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BEHAVIORAL VARIABILITY UNDER SCHEDULES OF INTERMITTENT REINFORCEMENT

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BEHAVIORAL VARIABILITY UNDER SCHEDULES OF INTERMITTENT REINFORCEMENT

by

PAUL J. TREMONT

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1981

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

9/14/81
date

Brett L. Cole
Chairman of Examining Committee

9/14/81
date

Herbert D. Saltzstein
Executive Officer

Bruce L. Brown

Robert N. Lanson

William N. Schoenfeld

David A. Eckerman

Gerald D. Lachter
Supervisory Committee

The City University of New York

Abstract

BEHAVIORAL VARIABILITY UNDER SCHEDULES OF INTERMITTENT REINFORCEMENT

by

Paul J. Tremont

Advisor: Professor Brett K. Cole

Variability of interresponse time (IRT), response force time integral (RFTI), and response duration, was examined under Random Interval (RI) and Random Ratio (RR) reinforcement schedules, using 2 groups of 6 rats. For the RI group, the probability of the first response in a repeating time cycle (T) being reinforced was held constant at .100, while the length of that cycle was varied as follows: T=1.5, 3.0, 6.0, 12.0, and 24.0 sec. The minimum mean interreinforcement intervals of the RI schedules thus generated was 15, 30, 60, 120, and 240 secs. For the RR group the probability (p) of reinforcement for each response assumed the following values: p=.100, .050, .025, .012, and .006, and the schedules thus generated were RR 10, 20, 40, 83.3, and 166.6. Sessions for the RI group were terminated after 600 T cycles; for the RR group they were terminated after the allotted number of reinforcements were obtained or after 45 min., whichever occurred first. Sixty reinforcements were allotted under the RR 10, 20 and

40 schedules, and 45 and 23 reinforcements under the RR 83.3 and 166.6 schedules respectively. Twelve daily sessions were run at each schedule value in the orders listed, and the initial schedule values were recovered for each group. Reinforcement consisted of 2.5 sec. access to .04 cc water and a response was defined as bar contact with a minimum 5 gram force for at least 20 msec. and subsequent reduction of contact force below 5 grams for at least 20 msec.

Response rate and post reinforcement pause functions, obtained from the final 4 sessions at each schedule value, were generally consistent with those found by other workers under similar conditions for both groups. Redetermination resulted in recovery of original rate and pause levels in most cases. The IRT distributions, which may be regarded as reflecting variability in behavior outside of the response class (not-R), were obtained by pooling data over the last 4 days at each condition. They revealed increasing variability, in not-R, with increases in interreinforcement time for the RI group and little systematic change with increases in average response requirement for the RR group. Variability of behavior within the response class (R), when estimated either from distributions of RFTIs or durations (again pooled over the last 4 days at each condition) was not systematically related to changes in intermittency of reinforcement on either RI or RR schedules, but overall was greater on the

interval schedules. Both not-R and R variability measures showed, from their recovery data, that extended training had no irreversible effects on variability. Additionally, RFTI and response duration were shown to be highly correlated measures across all experimental conditions; interresponse times were not highly correlated with the RFTIs of the responses terminating them although long IRTs infrequently preceded high RFTIs.

These findings show that the increasing variability of behavior which accompanies decreases in the rate of response occurs, to a large extent, in behavior exclusive of the response class. Moreover, they were suggestive of the possibility that different experiments on variability may incorporate differing amounts of behavior external to the response class (not-R), into their measures of R variability. Experiments using response locus were considered as more conducive to incorporating not-R variability into the R measure, and the possible influence of not-R on behavioral measures is suggested as a matter of importance for behavior theory.

To my parents

The author wishes to thank Drs. Brett K. Cole, Bruce L. Brown, and Robert N. Lanson for their time and efforts on my behalf. Especial thanks are due to Brett Cole for the intellectual support and guidance which was indispensable to the completion of this work. And to Robert Lanson for speedy and thorough review of material and for many helpful criticisms. The technical assistance offered by Geof Inglis, John Leong, and Donald Mintz is also much appreciated. Additionally, I would like to thank Joel Blaustein, Charles Long, Maureen Frawley, and Guadelupe Coll for their encouragement and patience.

Finally, I wish to thank Dr. William N. Schoenfeld for offering support and confidence to me through all of the years I have known him.

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Introduction

The purpose of the present study is to examine changes in the variability of behavior under schedules of varying intermittency of response dependent reinforcement. The behavior observed under such schedules may be regarded as classifiable into two categories: that occurring within the response class (R), and that which may be excluded from the response class, (not-R), (see Schoenfeld and Farmer, 1970, for a discussion of the roles of R and not-R in behavior theory). Variability in not-R, while not directly measurable, is nevertheless a factor contributing to overall behavioral variability including variability in R itself. The focus in variability experiments, however, has remained almost exclusively on R variability, the reason being that dimensions of R variability are directly measurable. In considering responses comprising the R class, it is recognized that individual occurrences may differ, for example, in their topography, force, or duration. The variability of responses occurring within the class will be determined, in part, by the common defining property which qualifies them for membership. If, for example, the common defining property is any movement of the organism which results in the excursion of a lever in a single direction, less variability among qualifying responses may be expected than if the common defining property permitted lever excursion in several directions. It is also true, however, that this choice is not entirely arbitrary. For the common defining property to be acceptable, the behavior so encompassed must reveal orderly changes with respect to changes in the independent variables of which it is a function (Skinner, 1935). Response variability is thus both a consequence and antecedent of the generic definition of the response.

