier regarding the redefinition of responses during differentiation, and is solved by the dual definition system employed by Notterman and Mintz (1965), in which all extinction responses above response threshold would be recorded, and the responses meeting a previously imposed but no longer operative criterion would be counted as a subset.

Of the recent studies already discussed, several included extinction as one of the test conditions. Millenson and Hurwitz (1961) found that extinction produced increases in various indices of central tendency and of dispersion for duration distributions for rats trained on CRF. Margulies (1961) showed that duration distributions very early in extinction were similar to those late in conditioning, but that as extinction progressed, the distributions came to resemble those produced in operant level.

Eckerman and Lanson (1969) showed that following differentiation of a pecking response in pigeons the response locus along a 10 inch wide pecking key was more variable during extinction than during conditioning, but the central tendency as indicated by the peaks of the locus distributions did not shift appreciably from those observed during conditioning.

One of the parameters which can be varied in any study of response differentiation, and which is likely to have an effect upon the behavior exhibited during extinction, is the amount of training undergone by the organism. To the degree that response strength builds up over time as the organism is exposed to a given contingency, and thus emits a certain response variant, then it seems likely that the changes which occur in the frequency of this response variant during extinction will be related to the total period during which the particular response variant was reinforced.

This relationship between training and extinction behavior is demonstrated by Thompson, Heistad, and Palermo (1963) who investigated the relationship between the amount of training undergone by rats prior to the onset of extinction and the changes in response rate and response duration following the onset of extinction. Using a CRF paradigm they observed that the onset of extinction would produce " 1) little or no change in the frequency, duration and variability of responses when initiated during the very earliest stages of conditioning, 2) a great increase in response frequency and duration when initiated in the middle stages of the acquisition of the operant, and 3) progressively smaller increases in frequency, duration and variability when initiated following longer courses of training beyond the point of stable asymptotic CRF response rate." Thus, a non-monotonic, inverted U shaped function appeared to exist between the duration of training, and the degree of disruption occuring immediately following the onset of extinction with regard to response rate, duration and variability. Stevenson and Clayton (1970) used a 40-second criterion for response duration in an interesting study involving secondary reinforcement. When the lever had been depressed for 40 seconds, white noise came on, at which point lever release was reinforced with food. Thus, a behavioral chain was created of the form:

R1 SD R2 SR

Press lever ----- White noise --- Release lever - Food
(40 seconds)

This resulted in distributions of duration which peaked at 40 - 41 seconds. For one group of rats during extinction, the chain was broken between R2 and reinforcement: thus a

40 second press still resulted in white noise but subsequent release did not cause reinforcement to be delivered. The duration distributions for this group showed minimal change, and the rate of complete chain emisions followed its usual course for extinction by rising sharply and then falling off. Another group had the chain broken between R1 and R2 so that no white noise or food was present. The duration distribution for these animals was immediately disrupted during extinction in addition to the usual rate changes.

It appears that for the first group, the tendency during extinction was to emit the same response learned during training, namely holding the lever until the onset of white noise, but with a reduced frequency of occurrence. The second group was, in effect, disrupted in its ability to emit this sequence of responses by the elimination of the noise stimulus. Since there was no requirement for a temporal discrimination during training, none was learned, and removal of the temporal cue previously provided by the white noise caused a reversion to an essentially random distribution of lever holding durations.

B. Response Force Studies

Of the studies already cited which involved force of response as part of a contingency, few have considered the effects of extinction. Notterman and Mintz (1965) looked at extinction following CRF training with 2.5g, 8 g, and 16 g force criteria, and found the characteristic increase followed by a decrease of peak force. The degree of initial increase in force was the greatest for the group that was trained with the 2.5 g criterion. Since 2.5 g was also the response threshold, this group, in effect, was on absolute CRF. The 8 g group showed much less of a shift. Following reconditioning of both groups at a 16g criterion level, a second extinction was run which showed still less of an increase in force than for either group during the initial extinction. Again, the possible interactions between amount of training and extinction are likely to be involved here, since the second period of conditioning represented an increase in the overall extent of exposure to a force criterion, albeit at a different level.

Filion, Fowler and Notterman (1969B, 1970A) also considered extinction in their studies of proportional reinforcement, and their results show the expected rise and fall of not only force, but also effort (time integral of force).

III. Summary of Questions Raised

Several questions arise out of a summary of the literature cited here. First, what is the most general effect of intermittant reinforcement on the variability of specific response characteristics, and what distinguises measures such as locus which typically are less variable , from force and other measures that are more variable when intermittant reinforcement is applied? Second, what happens to these characteristics during extinction and how are these effects related to the levels attained by these characteristics during training? Third, to what degree does the amount of training interact with these phenomena? Fourth, do an animal's responses in extinction resemble its responses during training while their probability of occurrence decreases? This final question is suggested by several studies, but one in particular raises it very clearly. Stevenson and Clayton (1970) in the study of exteroceptively cued differentiation of response duration just described showed that if the secondary reinforcer, white noise, was still present in extinction, the response durations were still controlled by it, even though primary reinforcement was withheld. If one considers the response-concomitant proprioceptive and cutaneous feedback as playing the same role of secondary reinforcer in a force differentiation which the white noise did in the duration differentiation, then it seems reasonable that during extinction these stimuli should maintain control over the response force, independently of response rate.

In general the point can be made that if any complex behavior, such as a differentiation, is examined very closely, it is possible to analyze the behavior in terms of smaller individual components. Many of these can play two roles, as "responses" in a chain, and as secondary reinforcers for previous response components in that chain. Then is is possible that the overall behavioral chain would tend to maintain its internal structure even when the primary reinforcer is no longer forthcoming. While the overall probability that the chain would be initiated should decrease during extinction, once the chain was initiated the internal secondary reinforcers could still serve to control the behavioral sequences which give the overall chain it properties. Furthermore one would expect the chain to break down from the end closest to reinforcement, and such a process of degradation would necessarily be gradual, so that the effect would last well into the course of extinction. Thus the phenomenon would be observed that the frequency of responding (or initiation of the chain) would follow the characteristic rapid decrease expected during extinction, but the nature of the response (the structure of the chain) would remain relatively unchanged until well after the onset of extinction. Additionally, the amount of training undergone by the organism in making the specific response would be expected to influence the strength of the secondary reinforcers and thus determine the time course of the degradation process, and the degree to which the response properties persisted during extinction.

IV. Purpose of the Present Study

The present experimental analysis includes an attempt to assess the validity of this theory, and to further examine the effect that the amount of training would have on the strength of the hypothetical secondary reinforcers.

In designing such an experiment, it was necessary to choose a schedule of reinforcement to be used during conditioning and final performance as a baseline against which to compare extinction data. Several requirements had to be met by this schedule. It had to provide for easy initial conditioning with a minimum of pretraining so that the animals training regimen could be as predefined as possible. It had to yield high rates of response during conditioning so that a large population of responses would be available for analysis, and the rate of response had to be uniform so that the animal engaged in a minimum amount of uncontrolled "other" behaviors.

Finally, the schedule had to yield reasonably high resistance to extinction so that a sufficient amount of extinction responding would occur to provide large enough populations of responses for establishing reliable behavioral measures and statistical analyses. CRF was obviously ruled out by the requirement for high resistance to extinction. FR and FI schedules were inappropriate because of the characteristically cyclic rates they produce. The choice then was between VR and VI, and the VI was chosen because it would provide experimental sessions of uniform length and number of reinforcements, as well as large populations of responses and relatively high response rates and persistence during extinction.

The selection of the VI length and dispersion was based on Catania and Reynolds (1968) comprehensive study of interval schedules of all types. One of the types they discussed is the constant probability schedule, where the probability of reinforcement of any IRT shorter than the shortest interval is held constant at the reciprocal of the number of intervals. The method for devising such a set of intervals is based upon the fact that as time since reinforcement increases, there are fewer and fewer intervals with times longer than or equal to the current time since reinforcement. Thus, the probability of reinforcement increases. If, on the other hand, the difference in the duration of intervals is greater as the intervals are longer, this probability increase is counteracted. A cogent discussion of the mathematics underlying these schedules was provided by Fleshler and Hoffman (1962). The actual constants chosen provided a constant probability of reinforcement equal to .02. The mean interval durations for the three schedules used were 15, 30,and 60 seconds.

The primary purpose of the study is to investigate the changes that occurred in rate and force of responding over the course of extended extinction. The independent variables were the force criterion in effect during training, and the amount of responding on that criterion. Force criteria of 5, 15, and 25 g were selected, values typical of earlier research. The manipulation of the amount of responding during conditioning was achieved by using the three different VI schedules just described. In addition, CRF was used as a condition to provide for comparisons with much of the existing literature and because it represents in a sense a limiting case of the VI continuum. Practical limitations on the availability of the single experimental apparatus and reasonable time limits on the duration of the experimental runs did not permit a complete factorial investigation of all possible combinations of force criteria and schedule length. The cells actually selected were chosen to provide the largest possible range of conditions for both independent variables.

Method

This research was run in two parts, separated by a period of approximately two months. Since the subjects, apparatus, and procedures were essentially identical for both parts, the method section deals with them as a single experiment.

Subjects

The subjects in this experiment were 36 male Sprague Dawley rats, approximately 75 days of age when obtained. All of the animals used were selected randomly from a larger population which was obtained from Holtzman Inc. in Madison, Wisconsin. Standard laboratory procedures were applied to insure the health and well being of the animal population both prior to and during the experiments.

Upon entering the laboratory each rat was placed in a stainless steel cage (Wahmann Mfg. Co.) and given free access to water and Purina Lab Chow in pellet form. The rats were maintained on this diet for approximately two weeks before food deprivation was begun. Two weeks prior to the beginning of training the experimental subjects were placed on a 23-hour food deprivation regimen. A cup containing Purina Lab Chow in mash form was placed in each cage for one hour every day. No food was available to the rats at any other time, but free access to water was maintained at all times throughout the course of the experiment in both the home cage and in the test chamber. The animal colony room was kept on a 12 hour light-dark cycle, controlled by an electric timing unit, with the lights coming on at 7:00 AM and remaining on until 7:00 PM. The temperature was maintained at approximately 21 degrees Celcius by heating and air conditioning as needed.

Apparatus

The test cage in which the experimental sessions were run was located in a sound insulated isolation room with interior dimensions of 1.52 m long, 1.22 m wide, and 1.52 m high.The walls, ceiling, and floor of the room consisted of a 7.6 cm thick sandwich of plywood-urethane insulation-plywood. The interior of the walls and ceiling was covered with two layers of acoustical tile, and the floor was carpeted. The entire room was mounted on a vibration damping pad consisting of a sandwich of carpet padding and Celotex.

The room was ventilated through two openings in the ceiling which were connected to an external 7.13 cu ft/min blower through a sound attenuating baffle. The air intake drew air from the overall laboratory space which was maintained at approximately 21 degrees Celcius. The room was illuminated by two 20 watt cool white fluorescent lamps mounted along the long walls near the ceiling, at a distance of approximately 1.5 meter from the cage. Although no formal noise attenuation measurements were made in the isolation room, reports from human subjects who occupied the chamber during other experiments idicated essentially complete attenuation of normal outside noises. In addition, during the experimental sessions, white noise was provided from a loudspeaker inside the room driven by a Grason Stadler White Noise Generator Model #12B , to further mask outside sounds which might pass the accoustical baffle.

Access to the isolation room was through a three by five foot door at one end of the chamber. The test apparatus stood on a table at the other end of the chamber. The test cage was a modified Scientific Prototype Model A102 Skinner Box, with interior dimensions 17.76 cm wide, 25.40 cm long, and 20.32 cm high. The cage assembly was suspended from blocks which rode on two aluminum rails so that it could be slid away from the operandum assembly for maintenance purposes. The pellet dispenser was also suspended from the same rails as the cage and was attached to the cage by a length of plastic tubing which carried the pellets to the feed cup. The entire framework which supported the apparatus was mounted to the metal table. The operandum/force transducer assembly was mounted on a massive aluminum plate which rested upon the table, and there was no direct contact between the cage/feeder components and the operandum/transducer unit. In this arrangement the heavy plate helped to damp out any cage or feeder vibrations before they reached the transducer.

The operandum was the polished top end of a vertical aluminum rod, 1.26 cm in diameter, inserted inside a larger aluminum cylinder in which it was free to move vertically. The bottom end of the aluminum rod rested upon the sensing element of a Statham Model UC-3 pressure transducer which was screwed into the bottom of the outer cylinder, so that any force applied to the operandum was directly transmitted to the transducer. Under normal operating conditions the smaller rod protruded approximately 4.0 mm beyond the end of larger cylinder. The outer cylinder served as a guard around the actual operandum rod, preventing contact except on its horizontal top surface.

The transducer is the basis for any force measuring system. It converts the force applied to its sensing shaft to an analog voltage which can then be measured by a variety of electronic techniques. The Statham Model UC-3 Force Transducer is capable of sensing forces applied to its shaft within a range from 0 to 60 g with a displacement of less than 1 mm at maximum force. Thus the operandum was essentially nonmoving regardless of the force applied to it. The output voltage provided by the UC-3 transducer is linear with the applied force within a tolerance of 1%.

The resonant frequency of the combined operandum and transducer mechanical assembly was approximately 300 HZ, a frequency which is well above the highest response rate produced by rats in these and other studies. This assembly was mounted vertically on an adjustable support which was bolted to a massive aluminum plate that rested on an isolation pad on the metal table. The operandum extended into the cage through a cutout located in the center of one of the short walls and was positioned so that the operandum contact surface was 3.0 cm above the floor of the cage. Since there was no direct attachment of the operandum assembly to the test cage, movements of the rat or vibration from the pellet dispenser were isolated from the force measurement system.

The feed cup into which the pellet dispenser emptied was located 4 cm to the left of the operandum assembly. A water bottle was located 4 cm to the right of the operandum. Thus the animals were not required to leave the vicinity of the operandum to eat or drink.

The output of the transducer was amplified by circuitry located in the isolation room , and the resulting high level analog signal (approximately 5 volts) was transmitted to the electronic system outside the room via shielded cables. The signal went directly to the input of an analogue to digital converter, (CYCON Model # 1205) which was interfaced to a Digital Equipment Corporation PDP-8E minicomputer by means of the external I/O Bus. While the converter was capable of sampling at a rate of 10,000 samples per second, other programming constraints required that the sampling rate be kept to 5 kHz.

The computer processed the converter output in one of two modes. In the calibrate mode, the computer repeatedly executed a program which sampled the transducer output 2000 times (at the 5 KHz rate) and then computed a frequency distribution with a resolution of .01 volt. The median of this distribution was displayed on a 3 digit remote readout located next to the amplifier in the isolation room. This readout was used to adjust the amplifier so that the transducer output in volts was made isomorphic with the force applied to the operandum in grams. Thus a force of 5 grams applied to the operandum produced an output of .5 volts, while 60 grams gave a 6.0 volt signal. The trandsucer was calibrated daily and was always linear from 0 to at least 60 grams with an error of less than 0.1 gram. Calibration was accomplished with the use of static weights.

It should be noted that throughout this report forces are expressed in grams to correspond to our calibration procedures which employed the static application of weights. Grams, technically units of mass or weight when operated upon by Earth's gravitation may be converted to true units of force, Newtons (N), by multiplication by the constant (.1) This derives from the value of the gravitational constant, 980.665 cm/sec/sec with a 1.0 g mass producing a force of 980.665 dynes, a dyne being 1 milliNewton.

In the run mode the computer sampled the amplified transducer output at the 5 KHz rate and recorded the occurrence of responses according to a set of carefully defined rules. A threshold level of 5 grams was used because earlier work in this laboratory had shown it to be reliably produced by most paw contacts with the operandum, yet a reasonably good filter for behavioral "noise". Whenever the force level went above threshold the computer began timing response duration. If the force fell below threshold in less than 10 milliseconds the timing register was cleared and the program again waited for a rise in force. If the force remained above threshold for more than 10 milliseconds a response was considered to have begun. The program then monitored the signal until a level below the threshold was detected. A 10 millisecond subthreshold requirement equivalent to that used to define the beginning of the response was applied to define response termination.

In this way a minimum value of 10 milliseconds was required for both IRTs and durations. This requirement acted as a filter preventing any vibrations or electrical transients from counting as responses or subdividing a single event into two responses. The 10 millisecond values were chosen arbitrarily but were taken as values that were unlikely to eliminate actual paw contacts with the operandum, nor to permit subdivision of one undivided behavior into several responses.

During each response the peak force reached was tracked by the computer program, and following the termination of the response,was stored in memory along with the duration and the preceding IRT. Eligibility for reinforcement was determined for each response based upon the schedule and force criteria in effect, and the pellet dispenser was activated for all reinforcable responses.In addition, a code was added to the stored force value for all reinforced responses to facilitate later analysis. The system was capable of storing the peak force, duration,and IRT values for 3000 responses. Simultaneaous with this, a 550 bin frequency distribution of peak force was kept in the system, and updated after each response. The status of the run was available at all times on the computer terminal, as was a printout of the updated frequency distribution.

Long term storage of the raw response data was made possible by writing the contents of the computer storage area onto magnetic tape cassettes. The data were available for later analysis either on the lab computer itself or on a more powerful computer located at the University Science Center.

The lights in the isolation room were under control of the program, and were automatically turned on at the start of a session and off at the end. A closed circuit TV camera was mounted inside the chamber and was connected to a monitor in the control area, so that the test cage could be viewed without disturbing the animals. Analog records of force were also monitored on a storage oscilloscope which aided in guaranteeing the reliability of the measuring and contingency implementing systems.

Procedure - Conditioning

The basic design of the experiment can be seen in Table 1 which shows that combinations of force criteria and reinforcement schedules tested and the number of subjects in each test group. While it would have been attractive to test all possible combinations with 5 or more subjects, the practical limitation of having only one apparatus set-up and a finite amount of time available for running animals forced the selection of specific cells from the matrix for study. The decision to investigate all the reinforcement schedules at a 5 gram criterion and all the force criteria under CRF was made to increase the chance that any force or schedule related trends would be revealed. The N for these cells was kept equal at 5 with the exception of the CRF 15g cell which sustained a mortality during the course of the study. The additional cells chosen were included to provide some indication of the effects of combining elevated criteria with longer VI schedules. The relatively long run time for VI30 and especially VI60 conditions precluded the inclusion of the remaining cells in this study.

The procedures followed were the same for every animal with the exception of the reinforcement contingency in effect during training. On day one, each animal was placed in the test cage and allowed 5 minutes to acclimate to the new environment. At this point the operandum assembly was not in place in the cage and the cutout in the cage wall was closed by a flat aluminum plate. After 5 minutes , tray training was begun. Pellets were delivered automatically once every 30 seconds for 15 minutes and then manually for another 15 minutes. During manual delivery the animals were observed on the T.V. monitor. An approximate 30 second period was used, but an effort was made to avoid reinforcing specific locations or actions. In every case, by the end of tray training the animals responded to the click of the pellet dispenser by approaching the food cup with a latency of less than 5 seconds.

On day two, the operandum was restored to its normal location and a CRF contingency was programed. Each animal was placed in the chamber to self shape, and was allowed 60 reinforcements. Initial contact was often made with the nose during exploratory sniffing, and since a CRF schedule was in effect these nose presses were reinforced. The location of the operandum and the low force requirement resulted in rapid development of the desired pawpress response in most cases. Some animals were more resistant and maintained either a nose press or a combined nose-paw press response form throughout the course of the study.

All of the rats completed the initial shaping session of 60 reinforcments within the preset 1-hour limit. The times ranged from 15 to 56 minutes. Due to the number of animals involved, it was not possible to complete tray training and shaping on consecutive days. The procedure adopted was to tray train all the animals, and then to shape all the animals. Since at the end of shaping, some of the animals had just been shaped, while others had not been in the box for 2 days, it was decided to give all the rats one more session of 60 reinforcements on CRF before imposing any new contingencies. This was done for all the animals in a single day and provided a more uniform starting point for contingency training.

Following the CRF day, the rats were run for 25 days with their assigned contingencies in effect. The individual response data from the final five days of training were stored on tape for later analysis. The last 8 days were run consecutively in all cases. While the varying reinforcement schedules utilized resulted in substantially different session durations, the number of reinforcements delivered per session was held constant at 50 for all experimental groups.

The contingencies used were a combination of a VI or CRF reinforcement schedule and a minumum force requirement. The VI series used were of the constant probability variety as generated by an algorithm given in Catania & Reynolds (1968) The mean interval lengths were 15, 30, and 60 seconds. The algorithm generated series of 50 different interval lengths ranging from 1 second to approximately 4 times the length of the mean interval. The values were given to 1 decimal place, but were truncated to the nearest second since the VI program being used to run the sessions had a maximum resolution of 1 second. This resulted in there being several 1 second intervals in each series. 10 randomized sets of intervals were generated from each VI series and were stored on tape. During the 25 running days the 10 sets were cycled through two and one half times to prevent patterns of intervals from being learned and to counterbalance any sequence effects which might be present in any particular set.