In dealing with certain areas of interest to behavior theorists, (e.g. those involving response rate functions), some of the differences in response properties must be ignored, and thus the utility of adopting the generic definition of the response (Skinner, 1935). However, when focus is shifted to other matters, by necessity we are led to an examination of the variation occurring within the R class (and possibly also to variation outside of that class). One of the more important of these matters is the acquisition of novel behaviors through the reinforcement of successive approximations to them. Indeed, a number of theorists equate acquisition with a reduction in variability (e.g. Staddon and Simmelhag, 1971). In addition, Schoenfeld and Farmer (1970) have argued that changes in the behavior which is taken to comprise the R class may underlie diverse behavioral phenomena. The difficulty of recovering low rates once higher rates have set in, and the appearance of behavioral contrast in discriminative conditioning are two examples mentioned by these workers. Of the various phenomena which have been suggested to be an outcome of changes in the composition of the R class, however, the partial reinforcement effect (PRE) has received the most attention. The partial reinforcement effect refers to the fact that, given an equal number of reinforcers, resistance to extinction is greater following intermittent reinforcement than it is following regular reinforcement. This finding was paradoxical because response strength was thought to be an increasing function of the proportion of reinforced responses, and resistance to extinction was thought to reflect that strength. Currently, theories of PRE emphasize either frustration (Amsel, 1962), or the sequential patterning of reinforced and unreinforced responses in time (Capaldi, 1966). However, in this paper, we will only consider Schoenfeld's (1950) treatment of PRE because it emphasizes a role of behavioral variability as contributing to this effect and, as such, has been the impetus of much of the work on variability. Schoenfeld (1950) suggested that since variability had been shown to increase during extinction (Antonitis, 1951), intermittent reinforcement schedules, which are comprised of multiple extinction periods, may support greater response variability than regular reinforcement schedules. And, if such is indeed the case, intermittent reinforcement schedules may generate a greater number of response subclasses, each individually susceptible to increases in response strength in accordance with the negatively accelerating function relating response strength to number of reinforcements. A given number of reinforcements for many subclasses would then yield more aggregate response strength than an equivalent number of reinforcements for fewer subclasses. One consequence would be a greater resistance to extinction following intermittent reinforcement of a response because more equivalent variations of it would be required to undergo extinction. In a test of one of the implications of this argument, Goldberg (1959) compared response variability in conditioning with response variability in extinction. After training groups under 3 gram and 15 gram force requirements for bar pressing, he found significant concordance between their respective conditioning and extinction peak force variability distributions. Margulies (1960) also examined the relation between conditioning and extinction distributions. He altered the characteristics of the conditioning distributions by varying the amount of training. Using response duration as a measure of variability, he too found correspondence in the rank order of response subcategories, and thus extended the generality of Goldberg's earlier result. Notterman and Mintz (1965), although concerned with the tendency of higher forces to appear in extinction than occurred during conditioning, also present data (Notterman and Block, 1960) which reveal the correspondence of response subclasses appearing in conditioning and extinction. The above experiments, as well as those of Skinner (1938) on force, and Herrick and Bromberger (1965) on displacement, support the conjecture that the response subcategories reinforced in conditioning are those which will appear in extinction (see, however, Herrick (1965), for data which failed to reveal this agreement).

Schoenfeld's (1950) remarks were followed up by a second group of studies. Rather than being focused upon the correspondence of acquisition and extinction response variants, these were directed at the question of the relation between variability and reinforcement intermittency. Herrnstein (1961) observed the locus of key pecks along a 10 inch, 10 position strip during regular reinforcement and then during Variable Interval 3 min. (VI 3 min.). He found less variability in response locus accompanying VI 3 min. than regular reinforcement (CRF). However, a similar experiment by Ferraro and Branch (1968) (using CRF and VI 1 min. schedules) resulted in greater response locus variability under the VI schedule than under CRF and was thus consistent with Schoenfeld's suggestion. Eckerman and Lanson (1969) using a 10 inch, 20 position response strip, also found variability of location pecked to be greater under intermittent schedules (i.e. Fixed Interval (FI) 15, Random Interval (RI) 150, 75, 30 sec.) than under CRF. Boren, Moerschbaecher, and Whyte (1978), in a study where monkeys were trained to operate any of six levers for reinforcement under both FI and Fixed Ratio (FR) schedules, found greater variability in lever choice under the interval schedules than under CRF. Fixed Ratio schedules, however, were not accompanied by greater variability than under CRF. The relation between behavioral variability and reinforcement intermittency emerging from the above studies, all of which used a discrete response locus continuum to track variability changes, is not completely clear.