The force requirements used were 5, 15, and 25 grams. The 15 and 25 gram requirements applied only to reinforcement, and any response over the 5 gram threshold was counted and recorded. An unlimited "hold" procedure was used for the VI schedules. Once reinforcement eligibility was established according to the then-programmed interval, eligibility persisted until the next criterion response occurred and the reinforcer was delivered.

The breakdown of animals assigned to particular conditions can be seen in Table 1. The rats identified with numbers from 50 to 61 were run in the first part of the experiment, those numbered 70-93 were run in the second part. The number of subjects for each cell in the main arms of the parametric square is 5 except for CRF 25g cell where a fatality reduced the number to 4. The inner cells all have an N of 2 and serve to elaborate the major data.

Procedure - extinction

On the day immediately following the final conditioning session, extinction was begun. The conditions in the isolation room and all procedures for the maintenance and experimental handling of the animals were identical to those during training. Extinction was run for a total of 10 days for each animal, in two blocks of 5 days separated by one day on which the animals were not run. Each extinction session consisted of placing the animal in the test cage for a period of 20 minutes, with the operandum present. The water bottle was in its place, and the pellet dispenser was loaded with food pellets as usual so that there would be no difference in the background olfactory stimulation between extinction and conditioning. The single difference was that the pellet dispenser was not activated following any response. The data collection system functioned as it had during conditioning and the were recorded as usual, and the animals were oberved on the closed circuit TV system for the purpose of noting any unusual behaviors that developed during extinction.

The independent detection and recording of all responses meeting the pre-extinction force criteria continued throughout extinction, thus providing quantitative measures of the changes in the relevant sub classes of responses, in addition to data on the overall rate of responding.

Results

The data collected and analyzed during the course of this study can be divided into two categories. Final performance conditioning data were collected during the last five consecutive days of training under the various reinforcement contingencies used. Extinction data were collected during all 10 days of training, run in two sequences of five consecutive days, during which the reinforcement contingencies were suspended and no pellets were given. Although data were collected for each animal during the entire 25 days of running, the data appear unremarkable. Since the purposes of the study did not include any investigations into the processes operating during the acquisition of the behavior under question, but rather were to assess the effects of the independent variables upon final performance and the course of subsequent extinction, these acquisition data have not been included in the analysis that follows.

Response Rate Data - Final Performance

The first part of this section deals with the final performance data collected for all nine experimental groups identified in Table 1 which shows the number of Ss in each of the nine experimental groups. Table 2 shows the mean number of responses per animal for the five final days. There were two possible dimensions with respect to which the contingencies differed, the minimum force required for a response to be eligible for reinforcement (or the force criterion), and the length of the VI schedule imposed. It is obvious from the Table that both higher criteria and longer schedules tend to produce greater numbers of responses. The relationship appears to be monotonic, the only exception to this being the VI15(15g) group.

Table 3 shows the overall response rates for the nine groups averaged over the final five days of training, and Table 4 shows the same data presented for each individual animal. The daily values were obtained by dividing the total number of responses emitted by each animal on each of the five days by the total session duration on that day. Figures 1 and 2 present these same data as well as the criterion response rates for the nine groups arranged by schedule and force criterion respectively. The data clearly indicate the same substantial increases in responding with higher criteria and longer schedules, that were evident in the total number of responses. That longer VI schedules and higher force criteria result in increased rates of response is clearly demonstrated by a comparison of the CRF(5g) group whose mean response rate was 15.6 responses per minute (r/min) with either the CRF(25g) group or the VI60(5g) group both of which manifested mean response rates of 40.7 r/min.

The imposition of force criteria and reinforcement schedules effects the behavior of the organism through changes in rate of reinforcement (Sr/min), and since the sessions were terminated based upon a total of 50 reinforcements, the total run duration will also vary proportionally with the reinforcement rate. Table 5 shows the average session duration for the nine groups over the final five days of training. Table 6 shows the average rate of reinforcement for the nine groups over the same period, and Table 7 shows the rate of reinforcement for individual animals over the same period. Rates of reinforcement were computed by dividing the total number of reinforcments (held constant at 50) by the daily session duration for each animal.

The data presented in Tables 2 through 7, and Figures 1 and 2, reveal an interesting fact about the basic design of the experiment. It is apparent that the imposition of elevated force criteria does not produce lower rates of reinforcement or longer run times, primarily because the animals increased their rates of response sufficiently to compensate for the effects of the different contingencies. This is not true for the contingencies involving VI schedules because it is the nature of an interval schedule that the maximum rate of reinforcement is governed by the average interval length in the schedule. The animal's behavior can at best serve to keep the rate at this maximum, by maintaining a high response rate and minimizing any delays between the onset of reinforcement eligibility and reinforcement delivery. The situation is complicated even further when elevated force criteria are combined with extended schedules, since the animal must maintain his rate of criterion responses at a high level to influence the reinforcement rate, but the maximum is still set by the schedule.

Table 8 shows the rate of responses meeting the force criteria in criterion responses per minute, (RC/min), and the percentage of the total response population falling in this category. For the CRF animals, since there was no temporal schedule in effect, the criterion rate is equivalent to the previously shown reinforcement rate. The animals run on a 5 gram criterion which was equivalent to the system threshold level had in effect all of their responses in the criterion category. It is interesting to note that all the animals run with elevated criteria managed to keep anywhere from 39% to 62% of their responses above the force criterion in effect. Figures 1 and 2 also show the overall and criterion response rate data, arranged by force criterion and schedule respectively. As would be expected, the lowest rates are observed for the CRF groups, where the relatively high rate of reinforcment leads to a substantial proportion of the total time being devoted to food acquisition and consumption. Looking across VI lengths within a particular force level, there is a tendency for overall rate to increase above CRF rates, amd then decrease as one looks at longer VI's. It must be noted however that the rate for the VI15(15g) group (n=2) is elevated by the atypical behavior of R52 who was observed to bite the operandum, in sharp contrast to the other Ss who applied pressure with either a paw or a nose press. His overall rate was 125.4 r/min while R53 had a rate of 53.7 r/min. The trend observed for the overall rates is mirrored by the criterion rates, although the absolute values are by necessity lower. When the rates are grouped by schedule length the most apparent characteristic is the relative invariance of criterion response rates within a given schedule. For the CRF group they are practically identical regardless of the criterion force level. This is not surprising since for these groups criterion rate is equivalent to reinforcment rate, and as mentioned previously this rate is limited by the duration of tray approach and consummatory behaviors. With a VI15 or VI30 schedule in effect, the criterion rates are still much less sensitive to the presence of an elevated force criterion than the overall rates even though the rate regulating effects of tray approach and consumatory behaviors are of neglible consequence.

Response Force Data - Final Performance

Table 9 gives the median peak force and the standard deviation for each of the experimental groups over the final five days of training. The force medians shown were computed by taking the medians from frequency distributions covering the five days for each animal, and then averaging these medians within a group, thus the different number of responses produced by different animals does not weight the average disproportionately. A similar procedure was used to computes the standard deviation figures. Figure 3 presents graphically the same peak force data shown in Table 9. The effects of the elevated force criteria are quite apparent from the uniform force peak force levels they generate. The mean of the medians for all three 15g groups are well above 15 grams. In reality there was a wide range of individual medians, as can be seen in Table 10 which shows the median peak force for each animal. Of the nine animals run at 15 grams, only 2 had medians below 15 grams and these were 12.3, and 14.3 grams. One animal was at 16.5 grams, and the remaining five were all above 20.0 grams. The value for the VI15(15g) group is probably inflated by the atypical data from R52 who, as previously mentioned, tended to bite the operandum and whose median force of 29.0 was by far the highest observed for a rat during this or previous studies in this lab.

One obvious phenomenon is that the imposition of a 15 gram force criterion produces a substantially higher response force than does a threshold criterion. However the 25 gram requirement adds relatively little. For the 25 gram groups neither average was above 22 grams, and only one animal's median was above 25 grams. The general picture is one of overshooting a moderate criterion and undershooting a high criterion. Also apparent from the data in Table 9 is the relatively small contribution of the schedules in determining response force. For the 5g groups the median peak force ranges from 8.4g to 9.5g. . Similarly the range for the 15g groups is 18.4g to 21.8g and the two 25 g groups differ by only 0.8 g .

Several statements can be made with regard to the variability of response force for each of the 9 groups as shown in Table 9, and given for each animal individually in Table 11. Just as there was no apparent difference in the level of force emmited by animals running under the same force criterion but with different reinforcement schedules, there is also no difference observed between these groups as far as variability is concerned. Similarly, the positive effect observed upon response force by the imposition of elevated force criteria, is matched by an increase in the variability of response force under the same circumstances. That the variability of force increases as the absolute level increases is not surprizing, considering what is known regarding Weber's law and the psychophysics of the difference threshold.

Table 12 shows the mean Weber ratios (Standard Deviation/Mean) for each of the nine groups, and Table 13 gives the ratios for individual animals. They were computed by dividing the individual animal's standard deviations of peak response force by their median peak response force, and then averaging across the members of each group. In traditional Weber Ratios the fraction expresses the proportion of absolute stimulus level subsumed by the difference threshold at that level. By analogy the ratio here is expressed as the standard deviation divided by the Mean, the numerator a quantification of variability which is assumed to be representative of the difference threshold, the denominator the absolute level. In general it appears that the ratios decrease as the level of forces being emitted increases. This implies that while the actual minimum difference that can be sensed is larger for higher forces, it does not increase linearly and thus the minumum difference that can be sensed is not as large as it would be if the ratios were constant. As Table 13 illustrates, there is substantial intra-group variability. This suggests that these Weber Ratios are subjects to the influence of other, and presumably uncontrolled determinants besides force criterion and reinforcement schedule.

A fuller description of the effects of the force criteria can be seen in Figures 4,5,and 6. These are frequency distributions of the peak force of response for each group over the 5 final conditioning days. For all the 5g groups up to VI30, the distributions are modal at 6.0 grams, with between 60 % and 70% of the responses falling in the 5 to 10 gram range.With the exception of a tendency to peak more sharply under CRF than under VI schedules, there does not appear to be any schedule related effect present in the data for the 5g groups. The distributions for the 15 and 25g groups have a much flatter shape. They are modal anywhere from 6 to 10 grams, and in all cases at least 70% of the responses are over 10 grams. As was the case for the 5g groups, there is no substantial effect related to the schedule length apparent in these figures. It us important to note that the CRF(5g) group is for all intents and purposes a control group since it has had no special contingeny imposed upon it other than the normal baseline requirements of the 5g threshold.

The differences in response force attributable to the elevated criterion can be demonstrated by hypothetically applying a 15 gram requirement to the CRF 5g distribution. Less than 25% of the overall response population would meet the elevated criterion. Using the overall rate for that group of 15.6 responses per minute the projected reinforcement rate would be approximately 4 reinforcements per minute. The real CRF(15g) group had 60.2% of its responses over 15 grams and had a reinforcement rate of 14.7 reinforcements per minute.

The basic finding evident here is that the imposition of an elevated force criterion profoundly influences the distribution of forces emmitted by the animals. This occurs reliably whether the force criterion is imposed with CRF or concurrent with a VI schedule, and the effect is independent (within the range tested) of the length of the VI schedule. The change which such a contingency induces in the distribution of forces in all cases results in at least a partial compensation for any reduction in reinforcement rate which the contingency would tend to create if applied to the distribution typical of CRF with a (5g) threshold criterion.

Response Duration Data - Final Performance

Response duration was also recorded for each response, and Table 14 shows the mean of the median response durations and the variability of response duration for each of the 9 experimental groups. For a specific force criterion level if one compares the durations generated by CRF with those under any of the VI schedules one sees a reduction in durations of approximately 50%. Thus the mean of the median response durations for the CRF(5g) group is 86 milliseconds, while for the three 5g, VI groups, it ranges from 36 to 54 milliseconds. If, on the other hand, one holds the schedule constant and looks down the column at the three force criteria used, the effect is almost exactly the opposite. Any deviation from a 5g threshold crtierion level results in a doubling of the response durations. Again, by way of example, the CRF(5g) group shows 86 milliseconds, while the CRF(15g) and CRF(25g) groups show 170 and 190 milliseconds respectively. Table 15 gives the individual median response durations for each animal, and it can be seen that while there are differences between the performance of individual animals within the same group, the general trends described appear to be supported in the majority of the cases.

The data on the variability of response duration do not present quite as clear a picture as the durations themselves. Two general trends do appear to be present which match the trends observed for duration, at least in terms of direction. The VI schedules in general seem to result in lower variability of response duration than CRF, while higher force requirements seem to result in greater variability of response duration than the threshold (5g) criterion. It is of interest to note two comparisons while examining the data on response duration and its variability. The CRF(5g) group and the VI15(15g) group produced almost the same median duration (86 vs 90 milliseconds) and Semi-Interquarter Range (120 vs 120 milliseconds). The overall rate data for these two groups show that they had the highest and lowest rates among the nine experimental groups, 15.6 r/min for CRF 5g and 89.6 r/min for VI15 15g. On the other hand, the two groups with the highest and lowest duration and SIQR, VI15 5g at 36 and 40 milliseconds, and CRF 25g at 190 and 250 milliseconds, in fact had very similar overall rates, 40.7 and 47.8 r/min respectively. It is clear from these relationships that the response duration and response rate are uncorrelated, This may be interpreted as these two time-based behavioral properties reflecting differentiation by different aspects of the reinforcement requirement.

Response Rate Data - Extinction

Extinction was run for 10 days, and consisted of a daily 20 minute session in the test cage with the operandum in place. All responses were recorded, but no reinforcements were delivered.

Table 17 shows the average number of responses emitted over the entire course of extinction for all nine groups. Since the numbers are averages, they are not confounded by the varying number of Ss in the groups. Table 18 presents the number of extinction responses for the individual animals in each of the groups. These tables reveal some interesting phenomena. It is clear that the animals run on the interval schedules for 25 days responded more frequently during extinction than the CRF animals, and thus would appear to have had greater resistance to extinction. There does not appear to be any pattern, however, to the average number of responses generated by the three VI lengths. There is also no clear relationship between the force criterion in effect during training and the average number of responses in extinction. In fact, it almost seems that the higher forces produce more responding among the VI groups, and less responding for the CRF groups, but the differences are too irregular to make any definitive statements.

Figures 7 through 9 show the changes in response rate across all 10 extinction sessions for all 9 groups. Each point in these graphs represents the mean of the response rates of all the animals in a particular group on the indicated day. The unconnected points near the ordinate show the average rate over the five final days of conditioning for each group. In every case the rate of response on day 1 of extinction is lower than the conditioning rate, and continues to decline at least up to day 3. From day 3 on, the rates drop more gradually, and in sme cases increase again although the increases are usually transient. The smallest change in rate with the onset of extinction is observed for the CRF(5g) group which also had the lowest final response rate. The most substantial rate rate changes are observed for those groups which had the highest of response during conditioning, particularly the VI15(15g) group, and the VI15(25g) group showed in Figure 8. The final response rate seems to be relatively uniform regardless of the variety of initial rates. With a single exception the response rate is below 6 responses per minute for all groups from day 6 on. The distinction among groups is clearest in the early days of extinction where the CRF animals shown in Fig. 7 are clearly responding at much lower rates than the various VI animals shown in Figs. 8 and 9.

The immediate drop in rate following the onset of extinction can also be seen in figures 10 - 17, which show response rate in extinction for individual animals. The relatively small initial rate change for the CRF(5g) group as a whole is seen to be the result of a bidirectional rate shifts for the individual animals shown in Fig. 10. One animal increased its rate on day one of extinction,1 remained virtually unchanged, and 3 decreased.

In addition to rate reduction, these figures show a convergence of the rates for the animals in each group. For the CRF(15g), and CRF(25g) groups (figures 11 & 12), the variability of rate within the group is dramatically reduced on extinction day 1, and is again substantially reduced on day 2. The mean response rates for the CRF(25g) group during the final five days of training range from 25.2 responses per minute to 59.4 responses per minute. On extinction day 1, the range for the same group was from

4.5 to 12.5, and on day 2 it was from 3.1 to 4.7. Less dramatic but similar trends are observed for all other groups.

Worth noting is the atypical behavior of several animals, noteably R82 (see figure 10) who, in spite of having been trained on CRF, with a 5 gram criterion, maintained an elevated rate throughout extinction. Less remarkable is the tenacity of R61 (see figure 17) whose history of training under VI60 would be expected to produce the resistance to extinction which is in fact observed.

In general the force requirement in effect during training, seemed to have little effect on either the absolute values, or the pattern of change of response rates during extinction. The only variable observed to exert any control over these parameters was the schedule imposed during training, and the effect was dichotomous: the CRF animals dropped their rate extremely rapidly, while the 15,30, and 60 second VI animals all performed uniformly, dropping their rates more gradually.

Response Force Data - Extinction

A rather different picture emerges for measures of response force during extinction. Table 19 shows the median peak force for each group computed as the means of the individual animal's daily medians for the first five and last five days of extinction as well as for the five final days of conditioning. From the figure it is possible to get an idea of how the various contingencies affected the peak force of the responses emitted during extinction, and also to see something of how that force level varied over the course of extinction, although with rather course resolution. It is obvious that the elevated force criteria used during conditioning resulted in elevated response force during extinction. In all but one case the force levels during either the early or late phases of extinction are higher for the animals trained on a 15g criterion than for those trained at threshold, (5g). For corresponding phases, (eg. days 1-5 or 6-10) the forces emitted by the 15g groups are invariably higher than the 5g group with the same schedule. Similarly, the animals run with the 25g criterion typically produced forces higher than those of the 15g animals. The sole exception to this was the CRF(25g) group whose 12.8g median force in the second half of extinction was lower than the 14.4g observed for the CRF(15g) group in the same period.

The differences between the peak forces in early and late extinction present an interesting picture in that for the three groups run under VI schedules with a 5g criterion, the late extinction forces are all slightly higher than those observed during early extinction. For all other groups, the reverse is true, namely that the forces dropped in the latter part of extinction by sizeable amounts, typically 4 to 8 grams which amounts to a force reduction of 20 to 40 percent. It should be pointed out, that even with these reductions in force the average force levels generated by the all the groups over the last five days of extinction were in the range of 9.1 to 14.4 grams, well above the 5 gram threshold. What appears to be true is that during the second half of extinction, the peak force emitted by the animals in all the groups which had trained with elevated criteria converged upon a value of approximately 13g The group means ranged from 12.5 to 14.4 a scant difference of 1.9g bewteen the highest and lowest groups. The sharp drop exhibited by the CRF(5g) group from 15.6 grams to 11.9 may best be understood as a reaction to that groups having the largest jump in force at the beginning of extinction. This groups training contingency ,pure CRF, produced the most discriminable difference between conditioning and extinction. All other groups experienced unreinforced responding during conditioning.

Figures 18 - 20 show median response force on a day by day basis for each group across the entire course of extinction. Each point is the average of the medians for all the animals in a group on a given day. Again the point closest to the ordinate is the average value for the 5 final days of conditioning preceeding the start of extinction. It is apparent that initial exposure to extinction tends to generate higher forces. With only one exception response force is higher on the first day of extinction than during the final days of conditioning. The exception is the VI15(15g) group, and is probably atypical and attributable to the extraordinarily high forces exhibited by R52 as mentioned previously.

The most profound force changes are exhibited by the CRF(5g) group, the same group which showed the lowest rates and least persistent responding during extinction. In general, for the groups trained with a 5g force requirement, the tendency for response force to remain elevated during extinction seems to be inversly related to the length of the VI schedule in effect during training and thus, to the amount of responding generated during conditioning (see figure 18). This relationship is not exhibited for the 15g and 25g groups (see figures 19 and 20). In fact, the opposite appears to be true; the longer VI's produce a greater tendency to maintain elevated forces in extinction. In figure 19, with the exception of the very high value shown for the CRF(5g) group on day 1, the VI30 group shows forces substantially above the other groups throughout the first four extinction days. Equally apparent is the perseverance of high force responding for the VI15(25g) group (see figure 20). While elevated forces would seem likely for animals trained with elevated force criteria, the maintenance of these force levels over several days of extinction is worth noting.

An additional demonstration of the maintenance of elevated forces over the course of extinction is given in Figure 21 which shows the percentage of the total responses exceeding the pre-extinction criterion level for all elevated criterion groups. The leftmost point for each curve is the average percentage above criterion for the last 5 days of training. The four threshold (5g) criterion groups were necessarily above the criterion 100% of the time throughout, and are not shown. As would be expected the animals on with the low (15g) criterion had higher percentages meeting the criterion than the animals with the high (25g) criterion. This relationship appears to remain relatively constant during extinction. What is most interesting is the slow decrease in these percentages over the course of extinction. With the exception of 4 points, all three 15g groups have greater than 40% criterion responses throughout extinction. The two 25g groups, with the exception of 2 points exceed criterion with better than 25% of their responses throughout extinction. That these elevated percentages are not simply related to rate variations following the onset of extinction is obvious if one looks the extinction response rates (figures 7 - 9) which dropped precipitously following the onset of extinction, and remained at low levels.

The data on the percentage of criterion responses during extinction, when taken together with the median force distributions during extinction suggests a clear behavioral trend, namely that the animals will tend to emit the same forces in extinction that they were reinforced for emitting during conditioning.

This phenomenon is made even more remarkable when it is recognized that the same animals that were maintaining their force of response in the range they had exhibited during conditioning were exhibiting rapid reductions in rate of response over the same period. The overall picture that emerges is one of independence between response rate and response force, or more simply, between the probability that a response will occur and the characteristics it will have if it does occur.

In addition there appears to be a relationship between the reinforcement schedule in effect during training and the liklihood that response force will remain elevated during extinction . Training with short schedules that produce high rates of reinforcement result in initial elevation of force during extinction, followed by rapid reductions of force. Higher force requirements during training coupled with the same short schedules results in less of an increase in force from the conditioning levels, but the force reduction that follows is more pronounced. Training on longer schedules with their associated lower reinforcement rates results in small increases in force during exctinction for animals with low force requirements during conditioning. Long schedules in conjunction with high force requirements during training generate small increases in force over the conditioning levels, but the rate with which these forces decline during extinction is substantially reduced, and the decline does not begin until much further on in the course of extinction.

Discussion

Review of Procedure

To recapitulate the procedure, the study consisted of 9 groups of rats which were run under differing reinforcement contingencies. The contingencies differed in two dimensions. The minimum force required for a response to be eligible for reinforcement was either 5, 15, or 25 grams. The reinforcement schedule in effect was either CRF, or a VI with an avergage interval of 15, 30, or 60 seconds. The VI intervals were based upon a constant probability of reinforcement model. The same set of contingencies was in effect for each animal throughout the course of the experiment. The animals were run for 25 days of training, and data were collected on the peak force and duration of every response emitted, regardless of whether or not it met the reinforcement force criterion in effect. The data from the last 5 days of training were used for purposes of data analysis.

Following the 25th day, the experiment entered its second phase in which all the animals were run in extinction for 10 days, two sequences of five consecutive days separated by one day. The extinction sessions were 20 minutes in length, and all conditions were exactly the same as conditioning except that no reinforcers were delivered. The same data collection procedures were used as during the conditioning phase of the study.

From the data collected, a combination of manual and computer analysis allowed reconstruction of frequency distributions for the two measures of interest, as well as calculation of response rate and indices of variability and central tendency.

Review of Purpose

At the outset the stated purpose of this study was to determine the effect of intermittent reinforcement upon the levels and variability of specific response characteristics, to observe the changes in these characteristics that occur over the course of extended extinction, and to determine what interactions exist between these changes and the schedules/contingencies in effect during training, and finally, to ascertain whether the responses emitted during extinction are similar in form or magnitude to the responses learned during conditioning. This last point is perhaps the most interesting as it approaches a very basic behavioral question, namely, is rate predictive of the intensive and temporal properties of a population of responses.

Because of the unequal N's in the experimental design, and also because of the small N of two in three of the experimental groups, it is not possible to make conclusive statements regarding intergroup comparisons. The study is essentially a within group experiment and the most valid comparisons are those made between the final performance and extinctions behaviors of an individual animal or group. Much that is interesting is suggested, however, by the intergroup comparisons that can be made and these are discussed with the purpose of setting the stage for future work that could be done by others.

Review of Rate Data

Historically rate has been taken as standard measure of response strength with each response being treated as an all-or-nothing event. In the present study the data regarding response rate is clear and unequivocal. Any non-CRF contingency which tended to reduce the animals rate of reinforcement, yielded higher rates of responding. This was true whether the contingency involved the imposition of a VI schedule of 15, 30, or 60 seconds in length, or the imposition of an elevated force criterion of 15 or 25g, or a combination of the above. When one compares the rate for the CRF(5g) group with the three VI groups run on a 5g criterion, there is an approximately threefold increase in response rate for the intermittantly reinforced groups taken as a whole. Similarly, if one contrasts the CRF(5g) group with the CRF(15g) and CRF(25g) groups one sees increases of 60% and 160% respectively. But this is only part of the picture. By looking only at the rate of all responses, we fail to take advantage of the analytic possibilities opened up by using a separate analysis of the behavior required for reinforcement, specifically responses meeting the reinforcement criterion. The data for criterion response rate provide an interesting picture for us, in that they help to explain the observed increases in overall response rate. For the CRF condition, the data show that the criterion response rate is virtually the same for all three groups, essentially 15 criterion responses per minute. At the same time, the percentages of the total response population meeting the criterion are 100% for the CRF(5g) group, 60.2% for the CRF(15g) group, and 39.7% for the CRF(25g) group. Thus it becomes clear that the overall behavior pattern must be the result of a titration of response rate against accuracy to produce a suitable reinforcement rate. Whether 15 reinforcers per minute represents some biological constant of digestion for rats, or an index of the time spent in tray approach and consummatory behaviors is not discriminable.

For the animals on the VI schedules, the maximum reinforcement rate was determined by the schedule parameters, and thus the criterion rate was important in minimizing any delays in receiving the reinforcer after the onset of the eligibility period. The percent of responses meeting criterion for the three groups which were exposed to simultaneaous elevated force criteria and VI schedules range from 41.2% to 62.7% . The criterion response rates are much higher than the 15 per minute observed for CRF, ranging from 27.4 to 46.8 criterion responses per minute. The overall response rates required to acheive these criterion rates were of course much higher, typically double those observed for the CRF groups, but since only a criterion response could interact with the VI schedule and be reinforced, the resulting higher reinforcment rates were apparently worth the effort expenditure. Low proportions of criterion responses would decrease reinforcement density through increased waiting following reinforcement eligibility.

Literature Review - Response Force

Recently researchers have attempted to find other, more sensitive measures, than simple rate. Some (Anger 1956, Catania & Reynolds 1968) have resorted to the study of IRT's and various sophisticated probability analyses to improve on simple rate studies. Others (Eckerson and Lanson 1969; Herrick 1964; Margulies 1961; Millenson and Hurwitz 1961) have used various response differentiation paradigms in which, to quote Notterman and Mintz (1965) , "The degree of conformity of the conditioned behavior to the reinforcement criterion" is used as an index of response strength.

Still others have chosen to use the force of the response as their dependent variable, and have attempted to differentiate responses with forces above some limit, or within a specified range, using various operant conditioning paradigms. Notterman and Mintz (1962,1965) did a large number of studies including experiments with fixed and variable ratio and interval schedules, exteroceptively cued discriminations, pharmacologically impaired proprioception, to mention just a few. Fillion, Fowler, and Notterman (1969, 1970, 1971) continued this research into the areas of proportional reinforcement, deprivation and prefeeding, and the psychophysics of response force. More recently, Mintz, Samuels, and Barber (1971,1976) have looked at the feedback during a force differentiation and the relationship between force and rate during force differentiation learning.

Among the things these recent studies have clearly shown is that animals (primarily rats) are capable of learning to produce responses of a particular magnitude in order to achieve reinforcement. They have also shown that in many cases, the animals will choose to increase their overall rate of responding rather than improve the accuracy of their response if the requirment placed upon them is too stringent. In particular, if the contingency is changed after training on a less stringent criterion, and the newly required response is rare in the current population, the animal will probably manifest an overall rate increase. This increase in rate serves to increase rate of reinforcment as effectively as increased accuracy, though at the cost of substantially increased effort expenditure. What seems apparent is the wide degree of flexibility manifested by the animals in dealing with the various contingencies imposed upon them. It is partly this sophisiticated behavioral mechanism which prompted the first question this study attempts to answer, namely what relationship exists between certain parameters of a reinforcement schedule/force criterion, and the properties of the responding that is produced by such schedules.

Review of Response Force And Duration Results

With respect to the levels of response force and the response durations observed during conditioning with the various schedules and force criteria employed in this study the findings are unambiguous.

Peak response force was clearly independent of the schedule in effect during conditioning. This is best demonstrated by the frequency distributions of response force taken during the last five days of conditioning which are essentially indistinguishable among all groups with the same force criterion, regardless of the schedule used. This is in sharp contrast to the large differences observed among the various VI groups with respect to response rates which were substantially effected by the schedules employed.

The elevated force criteria generated elevated response forces as would be expected. For all three 15g criterion groups, the mean of the median forces was well above the criterion level. For both of the 25g groups the mean of the median forces was just over 23 grams. Thus one can make the statement that response force was differentiated, in that with the imposition of elevated force criteria the frequency of high force responses increased, and as a result of this there evolved a reinforcement-eligible sub-class of the independently defined response to quote the previously cited definition of differentiation by Notterman and Mintz (1965).

The force elevations observed could not be attributed simply to an "extinction effect", a force elevation induced by non-reinfrocement of previously reinforced behavior. This effect has been widely shown (Notterman and Mintz, 1965), present study included. However, force levels during intermittent reinforcement should relate exclusively to reinforcement density if they are merely induced by non-reinforcement. Present data clearly show an important force predictive role in the criterion regardless of the reinforcement density. This of course says that force is a differentiable property of responding, although reinforcement density can also influence force level, particularly if it is suddenly and sharply reduced.

The relationship between the variability of response force and the contingency imposed is less clear than that just described for the peak force of response. Comparing the data across all three VI schedules at a given force criterion, response force can be shown to be no more or less variable under the VI schedules as a whole than under CRF. It also appears that no particular VI schedule produced a substantially different degree of variability from the others, although there is some suggestion that the 15 second VI did generate greater variability than all other conditions for the 5g and 15g groups. The high variability, however, is probably related to the higher force level produced by this group. There is a general tendency for force level and variability to be positively correlated. A comparison to other groups may not be completely appropriate because of the behavior of one of the Ss (R52) previously described. In general, an elevated force criterion does generate increased variablity, in a fashion reminiscent of Weber's law. If in fact the animals difference threshold for force increases in magnitude as the level of force applied increases, then one would expect that the variability of response force in a force differentiation would be proportional to the force level being differentiated. This contention assumes that force emission is critically related to sensory correlates of the response.

An examination of the response durations reveals that unlike response peak force they were greatly affected by the reinforcment schedule, but the data reveals a dichotomous rather than a continuous relationship. Large differences were found between the median response durations of the CRF groups and the VI groups run under the same force criteria. In all cases the durations for the VI groups were substantially shorter than those for the CRF group, typically being half as long. The logic of this is not obscure, since duration and rate are inherently related, and the VI schedules produced much greater response rates than did CRF. In order to achieve these high rates, the animals must of necessity have spent less time engaged in holding behavior. Furthermore, closed circuit television observations of the animals during experimental sessions revealed the fact that the VI schedules frequently generated a style of behavior which was characterized by vigorous bursts of responding followed by short periods of less activity. These bursts correspond to a rapid series of paw movements which would appear to be incompatible with long response durations. Differentiation of rate or force may correspond to differentiation of topographic variations of response which facilitate the rate or force. The CRF animals on the other hand tended to produce more single reponses, partly because in many cases a single response was followed immdediately by reinforcement and thus the behavioral chain had tray approach as the component following the response. Thus the CRF animals were not constrained from generating longer durations.

Another finding was that the elevated force criteria used in the present study produced responses with longer durations than the 5g threshold criterion, although no difference exists between the two elevated criteria in this respect. The durations for the 15g and 20g groups trained under a given reinforcement schedule were roughly twice those of the 5g group under the same schedule. This finding seems reasonable if the response was characterized by a gradually increasing application of force, and thus had the form of a press. For such a response formhigher forces would require longer operandum contact. If on the other hand the response takes the form of a rapid application of force, followed by an equally rapid rebound, as would occur if the animal accelerated its paw prior to contact with the operandum, or in other words an impact, then a faster attack would result in a more forceful but shorter response. In fact observations of the animals during conditioning both over the closed circuit TV system, and electronically using an oscilloscope to display the transducer's analogue output in real time, indicated that the typical response form was a controlled press rather than an impact. Thus the observed relationship between force and duration is probably attributable to an action pattern requiring longer durations for higher forces.

The general rule that emerged is that VI schedules (regardless of length) generated response durations half as long as those observed for CRF, while elevated force criteria (regardless of force level) generated response durations twice as long as those observed for a 5g (threshold) criterion. The median duration for the CRF(5g) group and the VI15(15g) group (which experienced both a VI and an elevated criterion) are almost identical at 86 and 90 milliseconds respectively, thus revealing the cancellation of the effect of one independent variable by the opposite effect of another.

The variability of response duration observed during the final days of conditioning seemed to be closely related to the actual median response durations. VI schedules of reinforcement produced lower variability of response duration, while elevated force criteria produce greater variability of response duration. There is some evidence to suggest that the variability increases continuously in relation to the magnitude of the force criteria, in contrast to the binary relationship observed between response duration and the criterion level.

While the data probably do not allow a conclusive statement on the overall relationship between response peak force, response duration, and the variability of these measures, some general findings are suggested.

Response peak force and the variability of response peak force are apparently related by simple psychophysical laws, and as such are directly but not linearly proportional. Response peak force and its variability are unaffected by VI reinforcement schedules, but are strongly affected by elevated force criteria.

Response duration may be related to response force by physical or biophysical laws, but the relationship appears to be a discontinuous rather than a continuous function. The variability of response duration seems to be related to the magnitude of the durations, but may be a more continuous function of response force.

One specific phenomenon that bears noting is that wherever the reinforcement schedule appears to have an effect on a parameter of the response (either the level or variability) the effect is dichotomous. CRF appears to generate one class of behaviors while the non-CRF schedules as a group appear to generate a different but relatively homogeneous class of behaviors. This dichotomy, of course, may relate to the schedules employed, all of which produced sharply contrasted reinforcement densities in comparision to CRF. Brief VI's of say 5 seconds might show a continuous as opposed to dichitomous relationship.

To summarize the findings of the current study with regard to final performance following conditioning on VI schedules and elevated force criteria in various combinations: response peak force appears to be most sensitive to contingency operations involving a force criterion, response rate appears to be most sensitive to VI schedule length, and response duration appears equally sensitive to both aspects of the contingencies. This last finding is not totally unexpected since duration incorporates influences from both rate and force and thus could logically share the sensitivities of both.

Comparison to Other Studies

Herrick's (1964) analysis of lever displacement yielded interesting results regarding the central tendencies of the displacement distributions when displacement band criteria were in effect. In his study ranges of lever displacement were required for reinforcement. He observed that at the end of conditioning the distributions peaked at the very low end of the range of displacements which qualified for reinforcement, his so called "reinforcement zone". Contrast this to the finding of the present study (and that observed by Notterman and Mintz (1965) for effort criteria) that the 15g criterion yielded median peak forces well above 15g, and one is drawn to the conclusion that the difference is probably due to the inhibiting effect of the upper limit which exists in a band criterion. This effect is also seen in several force studies (Notterman and Mintz 1965,Mintz Samuels and Barber 1976). Herrick's suggestion that the phenomenon is an example of a least effort law in operation is no doubt partly true, and is supported by the present findings that the 25g criterion is exceeded much less frequently. The medians for the 25g group were actually below 25g. Schwartz and Mintz (1980) provide data showing effort conservative response populations in human subjects.

It seems likely that the large effort required by these high force responses may have created an inherent upper limit, and that the effect of that limit was the same as if it were an externally imposed one, shifting the distributions downward. That the limit was not a species specific physiological phenomenon is suggested by the behavior of one rat who repeatedly produced forces in excess of 50g by hitting or even biting the operandum. However within the topographies of "paw press", high forces may be physiologically demanding, and it would appear reasonable that some psychological law was operates to generate behaviors which meet the environment's requirements for reinforcement as often as possible, but require as little effort as possible. These findings alone do not allow any statements about the efficiency of the behavior since other factors, notably temporal, and sequential ones are involved in any calculation of overall efficiency and these were not within the scope of the data collection in the present study.

The data of the present study are in full agreement with Skinner's (1938) early findings that if an elevated force criterion is imposed during CRF training, the distribution of emitted forces is shifted upwards. The finding of the present study that the mean of the median peak response force was above the criterion level for all three groups run under the 15 gram criterion corroborates Skinners finding that the force differentiation occurs for VI schedules as well as CRF.

The more recent results published by Notterman and Mintz (1965) in Dynamics of Response as well as in several journal articles are also supported by the findings of the present study. Both their work and that of the present study reveal that at the end of the training period the peak force of response was above the force criterion in effect during training. This was true for the the 8 and 16 gram criteria used by Notterman and Mintz, and for the 15g criterion used in the present study which yielded median peak forces in the 18 to 20 gram range. It was not true however for the 25g criterion used in present study, which generated force levels slightly below the criterion at 20 and 21 grams for the two groups run with that criterion. Notterman and Mintz also published the percentages of responses exceeding the force criterion under a variety of conditions. For animals exposed to elevated criteria of 8 and then 16g, the percent of criterion responses was 66.4% and 59.2% respectively. This compares remarkable well with the 60.2% value observed for the CRF(15g) group in the present study. The CRF(25g) group had a smaller percentage of responses meeting criterion, 39.7%, but due to a substantially higher overall response rate, the rate of criterion responses was almost identical to that of the 15g group and the 5g (threshold) group.

Notterman and Mintz (1965) also described a study in which animals were run on fixed and variable interval schedules combined with elevated effort criteria, and since as mentioned earlier, peak force of response and time integral of force (effort) are well correlated, it seems reasonable to make comparisons to the present study. They make the statement that " One characteristic of interval schedules is that a change in the temporal parameters does not change the minimum behavioral output necessary for each reinforcement. A single criterion response at the end of each interval will produce reinforcement. Nevertheless, the total behavioral output varies with the temporal parameters of the schedule and with the reinforcement criterion. "

The present study showed that variations in the level of the reinforcement criterion produced differences in the median peak force, as well as the rate of responding. Changes in the temporal parameters of the schedules produced large difference in response rate, but only bewteen CRF and the VI15 condition. The VI30 and VI60 reponse rates are the same as the VI15 for a given force criterion level, as were median peak force values, which did not vary at all as a function of the temporal parameters of the schedule. Given equal response rates and peak response force levels for three different VI lengths, the overall behavioral output will vary in direct proportion to the length of the VI, so that animals on a VI60 will produce four time the output of animals on a VI15. Thus the current data conforms to the relationship proposed by Notterman and Mintz with regard to both the reinforcement criterion and the temporal parameters of the reinforcement schedules.

In Filion, Fowler, and Notterman (1969) the relationship between various type of response feedback and accuracy of responding was investigated for human and simian subjects using the concept of the Weber ratio as an analytic tool. They found that as the force requirement was increased the Weber ratio was reduced. Direct comparison of data bewteen their results and those of the present study is not appropriate because of the fact that they worked with different species, and used force requirements ranging from 25 to 200 grams. The general trend they observed however, appears to be present in the current results in most instances. Approximations of the Weber ratio were calculated by dividing standard deviation of response force by the median peak force for each group, and the results tend to show a decrease in the ratio as the level forces being emitted goes up. Thus while the organism's sensitivity to changes in response force is reduced at higher force levels, the increases in the minimum difference that can be sensed become smaller as the force level reaches higher values. This represents, in a sense, a kind of law of diminishing losses with respect to sensitivity to change in emitted force. In any event, these findings would appear to bear out the earlier statement that response force and the variability of response force are related by psychophysical laws.

A recent unpublished doctoral dissertation by Samuels (1973) found among other things an inverse relationship between accuracy of response force and rate of response. Using a force band contingency and narrowing the band during the course of they experiment, he determined that the animals responded to the reduction of width of the band by increasing their overall rate of response, while letting the percentage of responses within the band decrease. The effect upon the reinforcement rate depended upon the sequence in which the animals went through the three bands used, (wide to narrow, or narrow to wide), and also upon the absolute force level at which the band was centered. Of the two groups which ran with a low band (centered at 17g) the animals that started with a wide band and progressed to a narrow band suffered a reduction in rate of reinforcement while the animals that went through the procedure in reverse experienced an increase in rate of reinforcement. The group which ran with the high force band (centered at 23g) and started with the wide band condition also showed reduced reinforcement rate. It is interesting to note that the reinforcement rates observed for either high or low band when the bands were at their widest was 12.4 Sr/min for two groups and 15.6 Sr/min for the third. This is comparable to the 15 Sr/min reported in the present study for all three CRF groups. With regard to the inverse relationship between rate and accuracy, to the extent that percentage of responses exceeding criterion is a measure of accuracy the current data supports the hypothesis. It seems likely that the causal relationship is one in which the animal generates an unacceptably low level of accuracy through the interaction bewteen the externally imposed contingency and his current response population and then generates an increase in response rate rather than an increase in accuracy of response force in order to counteract a reduction in rate of reinforcement which would otherwise occur.

A second experiment reported by Samuels held the width of the band constant but imposed a constant probability of reinforcement for within-band responses of 50%. The added probability contingency was found to have no effect upon the accuracy of responding as measured by the percent in band, but it did effect the overal response rate and rate of reinforcement. The group that shifted from 100% to 50% showed immediate icreases in response rate, but they were not sufficient to prevent a decrease in reinforcement rate. The group that shifted from 50% to 100% showed a small decrease in response rate and an increase in reinforcement rate. In the present study, the VI schedules can be thought of as imposing a reduced probability of reinforcement upon criterion responses (particularly since they were constant probability VI intervals) relative to CRF. The data show no reductions in the percentage of criterion responses under VI reinforcement which is in agreement with Samuels' findings.