Behavioral variability and reinforcement intermittency has been examined under quantitative dimensions (e.g. force, duration) as well as the discontinuous dimension of location discussed above. As Ferraro and Branch (1968) pointed out, quantitative dimensions differ from discrete (topographical) ones in two important ways: first, variations of responses under quantitative dimensions are not executable independently of one another, and second, quantitative dimensions may result in differential reinforcement of their minimum values required for reinforcement. Both of these characteristics may tend to reduce variability observed relative to that of a discrete dimension. In experiments where variability along quantitative dimensions has been examined, results have been fairly consistent in suggesting that intermittent schedules are accompanied by more variability than continuous reinforcement schedules, (Herrick, 1965; Herrick and Bromberger, 1965, (displacement); Notterman and Mintz, 1965, (force); Schaefer and Steinhorst, 1959; Millenson, Hurwitz, and Nixon, 1961, (duration)). Millenson et al. (1961) parametrically examined the variability - intermittency relation, observing variability in response duration under a sequence of CRF, FI 15, 30, 60, 120, and 240 sec. schedules, under extended exposure to FI 60 sec. (60 days), and under several Random and Fixed Ratio schedules. The CRF-FI sequence showed an initial increase in variability of duration with the shift from CRF, but thereafter little systematic trend in the variability of the duration distributions occurred. Thus while variability was not found to be an increasing function of FI length, it, nevertheless, was consistently greater under FI than under CRF. In the extended exposure experiment, no systematic trends in variability across sessions were observed. Data from the Random Ratio group revealed a non-monotonic function relating variability of duration to probability of reinforcement, with a possible maximum at p=.11. Given the non-systematic changes in variation of response duration obtained in these experiments, Millenson et al. (1961) cautioned against interpreting duration as a legitimate indicator of response variants.

The present experiment was intended to provide additional data on the relationship of behavioral variability to reinforcement intermittency. The focus is on intermittency in this study because the effects on variability of the transition from CRF to schedules of intermittent reinforcement and from CRF to extinction, are less equivocal than those accompanying changes within intermittency. Because the matter of the most useful means of assessing variability in behavior remains as yet unsettled, in the present experiment variability was tracked by three dependent measures: interresponse time (IRT), response force time integral (RFTI), and response duration. Inasmuch as the focus within the variability literature has been almost exclusively on R variability, the IRT measure in this study provides some preliminary data on concurrently tracked not-R variability. Time integral of force, and response duration serve, of course, as the measures of R variability. Two separate groups of rats were exposed to the following series of reinforcement schedules: Group T, Random Interval 15, 30, 60, 120, and 240 sec.; Group P, Random Ratio 10, 20, 40, 83.3, and 166.6. Each condition was maintained for 12 days and recovery sessions were run in both cases under initial schedule values. In addition to the general question of behavioral variability and reinforcement intermittency, the experimental arrangement also provided the opportunity (1) to gather some additional data on the forms of the response rate functions, obtainable with rats, under systematic variation of the parameters defining the above schedules, (2) to estimate, from recovery data, the effect of extended training on changes in variability, and (3) to consider whether the different measures of behavioral variability used herein are in general agreement with one another.

Method

Subjects

Twelve male hooded rats about 9 months old at the beginning of the study served. They were individually housed and had unlimited access to Purina rat chow. Access to water was restricted to the hour following the daily experimental session. Each rat had been dipper trained and was hand shaped to press the bar. Additionally, all rats had received extensive exposure to various reinforcement schedules including 30 days of Random Interval 15 sec. (RI 15) reinforcement just prior to the experiment. Two groups of 6 rats each, matched approximately for response rate were then established.

Apparatus

Two modified Scientific Prototype operant conditioning chambers (model A100) enclosed within wooden sound attenuating boxes were used. Interior dimensions were 20.4 cm. wide X 23.4 cm long X 19.3 cm high. Two sides and the top were made of Plexiglas; there was a grid floor; and the end walls were of aluminum. A GE 1819 bulb mounted on one end wall near the ceiling provided illumination. The dipper, available through a circular slot in the opposite end wall, was situated 5.0 cm to the right of center and 3.5 cm above the grid floor.

Reinforcement consisted of 2.5 sec. access to its .04 cc water filled cup, and was accompanied by a brief, 300 msec., offset of the houselight. The manipulandum, a steel rod, was mounted perpendicular to the floor through a slot in the same wall 10.8 cm from the dipper. The section available to the rat was a semicircular surface with a 6.25 mm radius at a height of 6.5 cm above the floor. All but the uppermost 1.5 mm of the rod was shielded so as to minimize the application of lateral forces. The rod was threaded into a 230 gram load cell (model UL-4, Gould Inc.) which in turn was attached to a Gould Statham UC-3 transducer. The movement of the manipulandum was limited to a vertical displacement of .12 mm and it was silent in operation. The entire assembly: rod, load cell, and transducer, was isolated from chamber vibrations by an external wall mount. A Beckman R611 polygraph used in conjunction with the transducer generated a voltage level proportional to force which was fed into the analog to digital converter of a PDP8/E computer. The system was calibrated daily using static weights with a maximum error of 1% across the 100 gram recording range. Sequential recording on disk of each interresponse time, response duration, and response force time integral, was accomplished under SUPERSKED (Snapper and Inglis, 1979) software at a clock rate of 100 Hz. Experimental contingencies were also programmed under SUPERSKED.

Cumulative and polygraph recorders were used to monitor responding. All control and recording equipment were located in adjacent rooms. White noise and ventilating fans provided continuous masking.

Procedure

Six rats were assigned to a Random Interval series of reinforcement schedules (T-group) and 6 to a Random Ratio series (P-Group). For the Random Interval group, the probability (p) of the first response in a repeating time cycle being reinforced, was held constant at .100, while T, the length of that cycle, was manipulated as follows: T= 1.5, 3.0, 6.0, 12.0, 24.0, and 1.5 sec.. The mean minimum interreinforcement intervals of the random interval schedules thus generated was 15, 30, 60, 120, 240, and 15 sec.. Twelve daily sessions were run at each value of T in the above listed order with each session comprised of 600 cycles. For the random-ratio group, the length of the repeating time cycle, T, was held constant at .01 sec., while p, the probability of the first response in each cycle being reinforced, assumed the following values: p= .100, .050, .025, .012, .006, and .100. Because the T cycle length (.01 sec.), was shorter than the minimum IRT (.02 sec.), each response occurred in a new cycle and was therefore reinforced with probability p. The sequence of

Random Ratio schedules generated was thus: RR 10, 20, 40, 83.3, 166.6, and 10. Twelve daily sessions were run at each value of the independent variable for this group as well. Sessions for the p group were terminated after 45 min. or when the allotted number of reinforcements were obtained, whichever occurred first. Sixty reinforcements were allotted under the RR 10 20, and 40 schedules; sessions run under RR 83.3 and 166.6 schedules were terminated after 45 and 23 reinforcements respectively.

A response was considered to have occurred when the rat contacted the bar with a minimum 5 gram force for a period of at least 20 msec. and subsequently reduced its contact force to below 5 grams for a period of 20 msec.. If, after meeting the initial response requirement, contact force on the bar fell below 5 grams for less than 20 msec., the response was considered not to have been completed, and subsequent contact at or above the minimum force level was treated as part of the contact previously made. All responses thus had a minimum RFTI of .10 gram-seconds. This response definition was used for both groups and remained unchanged throughout the experiment.

Results and Discussion

This section is divided into two parts. The first is comprised of functions showing mean response rates and post reinforcement pauses (PSRPs) across experimental conditions. Its purpose is to compare these measures with rate and pause data obtained from similar experiments using standard apparatus. Consistencies appearing between this and comparable experiments using standard apparatus, on the measures they have in common, may permit greater confidence in generalizing the findings derived from measures which are not in common, such as interresponse time (IRT), response duration, and response force time integral (RFTI). The second part presents cumulative relative frequency distributions, and medians and semi-interquartile ranges of these latter measures at each experimental condition. In this second part, the variability of behavior under the different reinforcement schedules will be examined. Also, in the second part, data on correlations between duration and RFTI, and a representative scatterplot of IRT vs. the time integral of force of the response terminating it are shown. The rate and pause functions were computed by averaging data obtained from the last 4 days at each experimental condition. Distributions are comprised of data pooled over the last 4 days.

I. Response Rate and Post Reinforcement Pause Functions

Response rates as a function of mean interreinforcement time (T/p) for group T are shown in Figure 1. Rates were computed with total reinforcement time subtracted from session length. With only occasional discrepancies, these corrected rate functions decline steadily at a decreasing rate. Rats A and E, for example, show rate increases when shifted from RI 15 to RI 30, but this effect was small and may be related to the lower initial rates of these animals. Recovery of response rates (indicated by unconnected diamonds) to levels closely approaching their initial values with the return to RI 15 was obtained for all subjects except rat D.

Subtracting total PSRP time in addition to SR time from session length when computing response rate, generates the running rate functions shown in Figure 2. Although their levels have been elevated, the functions are almost indistinguishable in form from their corrected rate counterparts. Rat D's redetermined rate at RI 15 is now in closer agreement with its initial level, indicating the extent to which PSRP contributed to the discrepancy in the corrected rate recovery data--see Figure 5 below.

The rate functions obtained here are consistent with those obtained with pigeons by Farmer, 1963; Cole, 1968;

Figure 1. Corrected response rates (reinforcement time removed) for each T-Group subject and for the group mean at each value of T/p. Each point represents the mean taken from the last 4 days at the condition. The disconnected point offset to the left of each function indicates redetermination of the first (T/p=15), condition.