Most recent of all the studies discussed is that of Mintz, Samuels and Barber (1976) in which VI schedules were used to assess the relationship between rate of response and response force. Two different force criteria were used as well as a force band, and these were superimposed upon CRF and VI60 in a variety of combinations. Because the conditions were run sequentially within animals, most of the data are not directly comparable to the current data. The starting condition for four animals was VI60(5g) criterion, and the overall response rate was 49.6 r/min which is comparable to the current figure of 40.7 r/min. As in the present study, their findings indicate that schedule/criterion combinations tend to differentiate reasonably high frequencies of the behavior required for reinforcement, frequencies high enough to approximate maximization of the possible rate of reinforcement.

Review of Extinction Results

The question of what behavioral changes occur following the onset of extinction has been studied by many researchers. The primary variable of interest has been rate of response and findings have usually been similar, namely a transient increase in response rate immediately following the withdrawal of reinforcment, followed by a rapid decline to a low asymptote, often below operant level. Amsel (1958) discussed extinction in terms of frustration which he defined as " a hypothetical, implicit reaction elicited by non-reward after a number of prior rewards." He specifically used the term "frustrative non-reward" to refer to an active factor which is responsible for both the "increase in the vigor of behavior" which immediately follows the onset of extinction and the later inhibition of responding in extinction.

Several researchers (Skinner, 1938, Notterman & Mintz, 1965, Morse in Honig 1966) have explainned this transient increase as a case where properties of behavior intensified by reinforcement are revealed in exagerated form when reinforcement, either regular or intermittent, is discontinued. This relates to the issue raised previously regarding the similarity of pre and post extinction responses.

The results of the present study are in general agreement with the predictions mentioned above.For all intents and purposes all of the animals in this study produced good approximations of a classical extinction curve for response rate regardless of the criterion or schedule they were exposed to during conditioning. The response rates manifested a very brief rise, and then began a rapid descent which started to level off after about three sessions of extinction. The rise in rate was so brief that in all cases the first extinction session ended up with a local rate well below that observed during the last days of conditioning. The visible differences between these curves appears to be at least related to if not directly caused by the differences in the rates that were being maintained prior to extinction.

The total number of responses made by the animals in each group during the entire course of extinction appears to reflect the differences established between the groups during training on the various schedules. CRF clearly produced substantially lower overall amounts of responding during the ten days that extinction was run than did the VI schedules, and to the extent that the sum total of the behavioral output is a valid measure of extinction behavior, the CRF groups manifested the least resistance to extinction of all the groups. The effect of the elevated force criteria, which during training generated substantially more responding that the 5g threshold, did not appear to persist during extinction when the criterion was no longer beinf differentiated.

Other parameters of responses besides rate have been studied during extinction. The variablility of response duration has been shown to increase following the onset of extinction (Millenson & Hurwitz 1961, Margulies 1961) and this change in variablility has been found to be greater when extinction is imposed after moderate amounts of training than when it occurs either very early or very late in a conditioning history. One group of studies (Antonitis,1951;Eckerman & Lanson 1969;Thompson, Herstad, & Palermo,1963) all looked at the topography of responses undergoing extinction and found that variabliity increased following the onset of extinction.

The response parameter of primary interest in the current study is, of course, peak force of response. In general, it can safely be said that the imposition of elevated force criteria during the course of training results in the emission of elevated forces during extinction. The median peak force of response was substantially higher for all the 15 and 25 gram groups, than for any of the 5g threshold groups. This is particularly true for the first five extinction days, but the effect is also visible in the latter half.

The sequence of changes observed in response force over the course of extinction is particularly interesting. At the onset of extinction, an initial jump in force is observed for all but one group. This was the VI15(15g) group which, as stated earlier, manifested very high forces during conditioning mainly because of the responses emmited by one of the two animals that comprised the group. These high forces were generated by either hitting or biting the transducer, a response style not observed in any of the other animals in the study. Following this initial jump in force, there was a steady but gradual decrease in peak force throughout the course of extinction. This agrees well with both Skinner (1938) and Filion, Fowler, and Notterman (1969B,1970A) all of whom reported the initial rise and subsequent decline of response force during extinction following various training experiences.

The animals in the groups with a 5g criterion (no elevation above threshold) showed the greatest magnitude of increase in peak force, while the animals trained with a 15g criterion manifested smaller but still substantial increases and the animals with a 25g criterion showed the smallest change. This is in agreement with the findings of Notterman and Mintz (1965) who ran CRF animals with 2.5g, 8g, and 16g criteria and found an inverse relationship between the degree of initial force elevation in extinction and the peak force of responding observed during training.

Within the 5g groups the CRF animals showed the greatest reaction to the onset of extinction, producing forces above those of the other 5g groups throughout most of extinction, in much the same way as they increased their rate. The general principle that appears to be at work here is that when an animal's responses exhibit low levels with respect to a given characteristic (force or rate) during training there is a greater probability that the animal will maintain or even exceed those levels during extinction. Conversely, response properties that are at high levels during training will tend to show decreases from the training levels when extinction is imposed. Part of this may be a sort of ceiling effect. When upper limits are approximated, change, if any, is downward. There remains , however, the question of why forces should change at all. Obviously it is the disruption in the ongoing behavioral stream brought about by the onset of extinction and the sudden disappearance of a previously operating set of rules which governed the organisms interactions with the environment.

These phenomena are all observable during the initial stages of extinction and do not appear to be related to the length of the schedule used during training, with the exception of the fact that true CRF (no VI, no elevated force criterion) produces a quantum jump in the size of the force increase to be expected. But what of the changes that occur over the course of extended extimction. All the animals eventually dropped their forces during extinction. The finding of interest is that following the initial force increase brought about by the disruptive effects of extinction onset, but prior to the inevitable long term degradation in the response magnitude in the absence of any controlling contingency other than the organism's built in minimum effort tendencies, the force of response tended to mimic the level that had been learned during 25 days of conditioning. Furthermore, this tendency was strongest in the animals that had the greatest amount of training as measured by the overall number of responses emmitted during the training period, in this case those groups run under the longer VI schedules. This corroborates the findings of Skinner (1938) that the decline of force in extinction is delayed by prolonged training.

Review of Questions Posed in Introduction

To summarize, the questions asked and the conclusions reached in the present study are as follows:

1) The effect of intermittent reinforcement upon the variability of particular response characteristics, specifically peak force of response, was investigated. No relationship was observed to exist between intermittancy of reinforcment and variability of response force at any of the three force levels utilized.

2) The effect of extinction upon particular response characteristics, specifically peak force of response, was investigated. Peak force of response was found to increase immediately following the onset of extinction and then decrease gradually over the course of extinction.

3) The relationship between the amount of training undergone by an animal and the changes in the particular response charactersitics, specifically peak force of response, in extinction was investigated. Larger amounts of training, as measured by the total number of responses emitted under the training contingency, were found to substantially delay the ultimate decrease in force during extinction.

4) The hypothesis that extinction responses have the same characteristics as the responses being emitted during

final training, while having greatly reduced probability of occurence was proposed. The results of the present study tend to support this hypothesis with the caveat that the phenomenon is not permanent and that over the course of extended extinction various influences ultimately reduce the level of response force, much as response rate is reduced early in extinction.

One of the interesting aspects of the results of the present study is the corroboration of the finding in various other studies cited that the imposition of elevated force criteria results in the production of responses distributions which clearly demonstrate the differentiation of high force responses. This last point, while seemingly trivial in light of the large amount of data available to back it up, actually presents some interesting questions. Notterman (1959) asked the question "do lawful relations exist between the E's operations and the intensive characteristics of S's response ?". He concluded that the answer was yes, and stressed the significance of the non rate oriented concept by stating: "That such lawfulness is predicated upon the response differentiation and not bar pressing rate does not diminish its possible importance."

But what may clearly appear to be lawful in one context may be revealed as very much random or as an artifact in another. Such was the case for results reported in one study by Chung (1965) challenged in another by Mintz et al.(1976) where changes in the sampling technique may have been responsible for differences in the response rates observed. The problem lay in an inadequate definition of differentiation.

A potential problem in our ability to understand the phenomenon of response force differentiation lies in the fact that at least two separate behavioral principles are in operation when one imposes a high force reinforcement criterion. First of all, the reinforcement of high force responses will lead to the production of high force responses as dictated by the most basic behavioral law, the law of reinforcement, an increase in frequency of that which is reinforced. Second, since there will be a number of responses which do not meet the criterion and thus are not reinforced, there will be a tendency for the response force to increase due to local extinction effects. Skinner (1938) alluded to a similar situation which occurs when a combined force level and reinforcement schedule are imposed. He stated that "when responses above a critical value are periodically reinforced, many responses above that value go unreinforced. Nevertheless, the mean intensity of the responses quickly rises and is maintained at about the same level as when all responses above the value are reinforced." The data from the present study clearly show that elevated force criteria alone or in combination with intermittant reinforcement schedules produce elevated response forces but they provide no clue to the relative contributions of the two factors. The fact that the forces are not higher when the schedules are superimposed upon the criterion would seem to indicate that the effects of the two are not additive.

The finding of the present study that the variability of response peak force is no greater with intermittant reinforcement schedules than with CRF can perhaps be partly explained by the previously mentioned low inter-group variability, with respect to peak response force,between the groups run with different schedule lengths. If as previously speculated, the variability of response force is determined substantially by the psycophysical laws which relate it to the absolute magnitude of the force, then groups emitting similar force levels should show similar variability. This still leaves unanswered the question of what lies behind the invariance of response force under widely differing degrees of intermittancy of reinforcement.

Perhaps the most interesting data resulting from the present study is that which describes the sequence of changes in response force over the course of the 10 days of extinction. The initial rise in force was predicted based upon earlier work by several investigators as was the ultimate decline of force. The magnitude of the upwards shift in response force appears to be related to a the forces being emmited just prior to the onset of extinction. Essentially, animals which are emitting low force responses are likely to exhibit a large increase in force while animals emitting high force responses are likely to exhibit a smaller increase or even a decrease. This relationship may appear to be simplistic, but in actuality the underlying principle may be subtle. Because the variability of force for animals generating low force responses is small, a large upwards shift in force at the beginning of exitinction represents the appearance of a large population of responses which are well above the pre extinction median peak force, and were being infrequently emitted before the onset of extinction. The situation may be radically different for animals whose pre extinction contingency required high force responses since the high forces were accompagnied by greater variability. Thus many responses were being emitted with forces above the actual median force level, and a shift in force following the onset of extinction would not require the generation of an entirely new sub-class of responses. Further, the CRF animals on low force criteria were experiencing very few unreinforced responses, and thus little local extinction prior to the actual onset of complete extinction, while the animals with the elevated criteria did have some extinction experience. This would tend to produce the observed effects. The imposition of VI schedules on top of the criteria, however, eliminates this difference to a very large degree, since all the VI animals experienced substantial local extinction during training, and yet similar effects are observed for the VI and CRF groups.

It appears then that the influence of the prevailing response force distribution as well as the animals cumulative experience with local extinction is not sufficient to explain the observed phenomenon. In the opinion of the author, the observed results are a combination of these two factors coupled with the least effort tendency mentioned earlier in this paper. The animals appear to be responding to the force elevating effects of extinction which are sufficiently strong to shift the response populations of animals making low force responses, but are not powerful enough to overcome the limiting effects of the least effort law which puts an inherent ceiling on response magnitude.

The gradual decline in response force over extinction is best understood in terms of the behavioral chain analysis presented earlier, and in fact the empirical data support this hypothesis. In essence, the response concomitant feedback which the animal experiences during the course of making a response can be thought of as becoming a secondary reinforcer after sufficient training. If one breaks the response into a series of finite elements, then the sequence discrete response-force / feedback-level couplets represent the component of a behavioral chain. When the primary reinforcer that has followed completion og the entire chain from, response start to response end,is no longer forthcoming, the chain begins to break down from the end closest to reinforcement. It is the sustaining effects of the individual secondary reinforcers, each of which continues to reinforce the response components preceding it until the response components following it have disappeared, that maintains the overall response force in extinction. What is fascinating is that while all this is happening, the response rate is dropping rapidly to operant level or lower. This reduction in rate probably helps to maintain the force levels by minimizing the number of times the chain is initiated and not reinforced, and thus delaying its ultimate breakdown, but it is undoubtably the amount of training and thus the strength of the secondary reinforcers within the response that is primarily

TABLE 1

Number of animals per experimental group

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	5	5	5	5
15 grams	5	2	2	
25 grams	4	2		

TABLE 2

Mean number of responses emitted per animal for all nine expermimental groups for the final five days of conditioning.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	250	3188	7070	10299
15 grams	397	5945	9449	
25 grams	647	4617		

TABLE 3

Mean response rates in responses per minute for all nine experimental groups for the five final days of conditioning.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	15.6	47.8	54.5	40.7
15 grams	24.9	89.6	74.6	
25 grams	40.7	66.3		

TABLE 4

Mean response rates in responses per minute shown by subject for all nine experimental groups for the five final days of conditioning.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	13.9	34.1	10.3	27.3
	14.4	34.7	26.7	30.4
	15.2	50.4	31.6	42.9
	15.7	52.5	46.8	43.5
	18.6	67.1	65.4	59.2
15 grams	16.6	53.7	66.1	
	18.4	125.4	83.1	
	23.3			
	32.9			
	33.5			
25 grams	25.1	57.8		
	36.1	74.8		
	41.9			
	59.7			

TABLE 5

Mean session duration in minutes for all nine experimental groups for the final five days of conditioning.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	3.1	13.3	25.9	51.5
15 grams	3.2	13.3	25.3	
25 grams	3.2	13.9		

TABLE 6

Mean reinforcement rates in reinforcements per minute for all nine experimental groups for the five final days of conditioning.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	15.6	3.8	1.9	0.96
15 grams	14.7	3.8	1.9	
25 grams	14.9	3.6		

TABLE 7

Mean reinforcement rates in reinforcements per minute shown by individual animals for the five final days of training.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	13.5	3.2	1.8	0.95
	13.9	3.4	1.8	0.96
	14.9	3.6	1.9	0.96
	18.3	3.7	1.9	0.97
	19.2	3.8	2.0	0.97
15 grams	13.9	3.2	1.9	
	14.3	4.1	1.9	
	14.9			
	15.2			
	15.4			
25 grams	13.1	3.3		
	13.9	3.7		
	14.4			
	18.1			

TABLE 8

Mean criterion response rates in responses per minute, and percentage of total responses meeting criterion for all nine experimental groups for the five final days of conditioning

		SCHEDULE			
CRITERION		CRF	VI15	VI30	VI60
5 grams	RATE	15.6	47.8	54.5	40.7
	PERCENT	100.0%	100.0%	100.0%	100.0%
15 grams	RATE	15.0	42.1	46.8	
	PERCENT	60.2%	55.8%	62.7%	
25 grams	RATE	16.1	27.4		
	PERCENT	39.7%	41.2%		

TABLE 9

Median response force and standard deviation in grams for all nine experimental groups for the final five days of conditioning. Data are the mean of the daily values for each subject.

		SCHEDULE			
CRITERION		CRF	VI15	VI30	VI60
5 grams	FORCE	8.7	9.4	9.5	8.4
	S.D.	7.2	6.8	4.2	7.5
15 grams	FORCE	19.8	21.8	18.4	
	S.D.	10.9	13.4	9.2	
25 grams	FORCE	21.3	20.5		
	S.D.	13.0	13.0		

TABLE 10

Median peak force in grams for all nine experimental groups for the final five days of training shown by animal.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	6.7	8.3	8.1	7.1
	8.5	8.4	8.7	7.4
	8.5	9.2	8.8	7.7
	9.4	9.8	10.6	8.8
	10.3	11.3	11.4	10.8
15 grams	14.3	12.3	16.5	
	15.2	29.0	20.3	
	21.4			
	22.1			
	26.2			
25 grams	18.6	17.8		
	19.1	23.2		
	22.2			
	25.5			

TABLE 11

Standard deviation of response force in grams shown by subject for all nine experimental groups for the five final days of training.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	3.7	4.0	3.6	4.8
	3.9	4.9	4.0	5.0
	4.4	5.7	4.1	5.4
	7.3	7.8	4.3	8.3
	16.7	11.5	5.1	14.1
15 grams	8.2	6.3	8.8	
	8.2	20.6	9.5	
	10.8			
	12.2			
	15.1			
25 grams	11.0	12.1		
	11.9	13.8		
	12.1			
	17.2			

TABLE 12

Weber ratios for all nine groups for the five final days of conditioning. Ratios were computed by dividing the standard deviation by the median peak force for each group.

	SCHEDULE				
CRITERION	CRF	VI15	VI30	VI60	CRITERION MEAN
5 grams	0.83	0.72	0.44	0.89	0.72
15 grams	0.55	0.65	0.50	-	0.57
25 grams	0.61	0.63	-	-	0.62
SCHEDULE MEAN	0.66	0.66	0.50	0.89	

TABLE 13

Weber Ratios for individual animals in all nine experimental groups for the five final days of training. Ratios were computed by dividing the individual standard deviation by the individual median peak force for each animal.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	0.38	0.48	0.38	0.46
	0.44	0.50	0.44	0.67
	0.46	0.68	0.45	0.72
	0.71	0.69	0.46	1.08
	1.78	1.25	0.49	1.60
15 grams	0.38	0.51	0.46	
	0.41	0.71	0.53	
	0.55			
	0.57			
	0.99			
25 grams	0.43	0.59		
	0.54	0.68		
	0.62			
	0.91			

TABLE 14

Median response duration and SIQR in milliseconds for all nine groups for the five final days of conditioning. Medians were computed as the mean of the pooled five day medians for each animal. SIQRs were computed from the pooled total group distribution.

		SCHEDULE			
CRITERION		CRF	VI15	VI30	VI60
5 grams	DURATION	86	36	54	48
	S.I.Q.R	120	40	60	70
15 grams	DURATION	170	90	95	
	S.I.Q.R	130	120	110	
25 grams	DURATION	190	85		
	S.I.Q.R	250	210		

TABLE 15

Mean response durations in milliseconds shown by subject for all nine experimental groups for the five final days of training.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	40	30	30	20
	70	30	40	30
	100	30	50	50
	100	40	60	70
	120	50	70	70
15 grams	120	50		
	140	130		
	150			
	210			
	230			
25 grams	70	80		
	130	90		
	200			
	360			

TABLE 16

Semi-Inter-Quartile range for response duration in milliseconds shown by subject for all nine experimental groups for the five final days of training.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	36	20	22	22
	113	24	24	25
	166	36	76	45
	173	53	89	145
	270	59	210	167
15 grams	65	36	75	
	103	161	132	
	104			
	188			
	no data			
25 grams	126	180		
	140	238		
	207			
	342			

TABLE 17

Mean number of responses emitted by each animal over the entire course of extinction for all nine experimental groups

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	991	1488	1204	1233
15 grams	222	2047	2485	
25 grams	421	1977		

TABLE 18

Total responses emitted by each animal over the entire course of extinction.

	SCHEDULE			
CRITERION	CRF	VI15	VI30	VI60
5 grams	397	897	375	600
	509	928	852	688
	536	1452	972	1012
	554	1872	1512	1440
	2960	2289	2308	2426
15 grams	120	1264	2228	
	192	2831	2742	
	211			
	273			
	315			
25 grams	230	1318		
	431	2677		
	506			
	519			

TABLE 19

Median peak force during the final five days and the first and last five days of extinction for all nine groups. Data are the means of the daily medians for all animals.

		SCHEDULE			
CRITERION	PHASE	CRF	VI15	VI30	VI60
	CONDITIONING	8.7	9.4	9.5	8.4
5 grams	EXTINCTION 1-5	15.6	10.0	9.6	8.3
	EXTINCTION 5-10	11.9	10.7	10.7	9.1
	CONDITIONING	19.8	21.8	18.4	
15 grams	EXTINCTION 1-5	17.6	16.4	19.5	
	EXTINCTION 5-10	14.4	12.5	14.3	
	CONDITIONING	21.3	20.5		
25 grams	EXTINCTION 1-5	17.8	22.5		
	EXTINCTION 5-10	12.8	14.3		

TABLE 20

Percentage of extinction responses above the previously imposed force criterion for all elevated criterion groups, shown by individual days. Final performance data are given in parentheses.