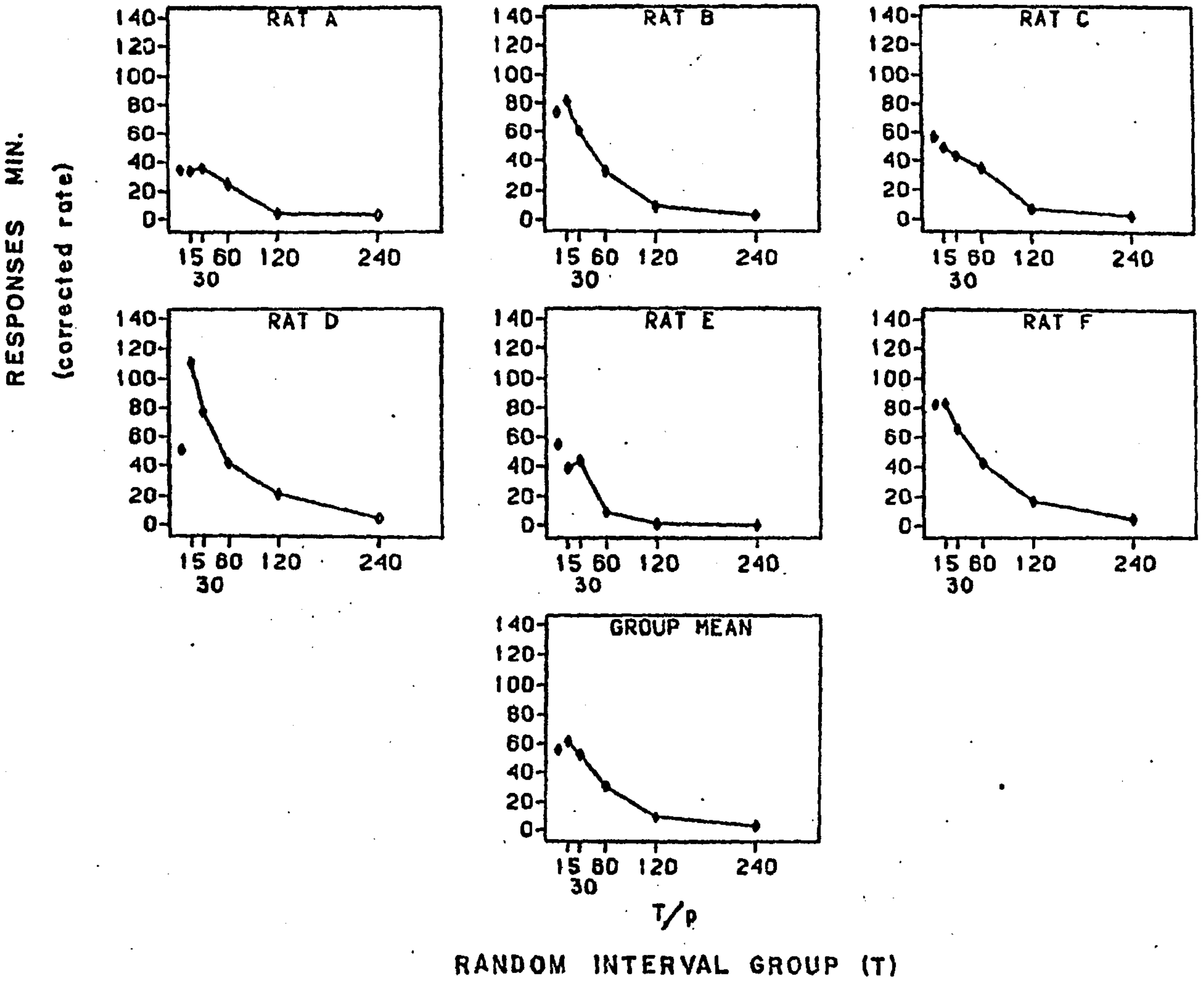
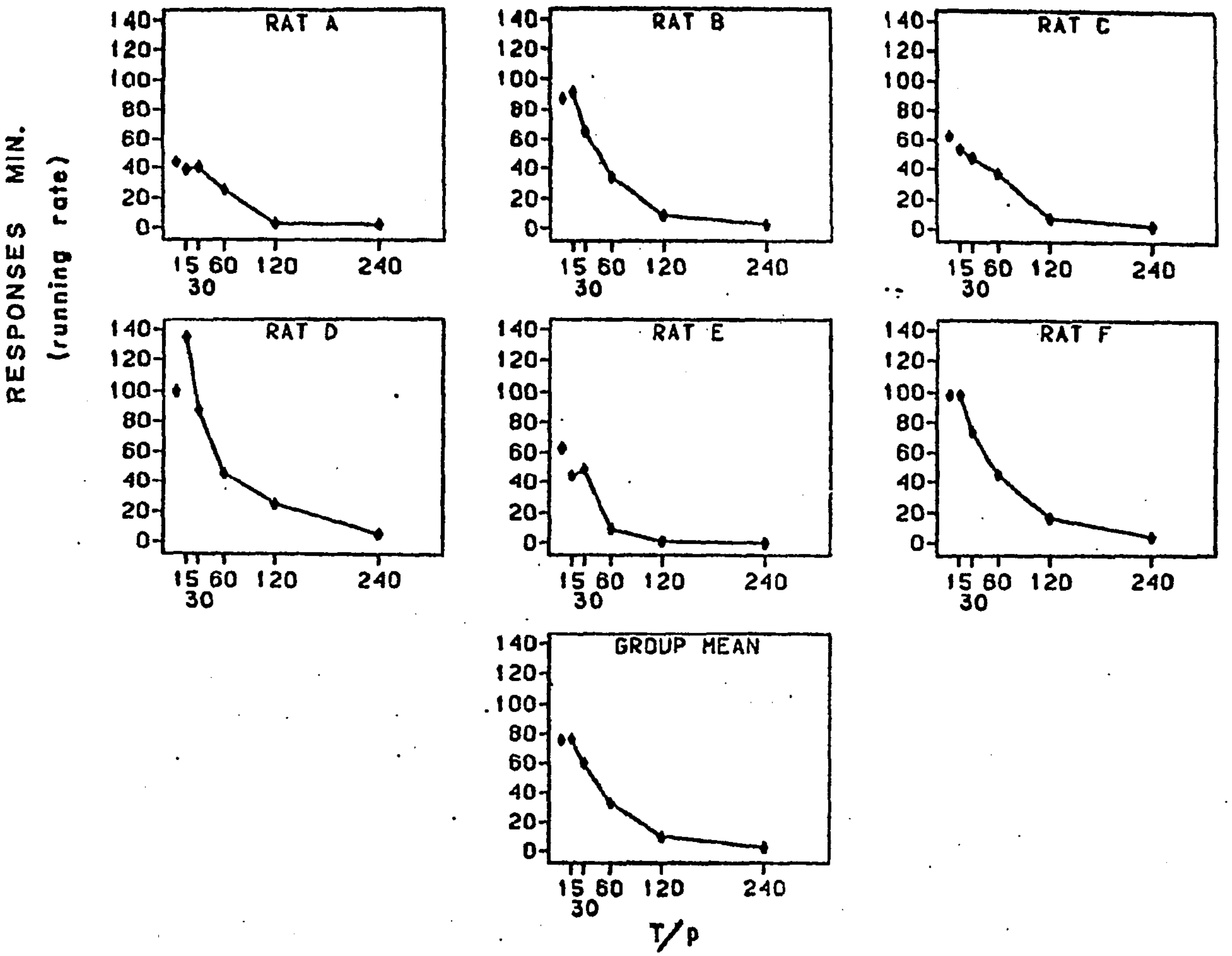

RESPONSES MIN.
(corrected rate)
RAT A
RAT B
RAT C
RAT D
RAT E
RAT F
GROUP MEAN
0
20
40
60
80
100
120
140
15
30
60
120
240
T/p
RANDOM INTERVAL GROUP (T)

Figure 2. Running response rates (reinforcement time and post reinforcement pause time removed) for each T-Group subject and for the group mean at each value of T/p. Each point represents the mean taken from the last 4 days at the condition. The disconnected point offset to the left of each function indicates redetermination of the first (T/p=15), condition.



RANDOM INTERVAL GROUP (T)

and Lachter, 1971 all of whom varied T/p under RI schedules. Rate functions obtained from rats responding under Random Interval schedules are not available, but similar functions have been obtained from rats under a group design using VI schedules, (Clark, 1958). Thus, in spite of apparatus and subject differences, the rate functions obtained here are characteristic of those observed when interreinforcement time on interval schedules is varied.

Corrected response rates plotted as a function of the mean Random Ratio (T/p) are shown in Figure 3. These functions are more divergent from one another than are the random interval functions, but may be grouped into two predominant patterns: one of no systematic change in rate across p values (G and H), or one of steady decline in rate with reductions in p (I,J,K,L). Of those in the latter group, responding virtually ceased under RR 83.3 for rats I and K and under RR 166.6 for rat J. Rat L was exceptional in that his responding continued to be well maintained across all p values in spite of its steady decline. With the return to RR 10 all animals recovered their initial rates.

Running rate functions for the P-Group (Figure 4) reveal the same divergences from one another, and for all subjects except rat G, are of the same general form as their corrected rate counterparts. The differences in

Figure 3. Corrected response rates (reinforcement time removed) for each P-Group subject and for the group mean at each value of 1/p. Each point represents the mean taken from the last 4 days at the condition. The disconnected point offset to the left of each function indicates redetermination of the first (1/p=10), condition.