PREVIOUS CRITERION	EXTINCTION DAY	SCHEDULE CRF	VI15	VI30
15 Grams	(FINAL P)	60.2%	55.8%	62.7%
	1	65.4%	54.1%	71.7%
	2	43.8%	48.5%	65.3%
	3	66.2%	46.5%	59.9%
	4	48.4%	42.2%	64.4%
	5	34.0%	47.1%	50.8%
	6	54.8%	40.3%	54.1%
	7	49.7%	37.3%	45.9%
	8	47.9%	18.5%	47.5%
	9	56.2%	28.5%	56.5%
	10	56.3%	45.1%	45.3%
25 Grams	(FINAL P)	39.7%	41.2%	
	1	47.5%	50.2%	
	2	38.3%	40.8%	
	3	30.0%	46.7%	
	4	36.3%	41.1%	
	5	30.5%	47.4%	
	6	28.7%	31.1%	
	7	28.4%	24.5%	
	8	33.3%	19.8%	
	9	33.5%	14.7%	
	10	28.1%	33.6%	

Figure 1

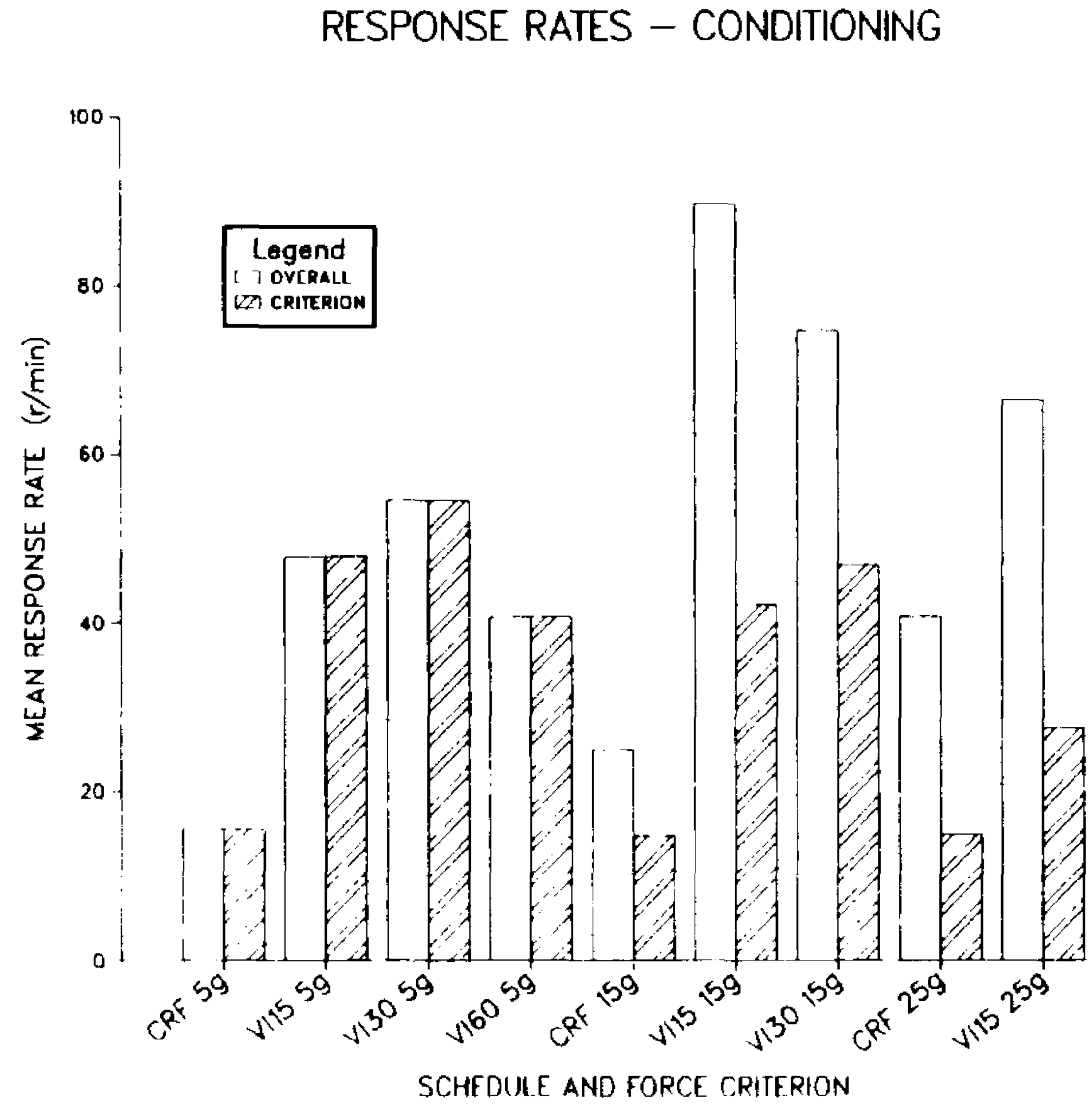

RESPONSE RATES – CONDITIONING
Legend
☐ OVERALL
▨ CRITERION
MEAN RESPONSE RATE (r/min)
100
80
60
40
20
0
CRF 5g
VI15 5g
VI30 5g
VI60 5g
CRF 15g
VI15 15g
VI30 15g
CRF 25g
VI15 25g
SCHEDULE AND FORCE CRITERION

Figure 2

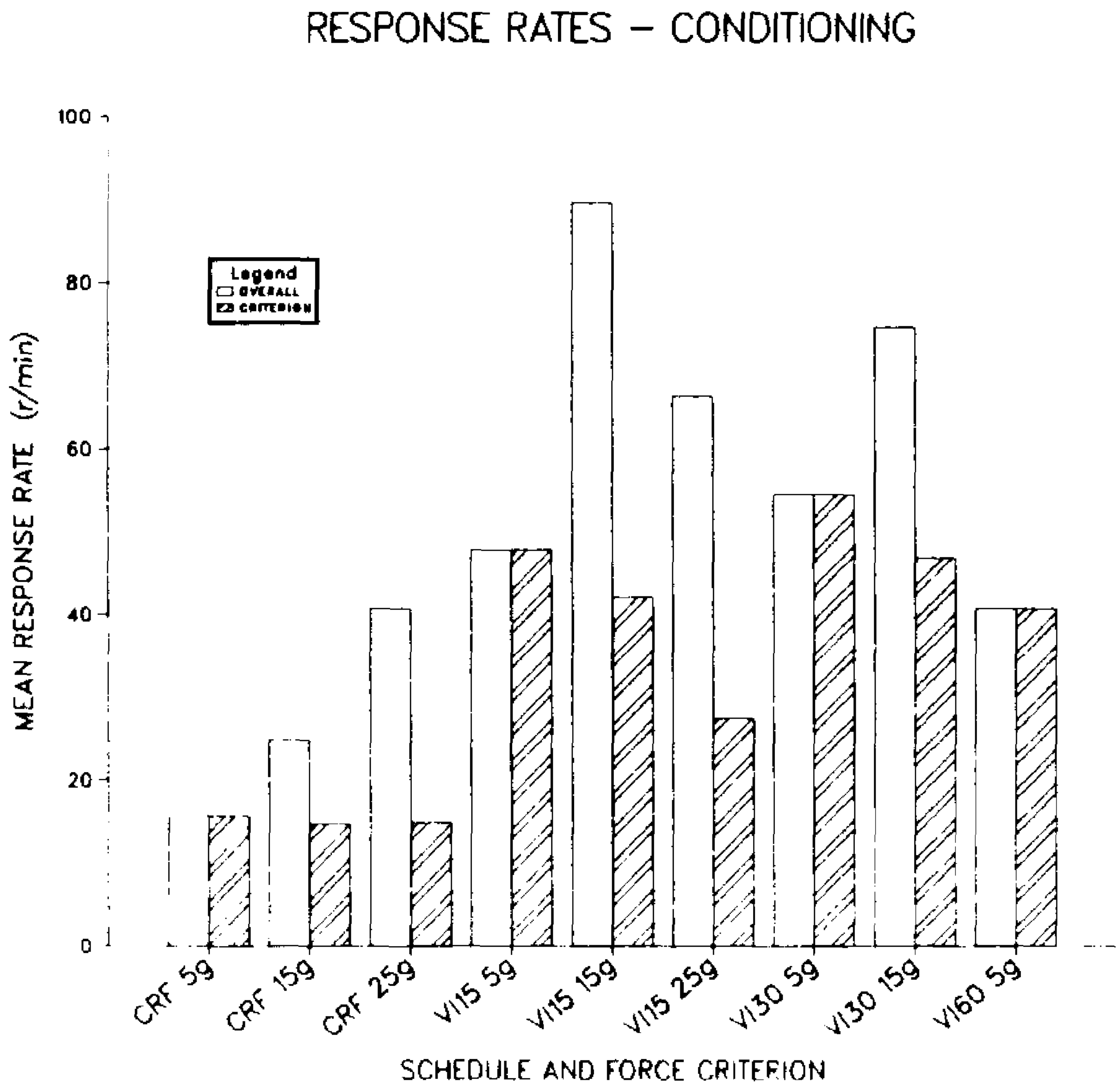

RESPONSE RATES – CONDITIONING
Legend
▭ OVERALL
▨ CRITERION
MEAN RESPONSE RATE (r/min)
100
80
60
40
20
0
CRF 5g
CRF 15g
CRF 25g
VI15 5g
VI15 15g
VI15 25g
VI30 5g
VI30 15g
VI60 5g
SCHEDULE AND FORCE CRITERION

Figure 3

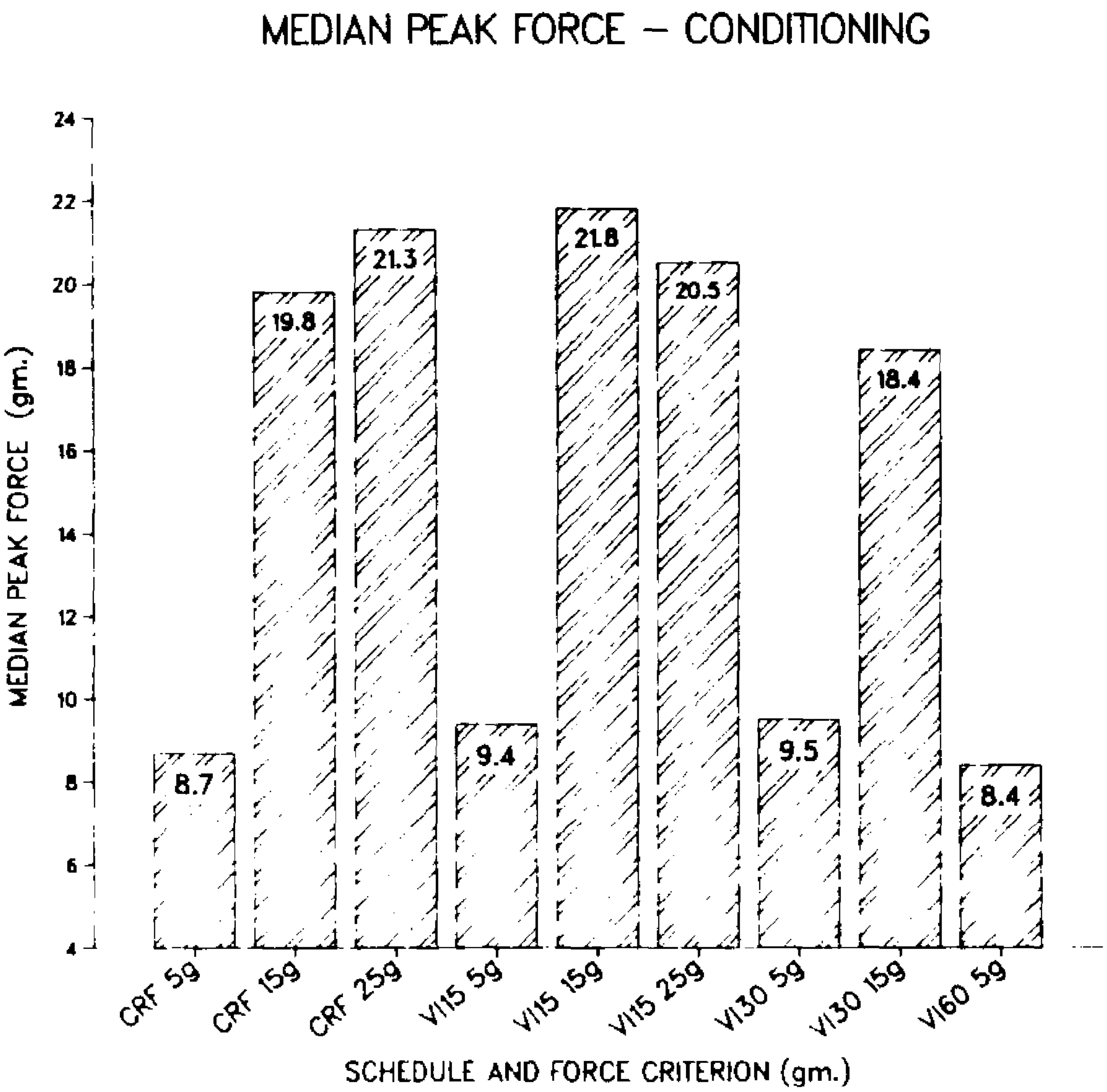

MEDIAN PEAK FORCE – CONDITIONING
MEDIAN PEAK FORCE (gm.)
24
22
20
18
16
14
12
10
8
6
4
8.7
19.8
21.3
9.4
21.8
20.5
9.5
18.4
8.4
CRF 5g
CRF 15g
CRF 25g
VI15 5g
VI15 15g
VI15 25g
VI30 5g
VI30 15g
VI60 5g
SCHEDULE AND FORCE CRITERION (gm.)