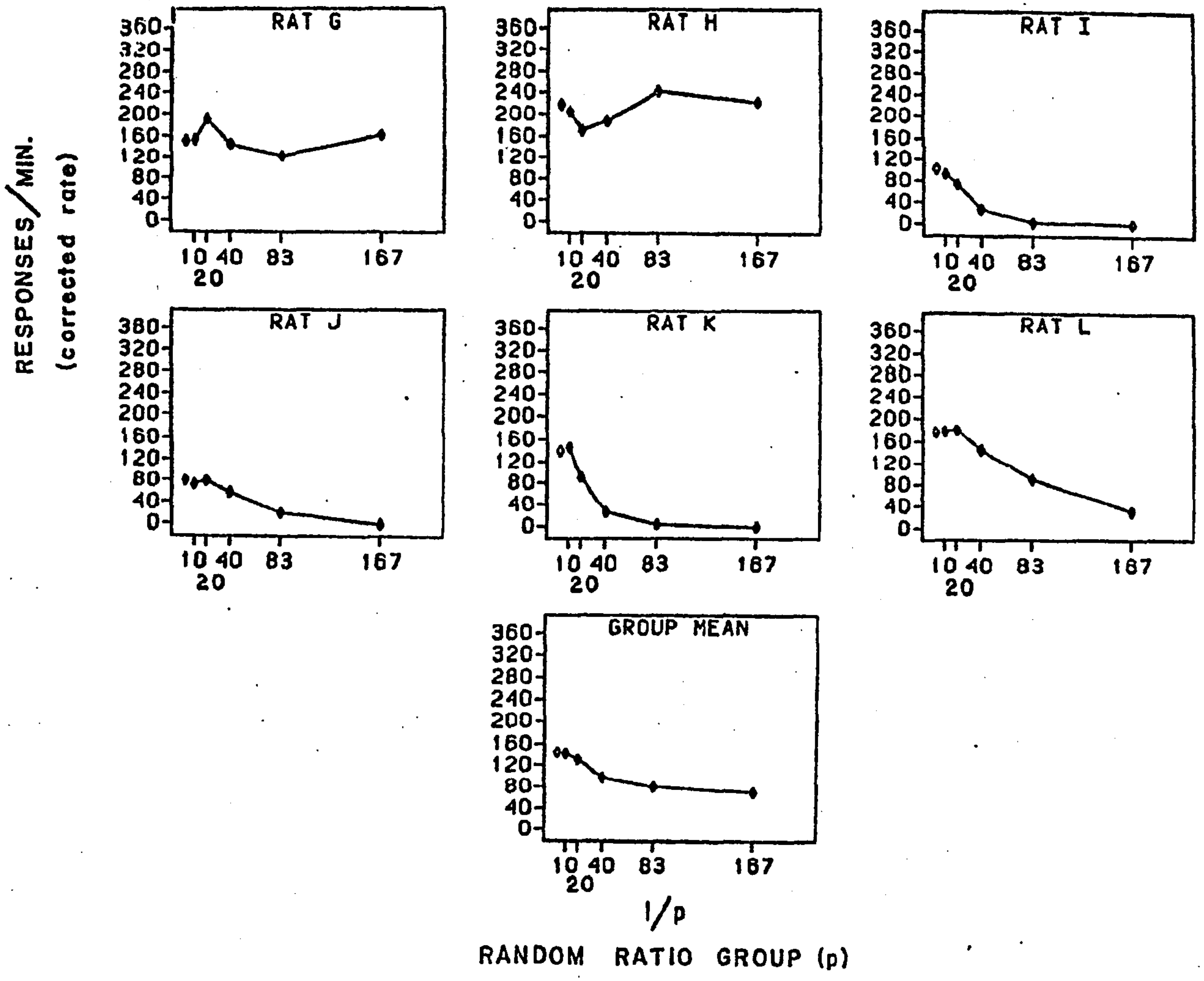
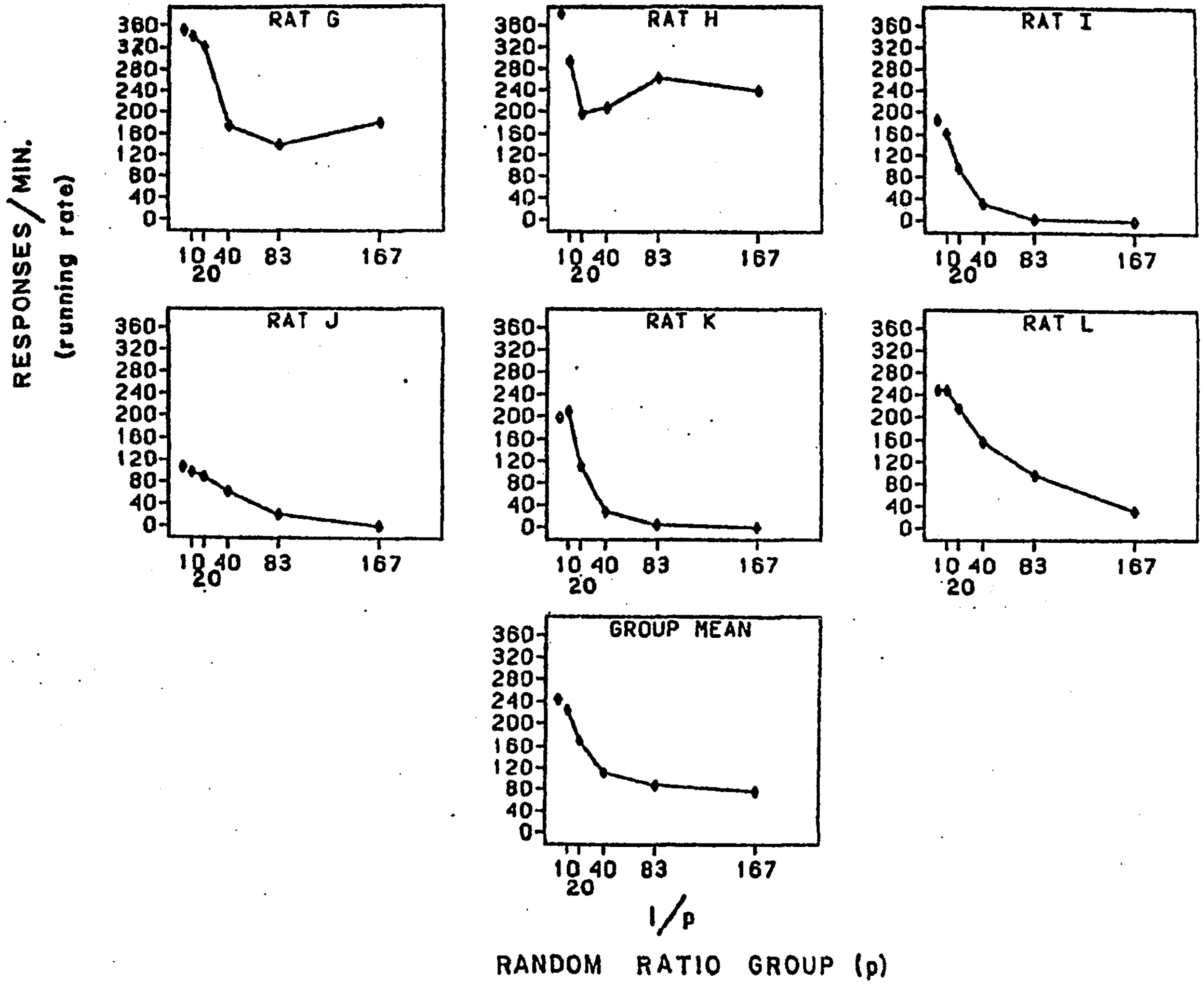

RESPONSES/MIN.
(corrected rate)
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
GROUP MEAN
360
320
280
240
200
160
120
80
40
0
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

Figure 4. Running response rates (reinforcement time and post reinforcement time removed) for each P-Group subject and for the group mean at each value of 1/p. Each point represents the mean taken from the last 4 days at the condition. The disconnected point offset to the left of each function indicates redetermination of the first (1/p=10), condition.