Figure 4

RELATIVE FREQUENCY DISTRIBUTIONS OF RESPONSE FORCE – ALL CRF GROUPS

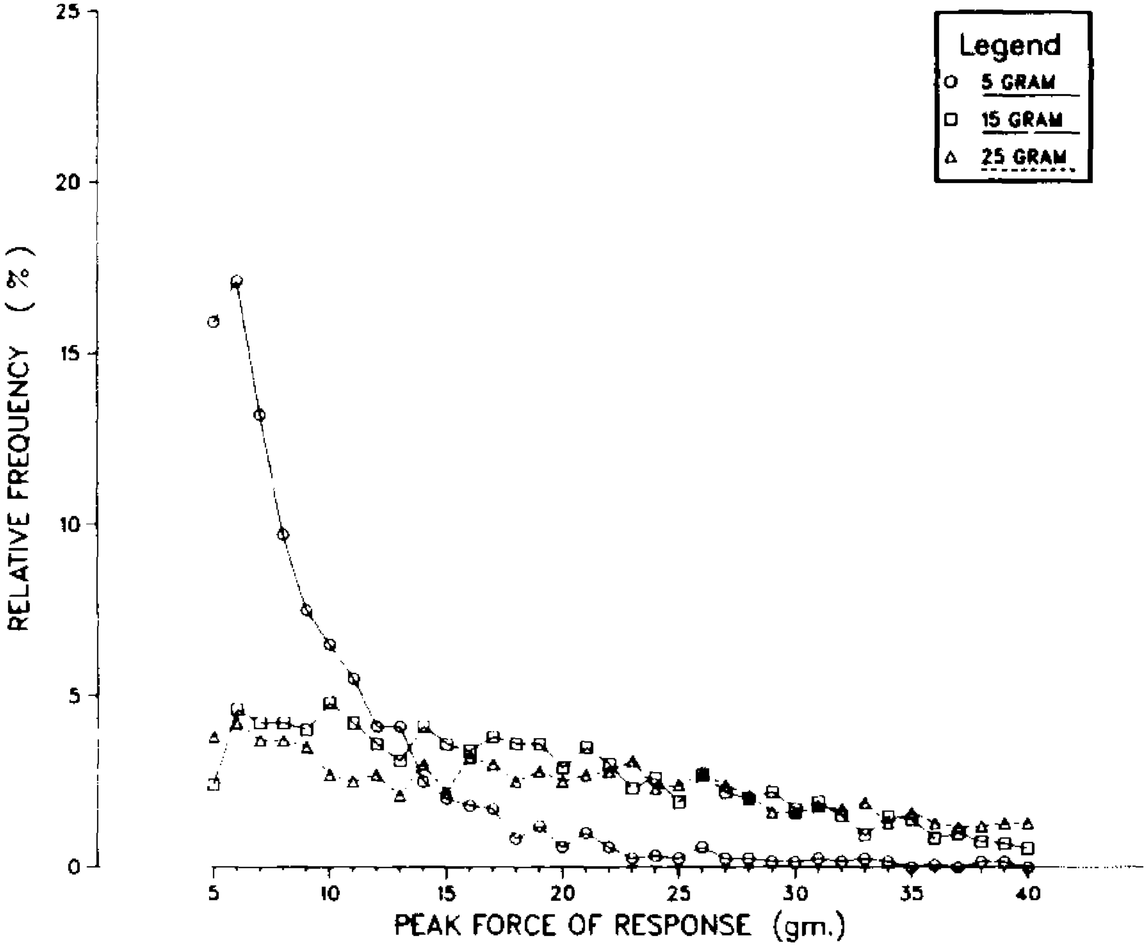


Figure 5

RELATIVE FREQUENCY DISTRIBUTIONS OF RESPONSE FORCE – ALL VI 15 GROUPS

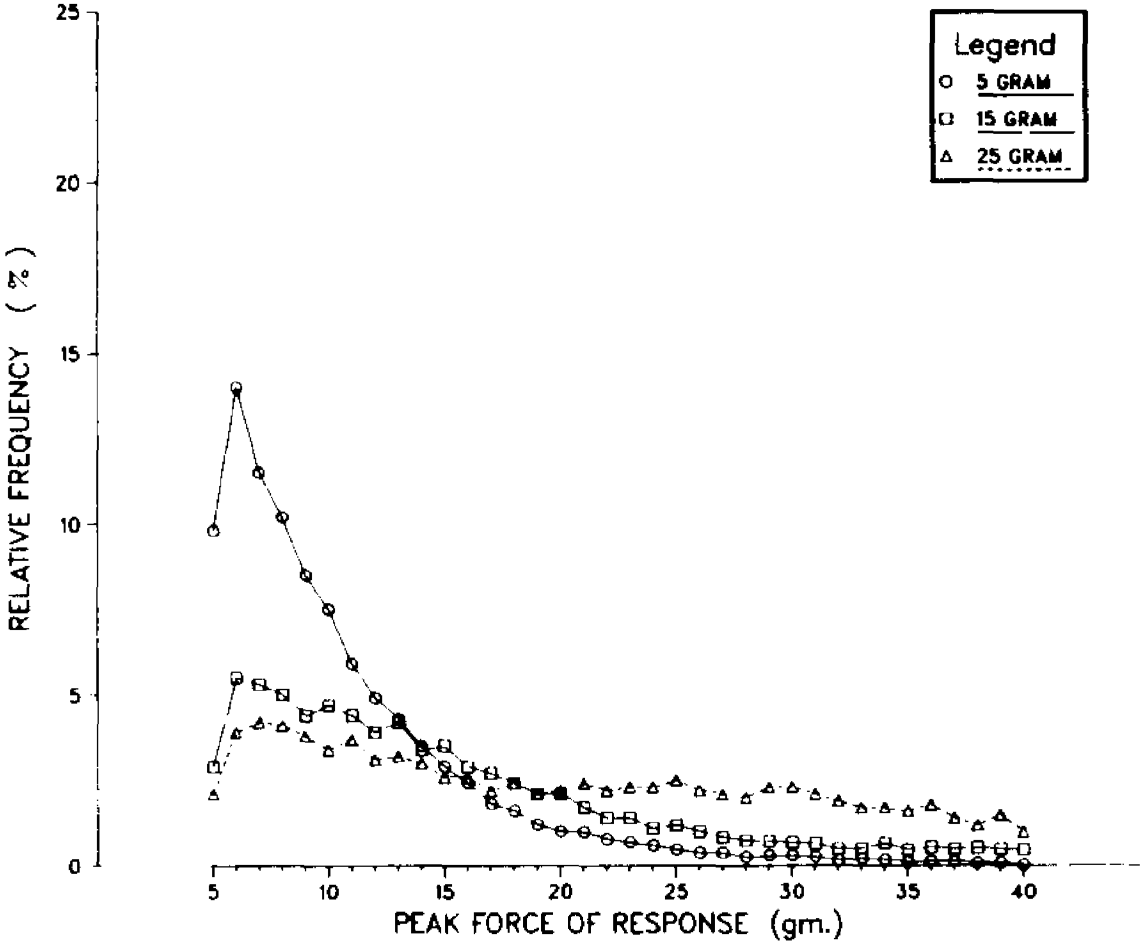


Figure 6

RELATIVE FREQUENCY DISTRIBUTIONS OF RESPONSE FORCE ALL VI 30 & 60 GROUPS

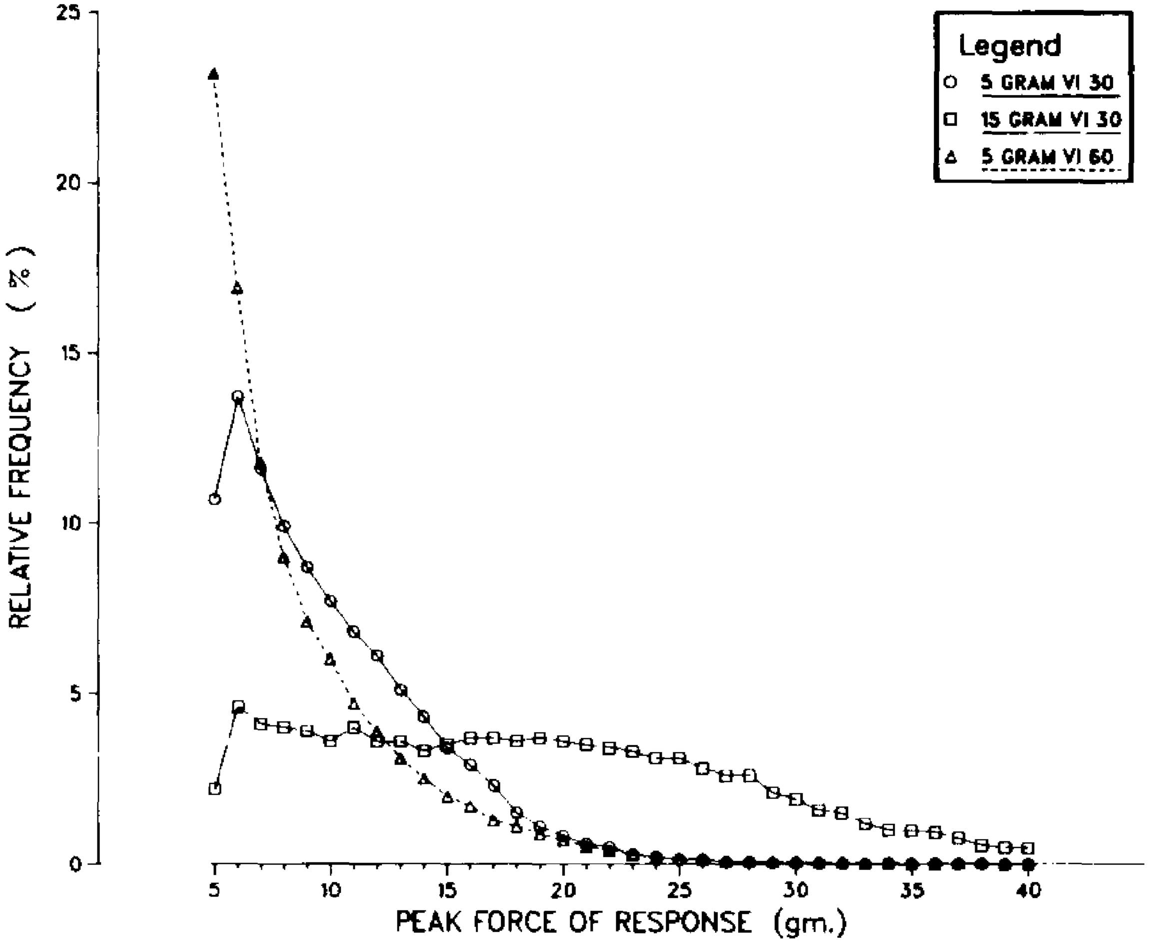


Figure 7

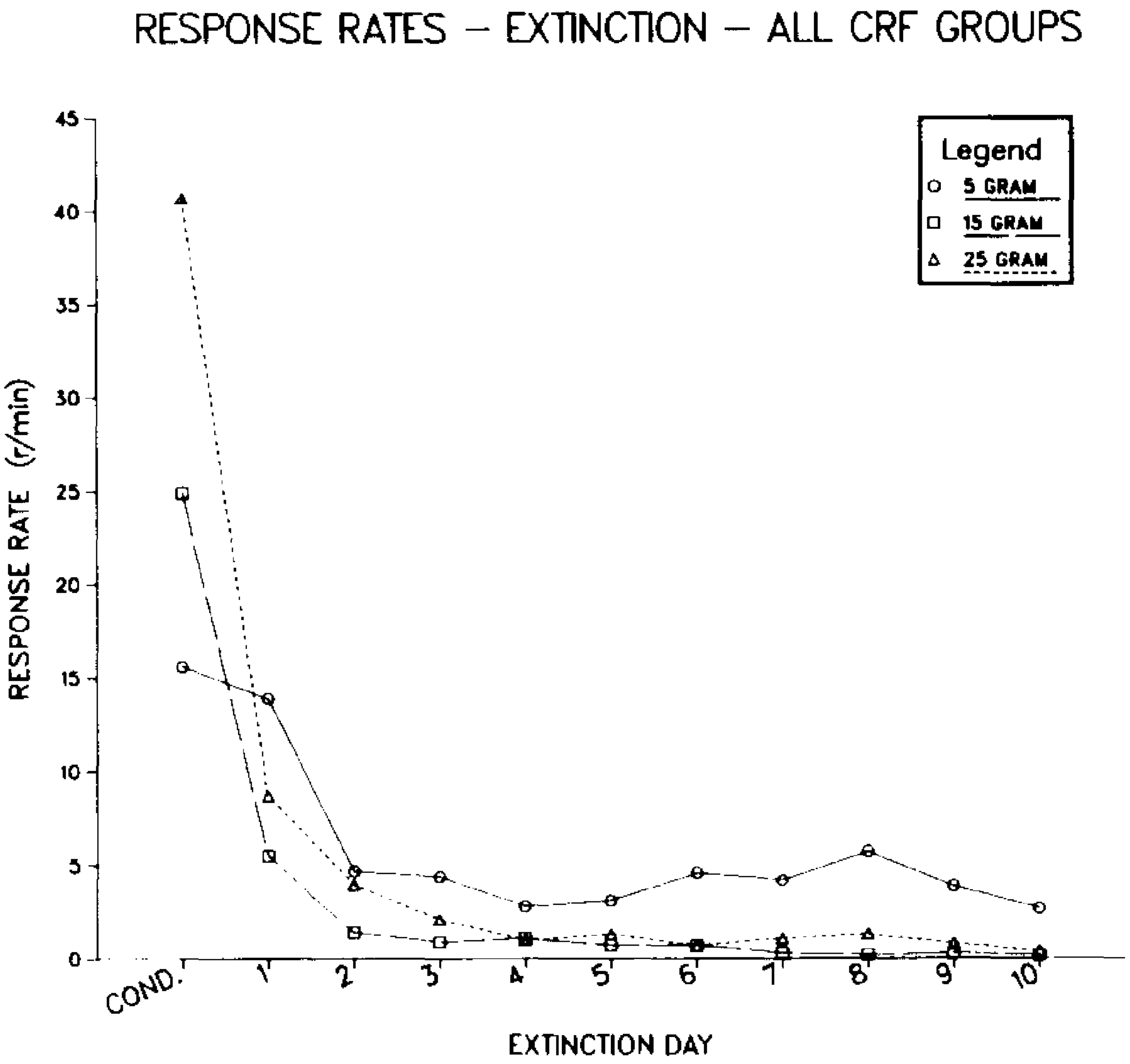

RESPONSE RATES – EXTINCTION – ALL CRF GROUPS
Legend
○ 5 GRAM
□ 15 GRAM
△ 25 GRAM
RESPONSE RATE (r/min)
45
40
35
30
25
20
15
10
5
0
COND.
1
2
3
4
5
6
7
8
9
10
EXTINCTION DAY

Figure 8

RESPONSE RATES – EXTINCTION – ALL VI 15 GROUPS

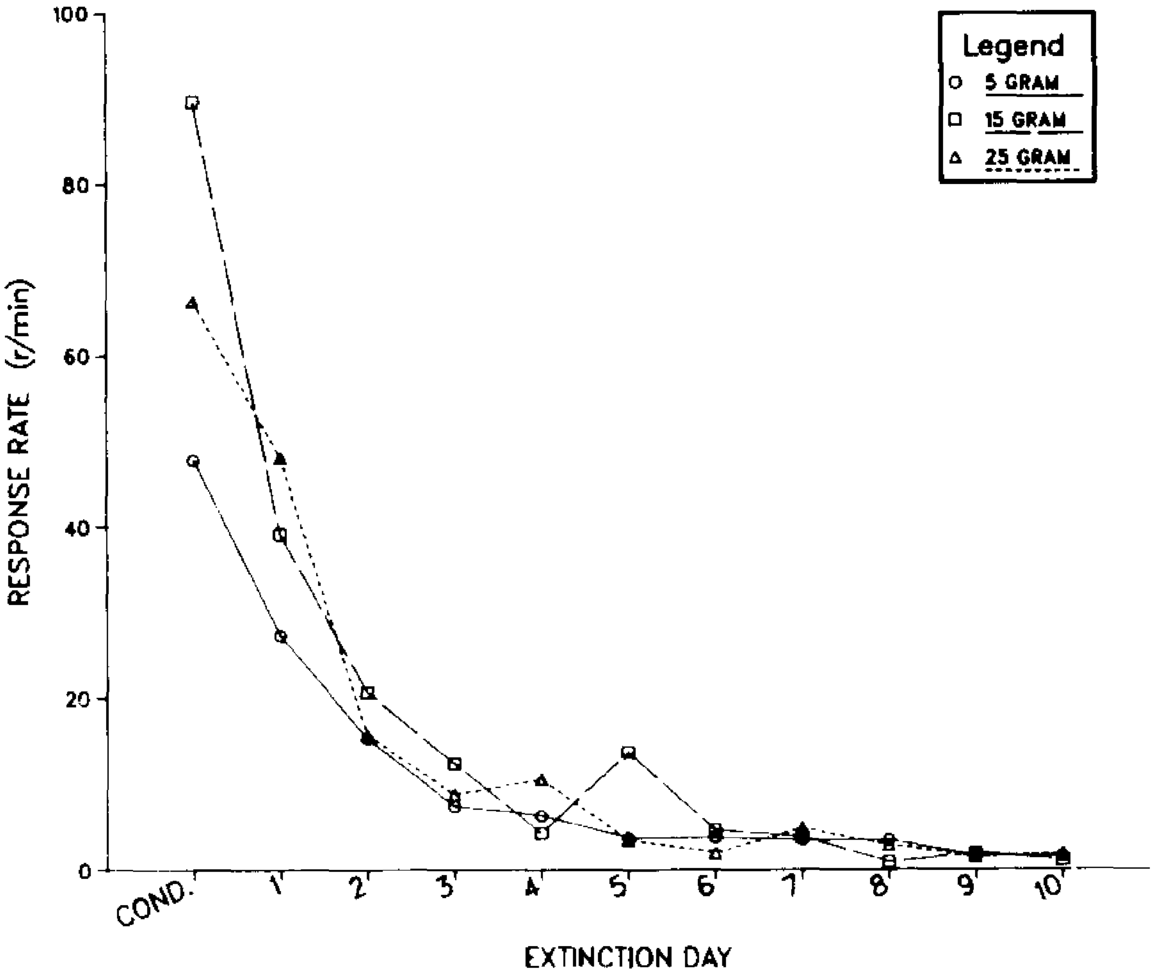


Figure 9

RESPONSE RATES – EXTINCTION – ALL VI 30 & 60 GROUPS

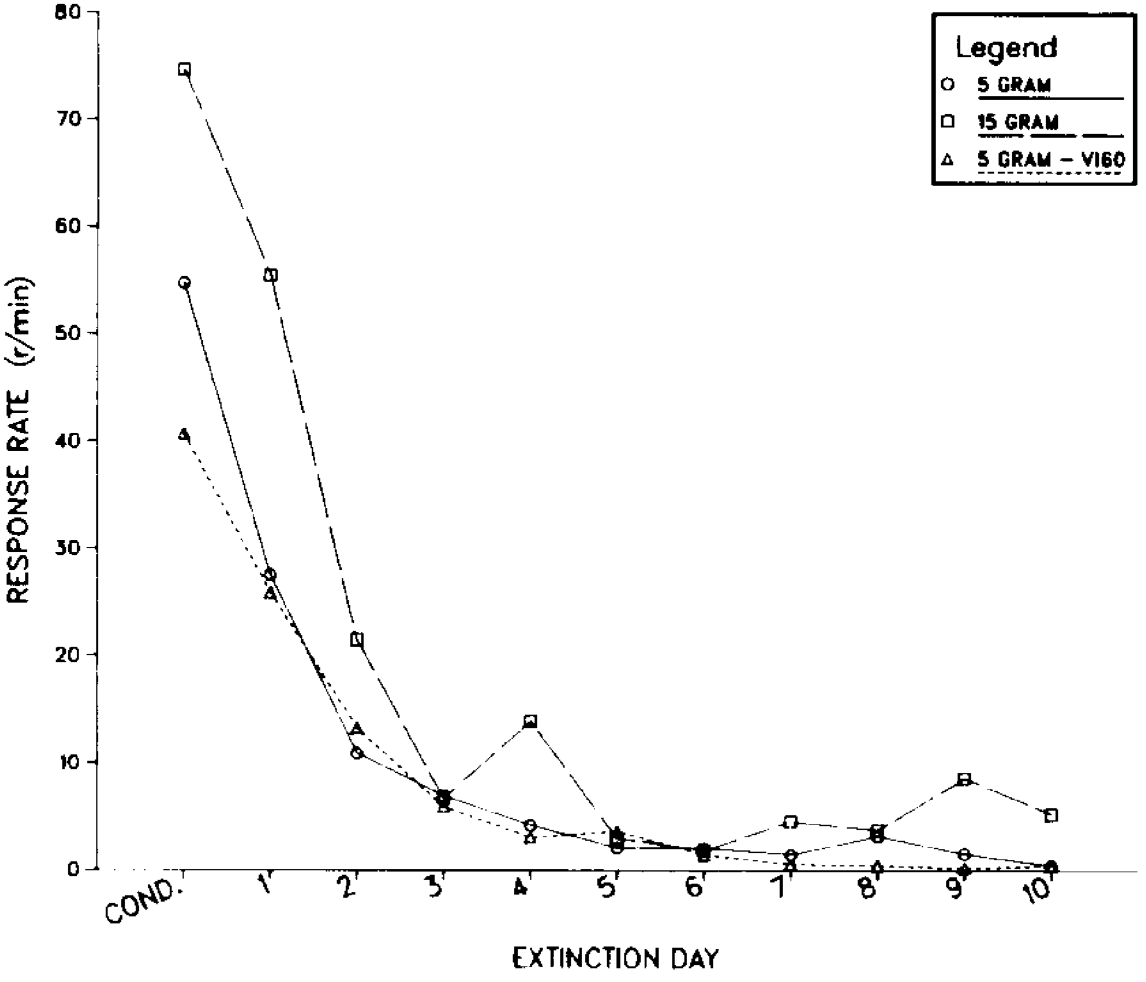


Figure 10

RESPONSE RATE – EXTINCTION – CRF 5g ANIMALS

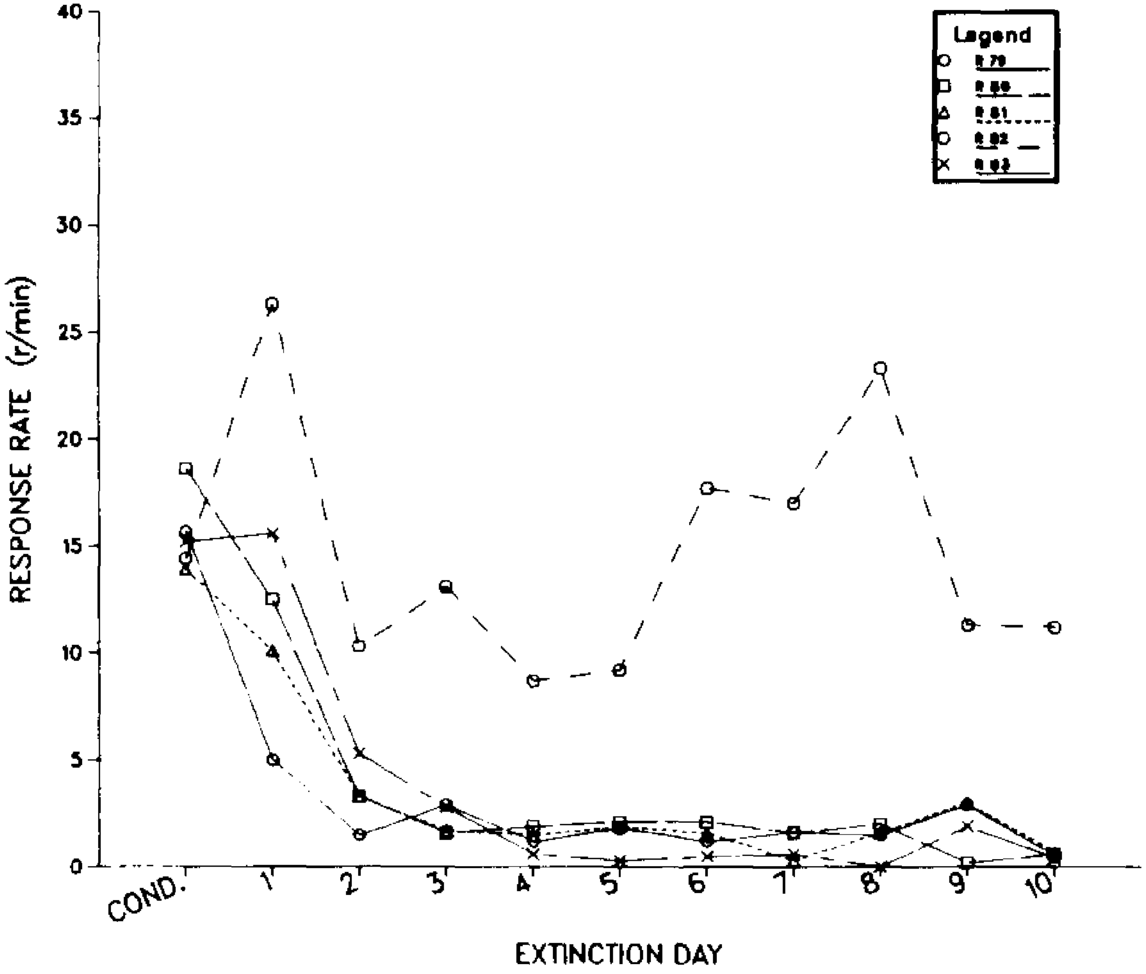


Figure 11

RESPONSE RATE – EXTINCTION – CRF 15g ANIMALS

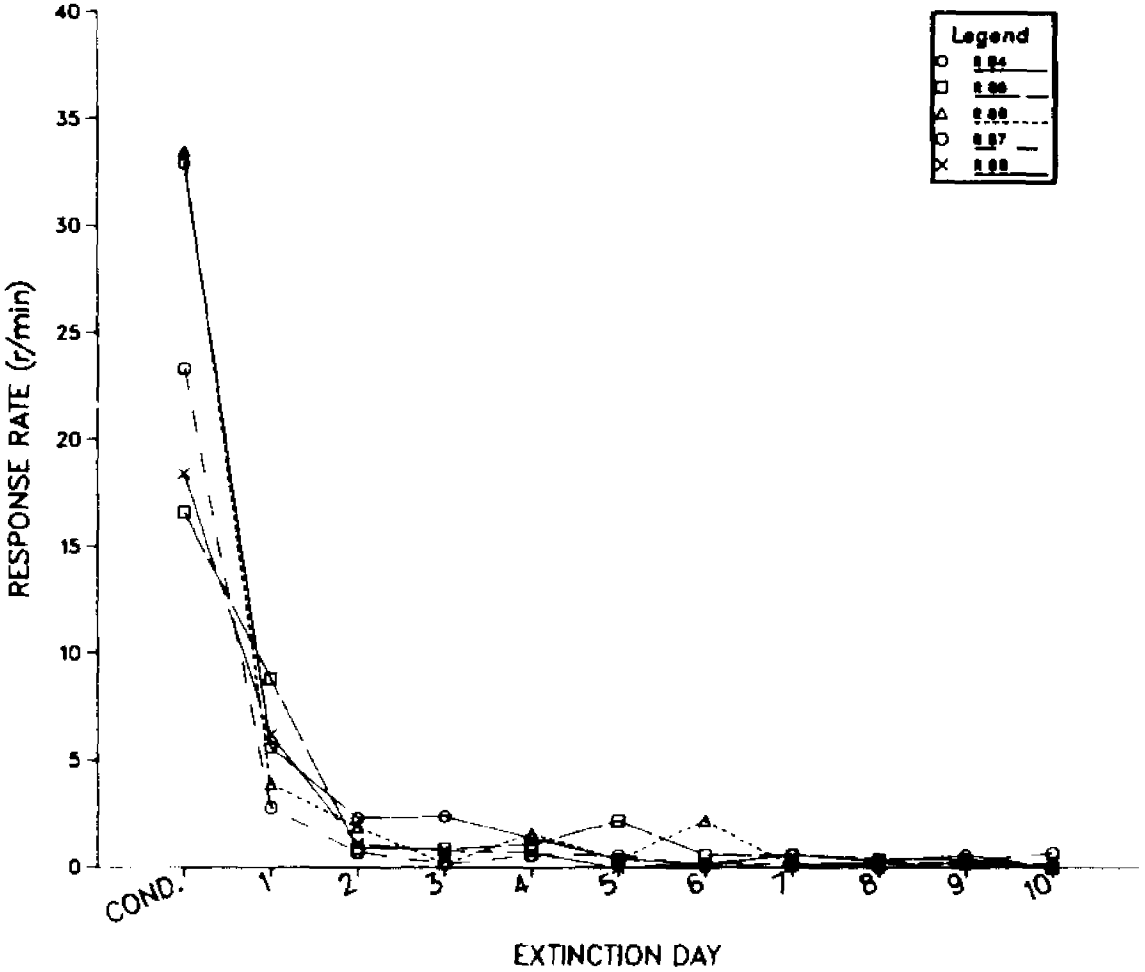


Figure 12

RESPONSE RATE – EXTINCTION – CRF 25g ANIMALS

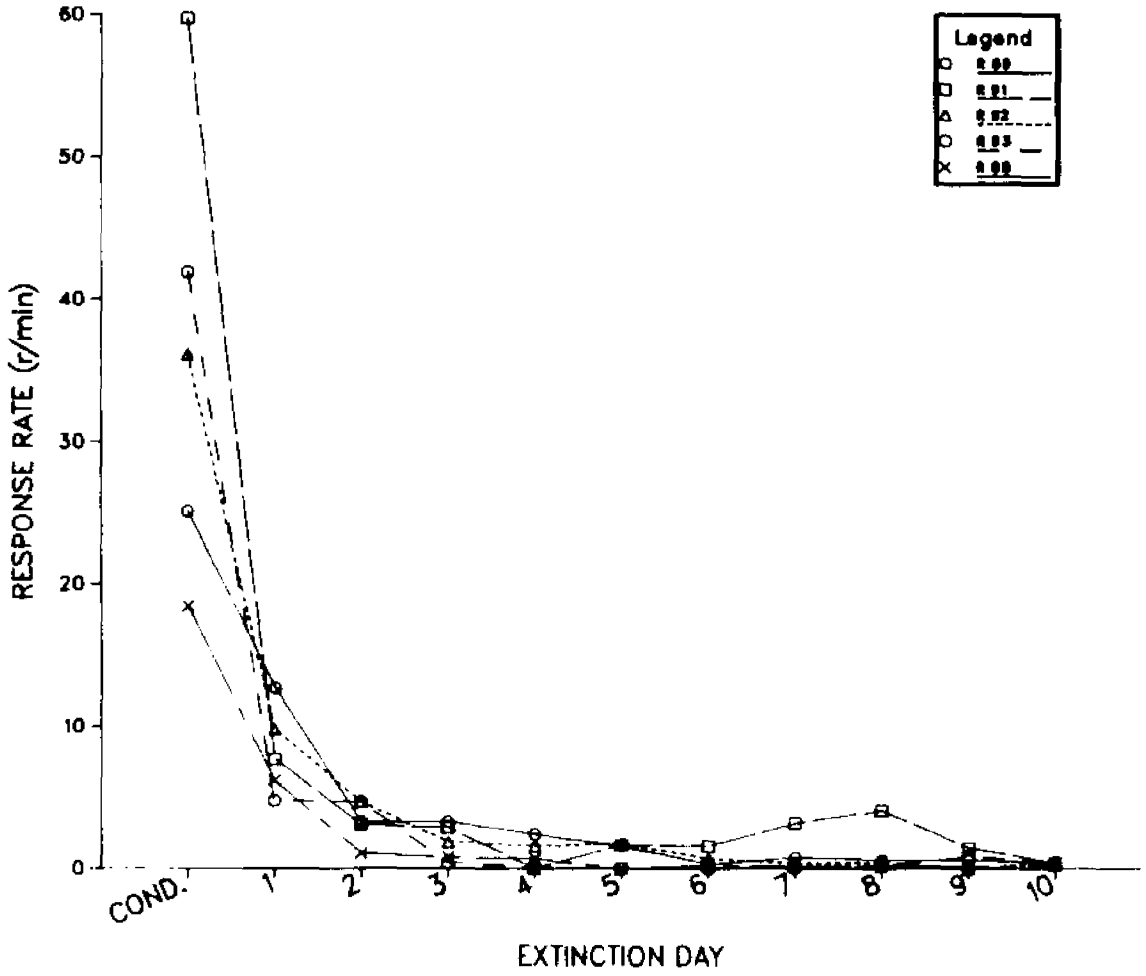


Figure 13

RESPONSE RATE – EXTINCTION – VI15 5g ANIMALS

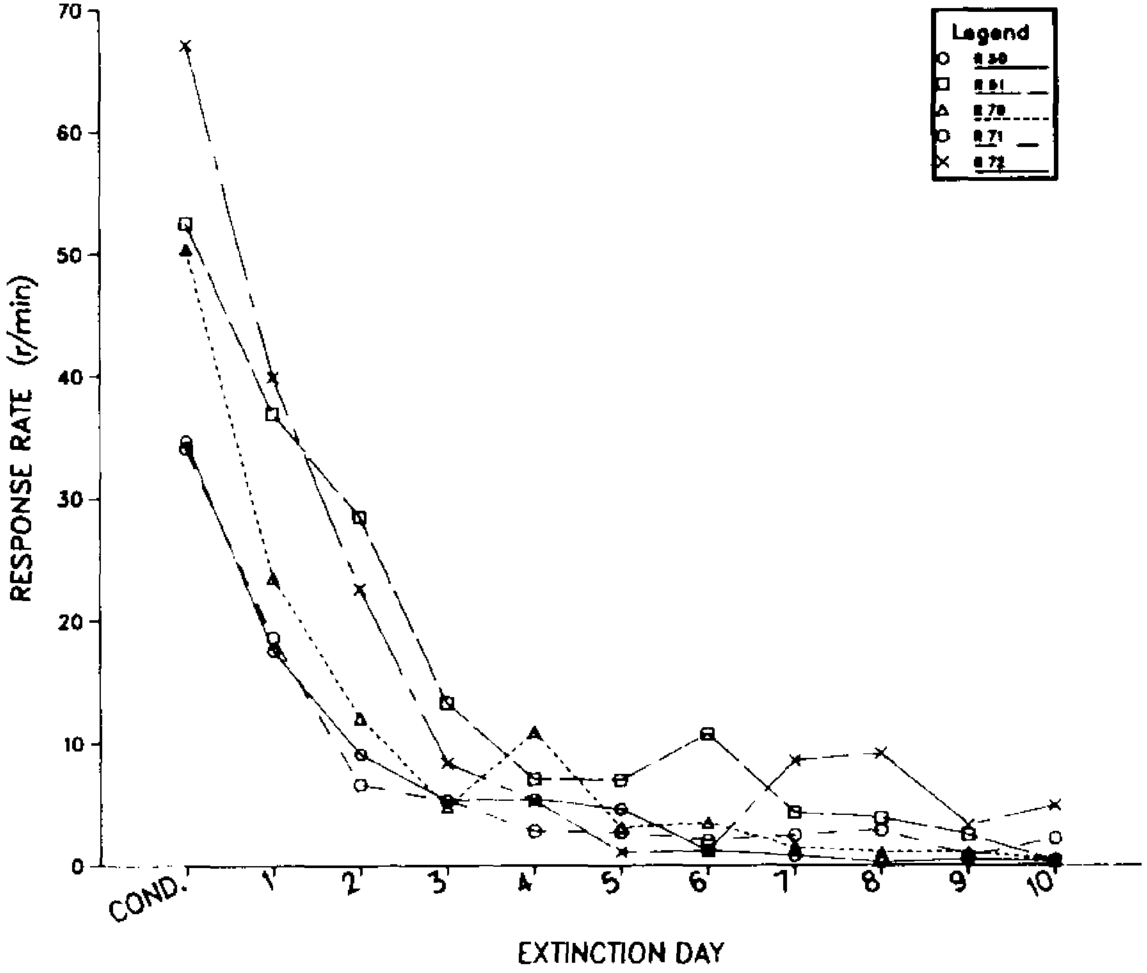


Figure 14

RESPONSE RATE – EXTINCTION – VI15 15g ANIMALS

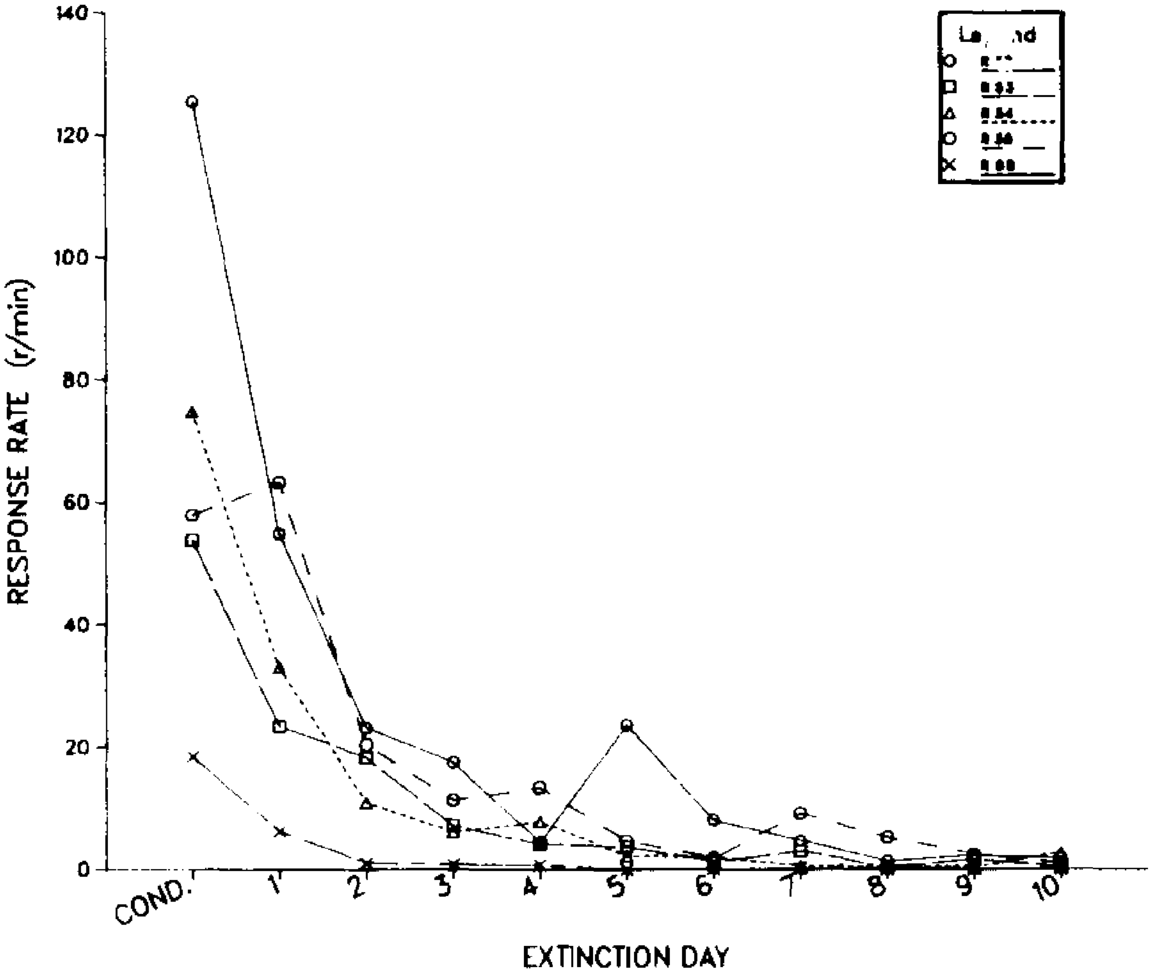


Figure 15

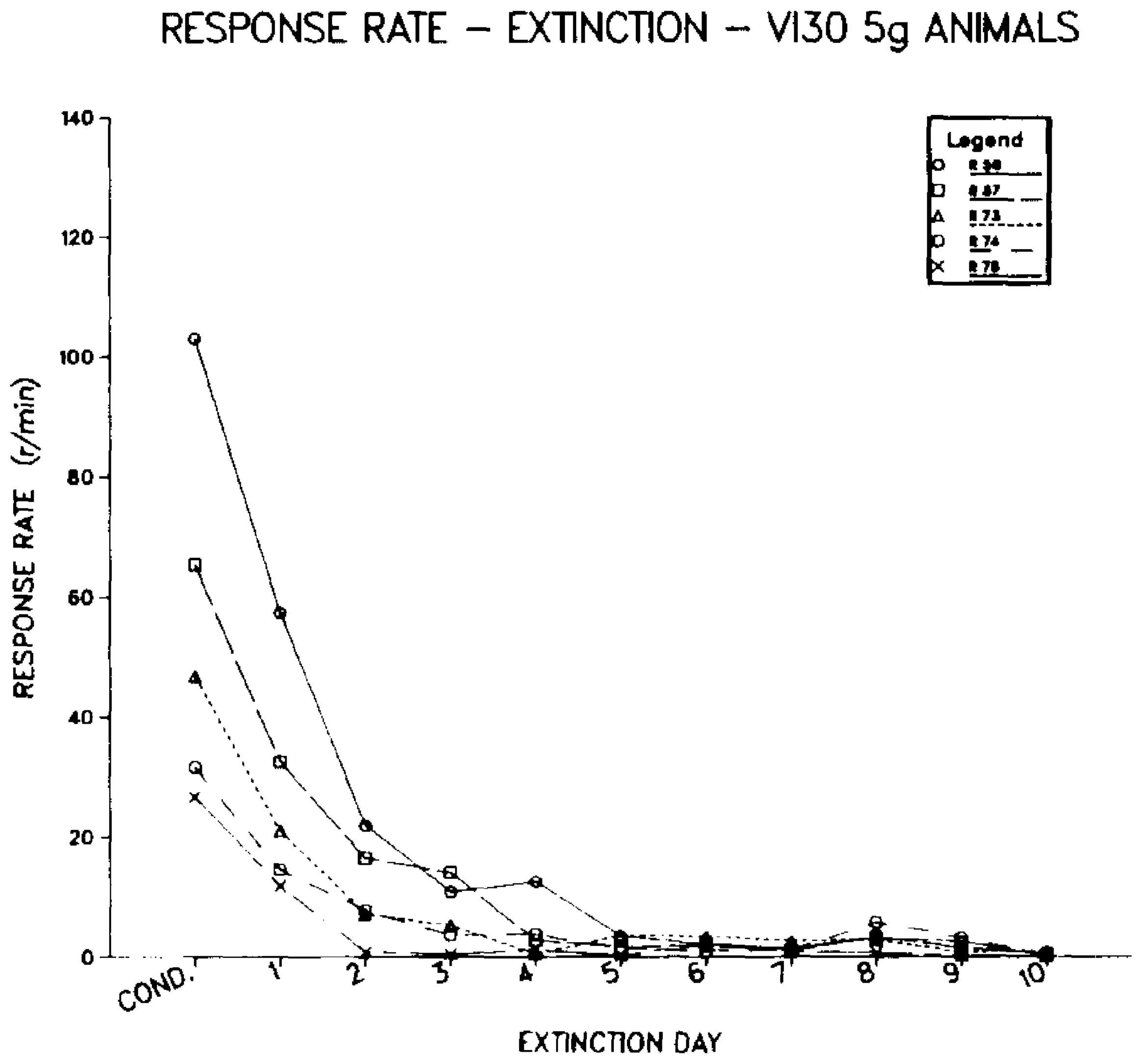

RESPONSE RATE – EXTINCTION – VI30 5g ANIMALS
RESPONSE RATE (r/min)
140
120
100
80
60
40
20
0
COND.
1
2
3
4
5
6
7
8
9
10
EXTINCTION DAY
Legend
○ R 58
□ R 67
△ R 73
◇ R 74
× R 78

Figure 16

RESPONSE RATE – EXTINCTION – VI30 15g ANIMALS

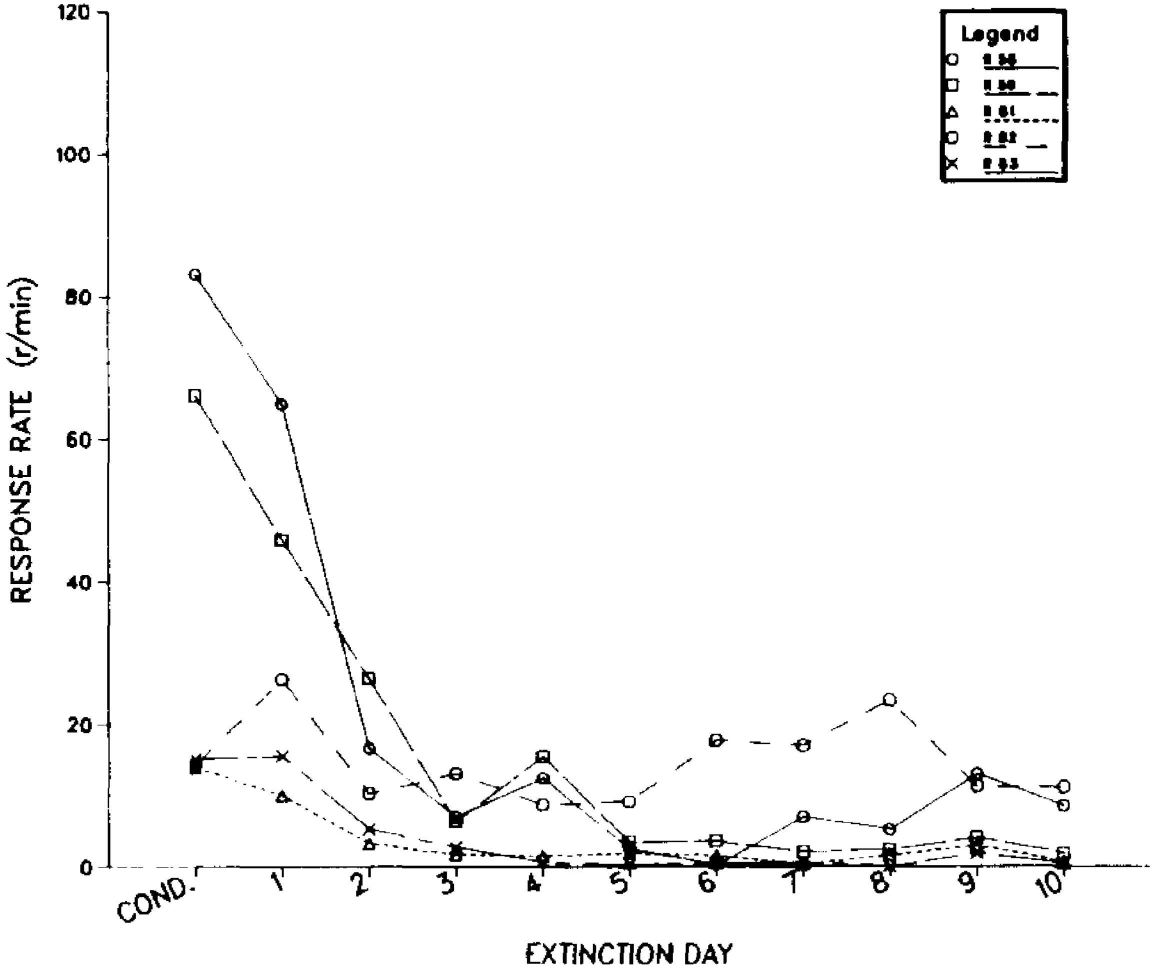


Figure 17

RESPONSE RATE – EXTINCTION – VI60 5g ANIMALS

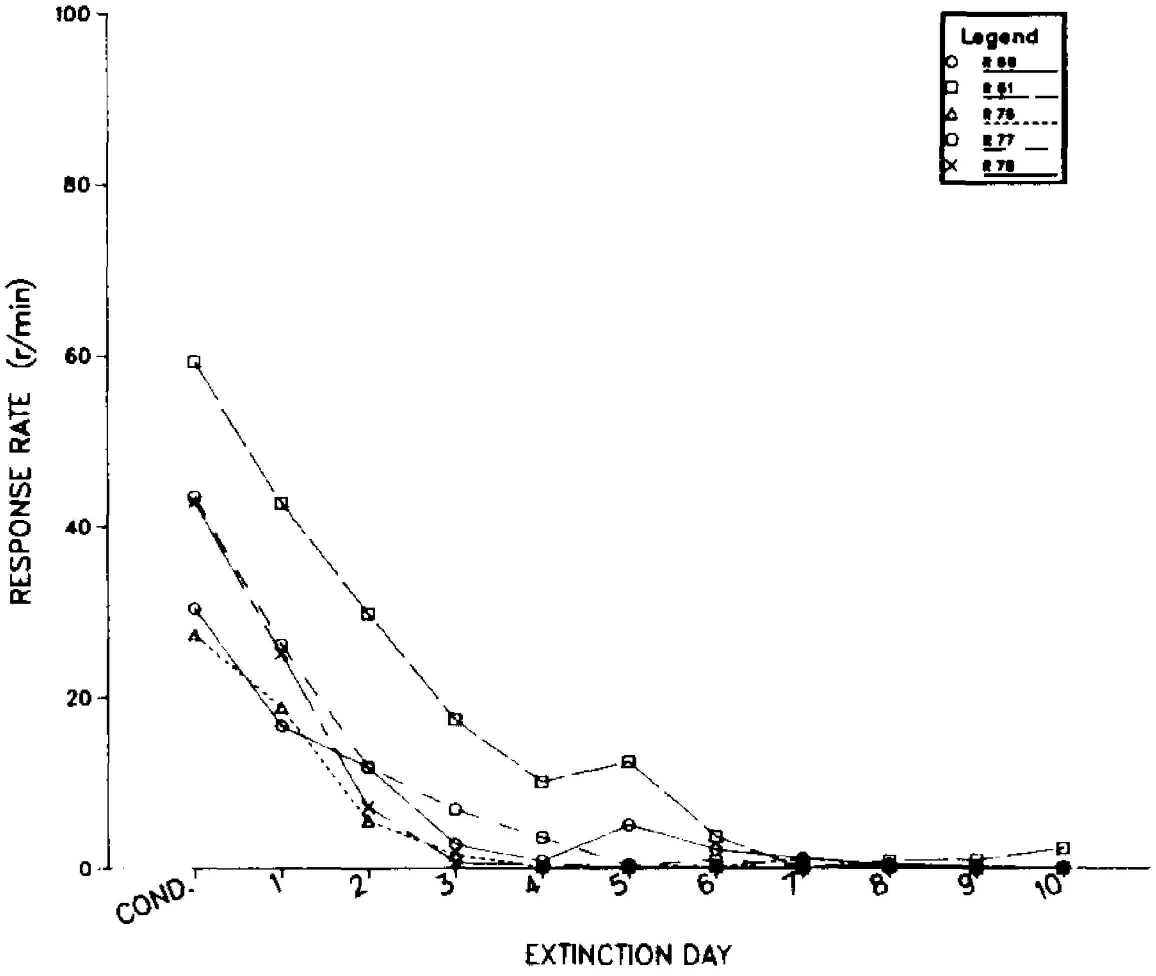


Figure 18

MEDIAN PEAK FORCE – EXTINCTION – ALL 5 GRAM GROUPS

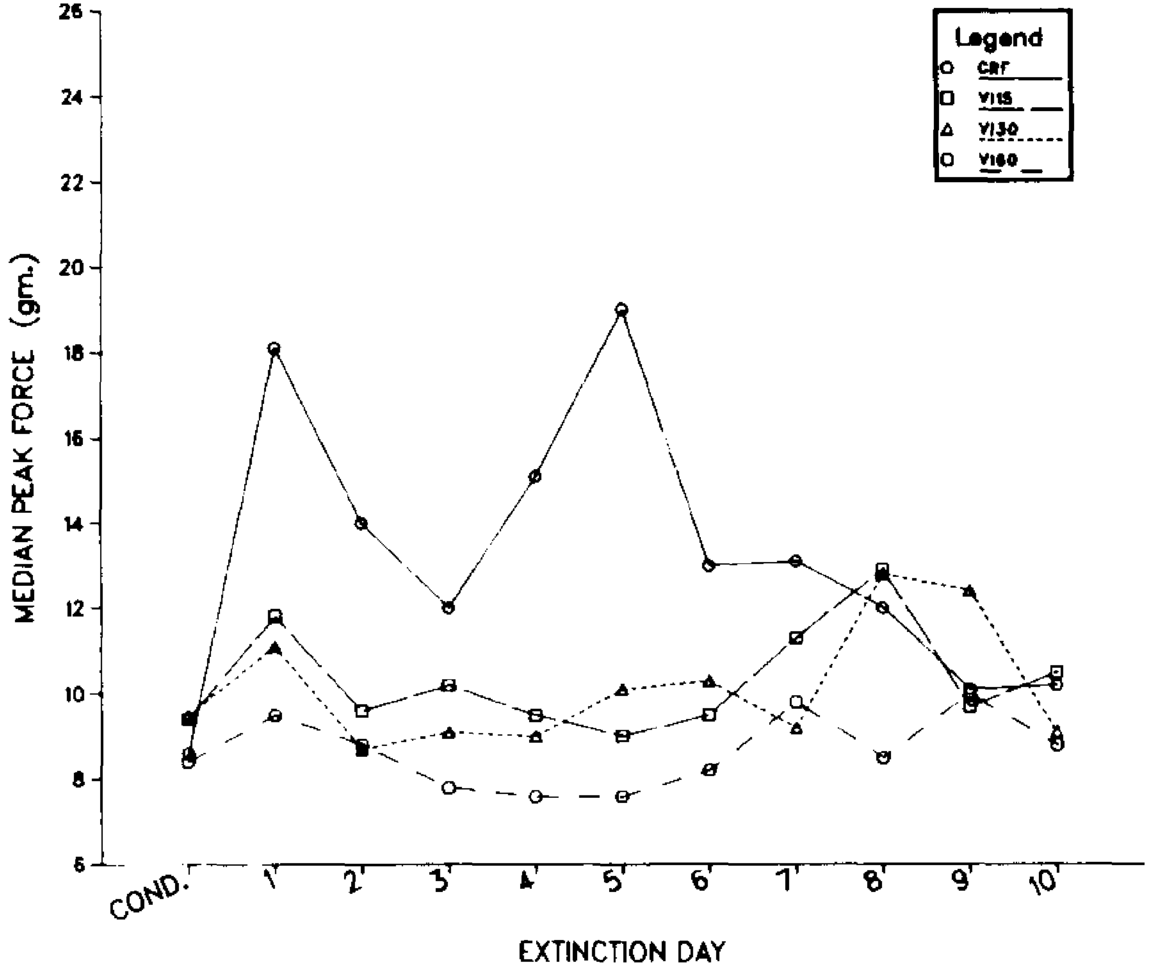


Figure 19

MEDIAN PEAK FORCE – EXTINCTION – ALL 15 GRAM GROUPS

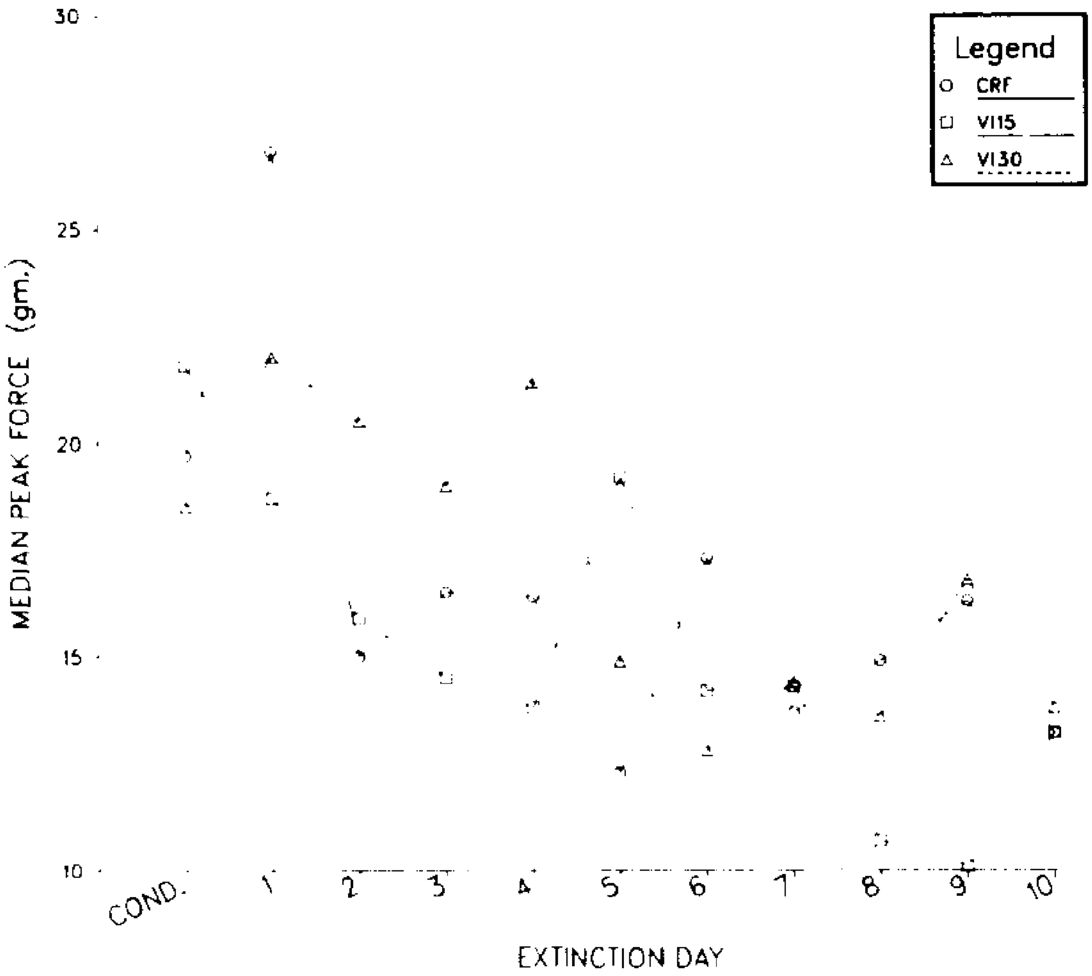


Figure 20

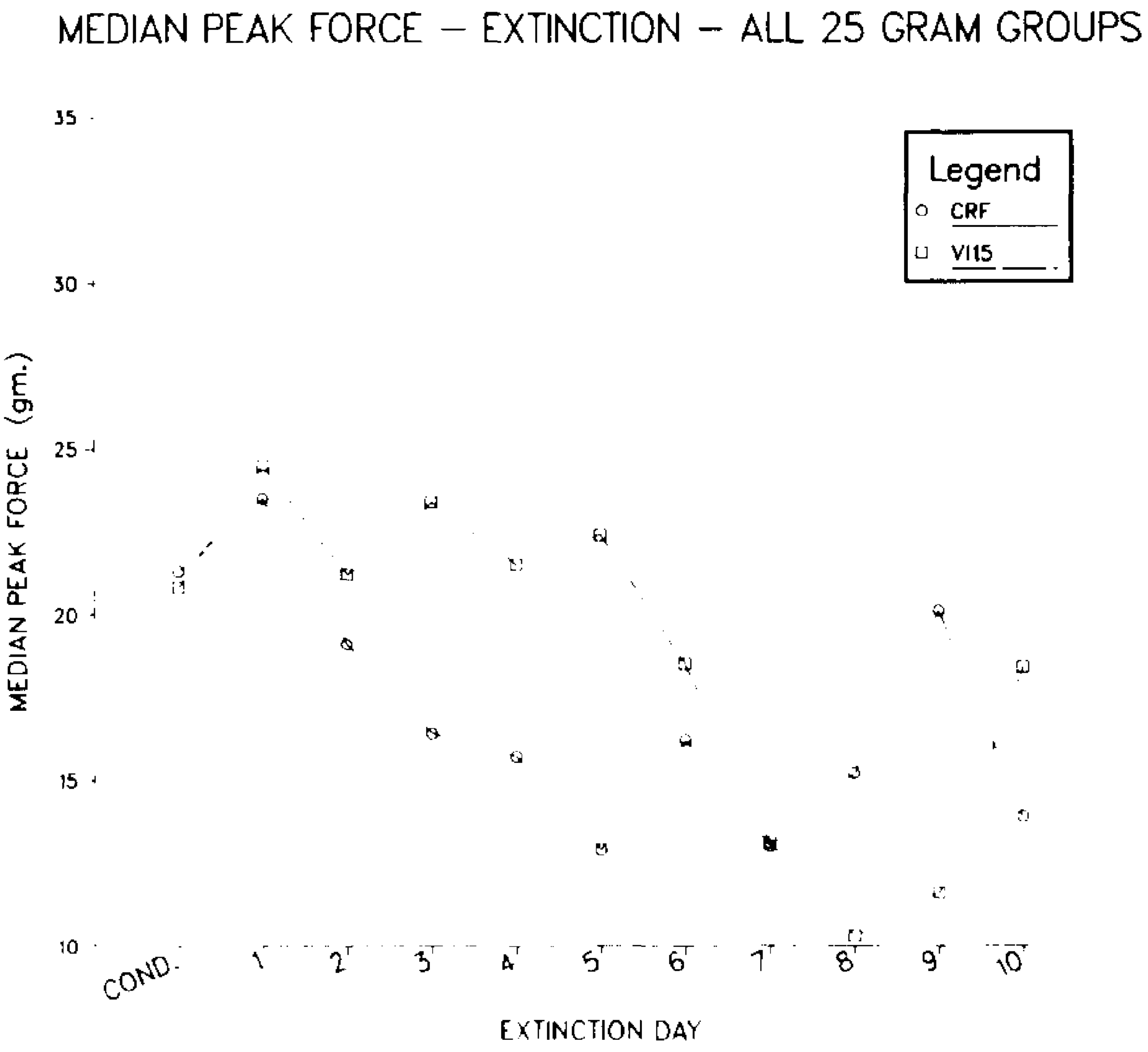
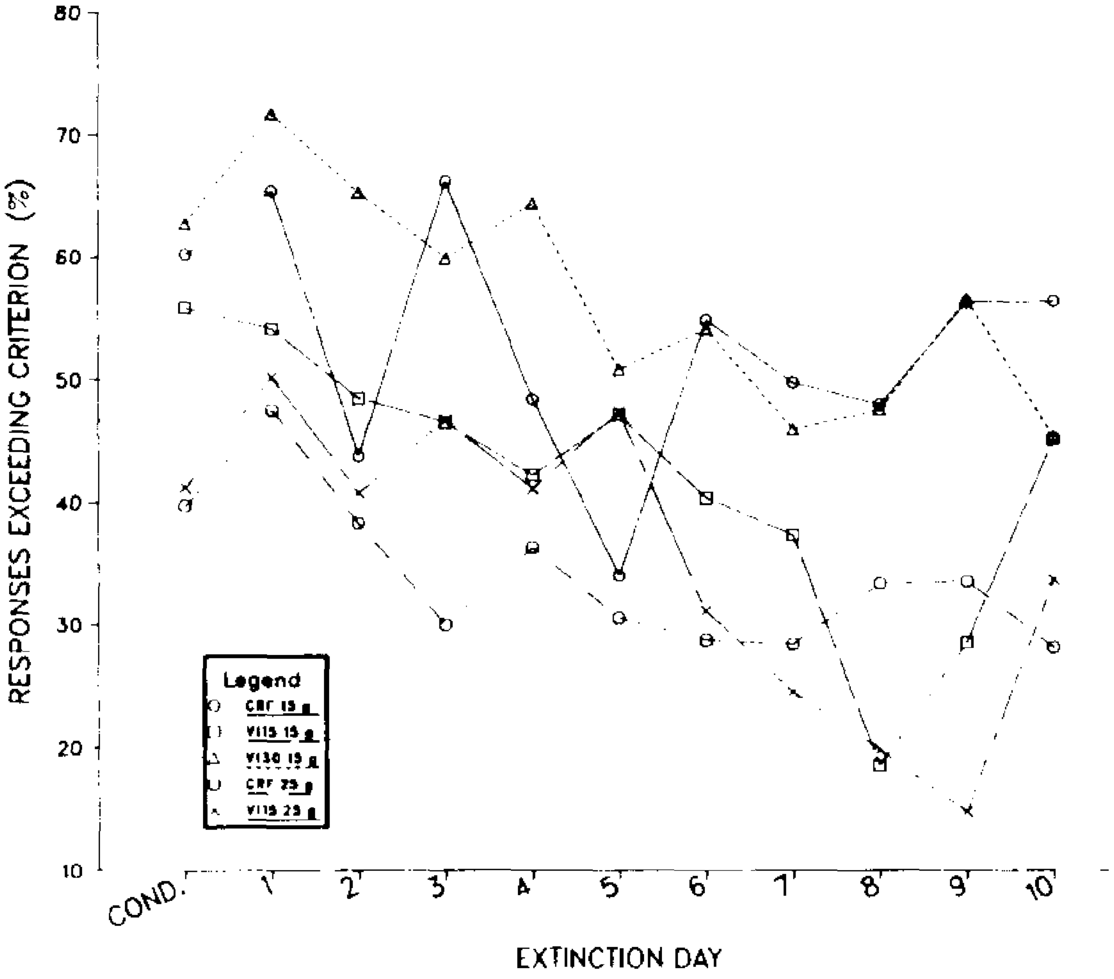

MEDIAN PEAK FORCE — EXTINCTION — ALL 25 GRAM GROUPS
Legend
○ CRF
□ VI15
MEDIAN PEAK FORCE (gm.)
35
30
25
20
15
10
COND.
1
2
3
4
5
6
7
8
9
10
EXTINCTION DAY

Figure 21

RESPONSES EXCEEDING CRITERION – EXTINCTION



BIBLIOGRAPHY

Amsel, A. The role of frustrative nonreward in noncontinuous reward situations. Psychological Bulletin, 1958,55,102-118.

Antonitis, J.J. Response variation in the white rat during conditioning extinction and reconditioning. Journal of Experimental Psychology, 1951,42,.

Birch, J.D. Differentiation of response characteristics during multiple fixed ratio extinction. Psychological Reports, 1964,15,495-502

Catania, A.C. and Reynolds, G.S. A quantitative analysis of the behavior maintained by interval schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 1968, 11, 327-383.

Chung, S. Effects of effort on response rate. Journal of the Experimental Analysis of Behavior, 1965, 8, 1-7.

Eckerman, D.A. and Lanson, R.N. Variability of response location for pigeons responding under continuous reinforcement, intermittant reinforcement, and extinction. Journal of the Experimental Analysis of Behavior, 1969,12,73-80.

Filion, R.D.L., Fowler, S.C. and Notterman, J.M. Psychophysical evaluation of feedback phenomena as related to precision of force emission: some methodological considerations. American Journal of Psychology, 1969A,82,266-271.

Filion, R.D.L., Fowler, S.C. and Notterman, J.M. Some effects of simultaneous force-proportional positive and negative reinforcment. Journal of Experimental Psychology, 1969b, 82,267-271

Filion, R.D.L., Fowler, S.C. and Notterman, J.M. Effort expenditure during proportionally reinforced responding. Quarterly Journal of Psychology, 1970a,22,398-405.

Filion, R.D.L., Fowler, S.C. and Notterman, J.M. Some effects of prefeering and training upon rate and precision of bar=pressing response. Journal of Comparative and Physiological Psychology, 1970b,73,328-333.

Filion, R.D.L., Fowler, S.C. and Notterman, J.M. Prefeeding, discontinuance of prefeeding and force proportional reinforcement. *The Journal of General Psychology*, 1971, *85*, 145-147.

M. and Hoffman, H.E. A progression for generating variableinterval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, *5*, 529-530

Fowler, S.C., Morgenstern, C., and Notterman, J.M. Spectral analysis of variations in force during a bar-pressing time discrimination. *Science*, 1972, *176*, 1126-1127.

Hefferline, R.F. and Keenan, B. Amplitude-induction gradient of a small human operant in an escape-avoidance situation. *Journal of the Experimental Analysis of Behavior*, 1961,*4*,41-43.

Herrick, R.M. The successive differentiation of a lever displacement response. *Journal of the Experimental Analysis of Behavior*, 1964, *7*, 211-215.

Herrnstein, R.J. Stereotypy and intermittant reinforcement. *Science*, 1961, *133*, 2067-2069.

Kimble, G. Hilgard and Marquis' Conditioning and Learning: Second Edition. New York: Appleton-Century, 1961.

Margulies, S. Response duration in operant level, regular reinforcement, and extinction. *Journal of the* Experimental Analysis of Behavior, 1961, 4, 317-321.

Millenson, J.R. and Hurwitz, H.M.B. Some temporal and structural properties of behavior during conditioning and extinction. *Journal of the Experimental Analysis of Behavior*, 1961a, *4*, 97-106.

Millenson, J.R. and Hurwitz, H.M.B. Influence of reinforcement schedules on response duration. *Journal of the Experimental Analysis of Behavior*, 1961b, *4*, 243-250.

Mintz, D.E., Samuels, R.M. and Barber, N.G. Force and rate relations in responding during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1976, *26*, 387-393.

Mintz, D.E., Samuels,R.M., Barber, N.G., and Grossman, L.R. Human force differentiation: Indifference to pressure. *Psychonomic Science*, 1971, *24*, 186-187.

Mintz, D.E.,and Notterman, J.M. Force differentiation in human subjects. Psychonomic Science, 1965, 2, 289-290.

Notterman, J.M., and Mintz, D.E. Exteroceptive cueing of response force. Science, 1962,135,1070-1071.

Notterman, J.M. Force emission during bar pressing. Journal of Experimental Psychology, 1959, 58, 341-347.

Notterman, J.M., and Block, A.H. Response differentiation during a simple discrimination. Journal of the Experimental Analysis of Behavior, 1960, 3, 289-291.

Notterman, J.M. and Mintz, D.E Dynamics of Response. New York: Wiley, 1965.

Schwartz, G.E. and Mintz, D.E Force differentiation in human subjects: Effects of Criterion range and level. Perceptual and Motor Skills, 1980, 51, 575-581.

Skinner, B.F. The Behavior of Organisms. New York: Appleton-Century, 1938.

Stevenson, J.G.,Clayton, F.L. A response duration schedule: Effects of training, extinction, and deprivation. Journal of the Experimental Analysis of Behavior, 1970, 13, 359-367.

Thompson, T., Heistad, G.T. and Palermo, D.S. Effect of amount of training on rate and duration of responding during extinction. Journal of the Experimental Analysis of Behavior, 1963, 6, 155-161.