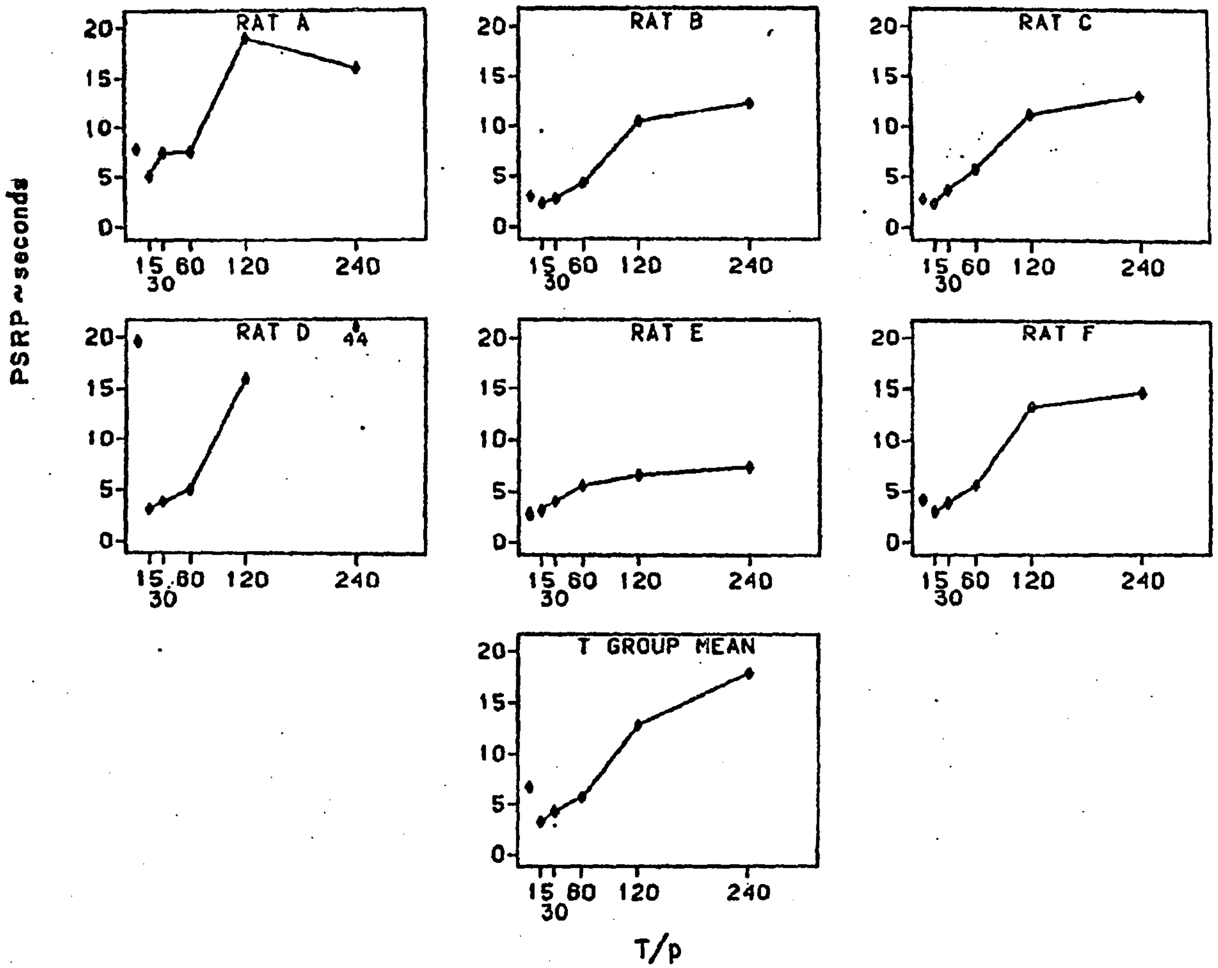

RESPONSES/MIN.
(running rate)
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
GROUP MEAN
360
320
280
240
200
160
120
80
40
0
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

corrected and running rate functions observed in rat G occur at the higher p values (i.e. .10, .20) which result in extremely short sessions. Consequently, the relatively small change occurring in PSRP, (see Figure 6 below) had substantial effects on corrected rate values. Running rates returned to their initial levels under RR 10 for all animals except H for whom recovery was considerably higher.

The characteristic form of the rate probability function is currently open to some question as inconsistencies appear among previous investigations. Brandauer (1958), using pigeons, obtained a non-monotonic rate-probability function with its maximum at p=.02 (RR 50) when he varied p across a range of 1.0 to .00167 (CRF to RR 598.8). Sidley and Schoenfeld (1964) under a group design with pigeons, varied p from 1.0 to .0068 (CRF to RR 147.1), and also failed to observe a monotonic rate function. Moreover, their data show that the obtained function is not independent of amount of training at the various p values. Using RR schedules, (Farmer and Schoenfeld, 1967), shaped pigeons to ensure the maintenance of responding at the lowest p values used in the study. Following this training, the subjects were exposed to the various p values in a mixed order for final determination of the probability-rate function. These workers found no differential effect of probability on rate across the p range of .8 to .002. (RR 1.25 to RR 500). The above mentioned studies illustrate, as had been previously pointed out (Morse, 1966), that performance on random ratio schedules depends both upon the reinforcement history and the sequential development of the final performance. Nevertheless, the question of why individual subjects, presumably with the same experimental history, would differ from one another is problematical. However, the inherently unstable nature of ratio schedules owing to the direct relation between response rate and reinforcement rate occurring under them (cf. Zeiler, 1977) would tend to maximize any individual differences. In view of the above, it would seem that the present results may be regarded as not uncharacteristic of what may be expected to occur on these schedules.

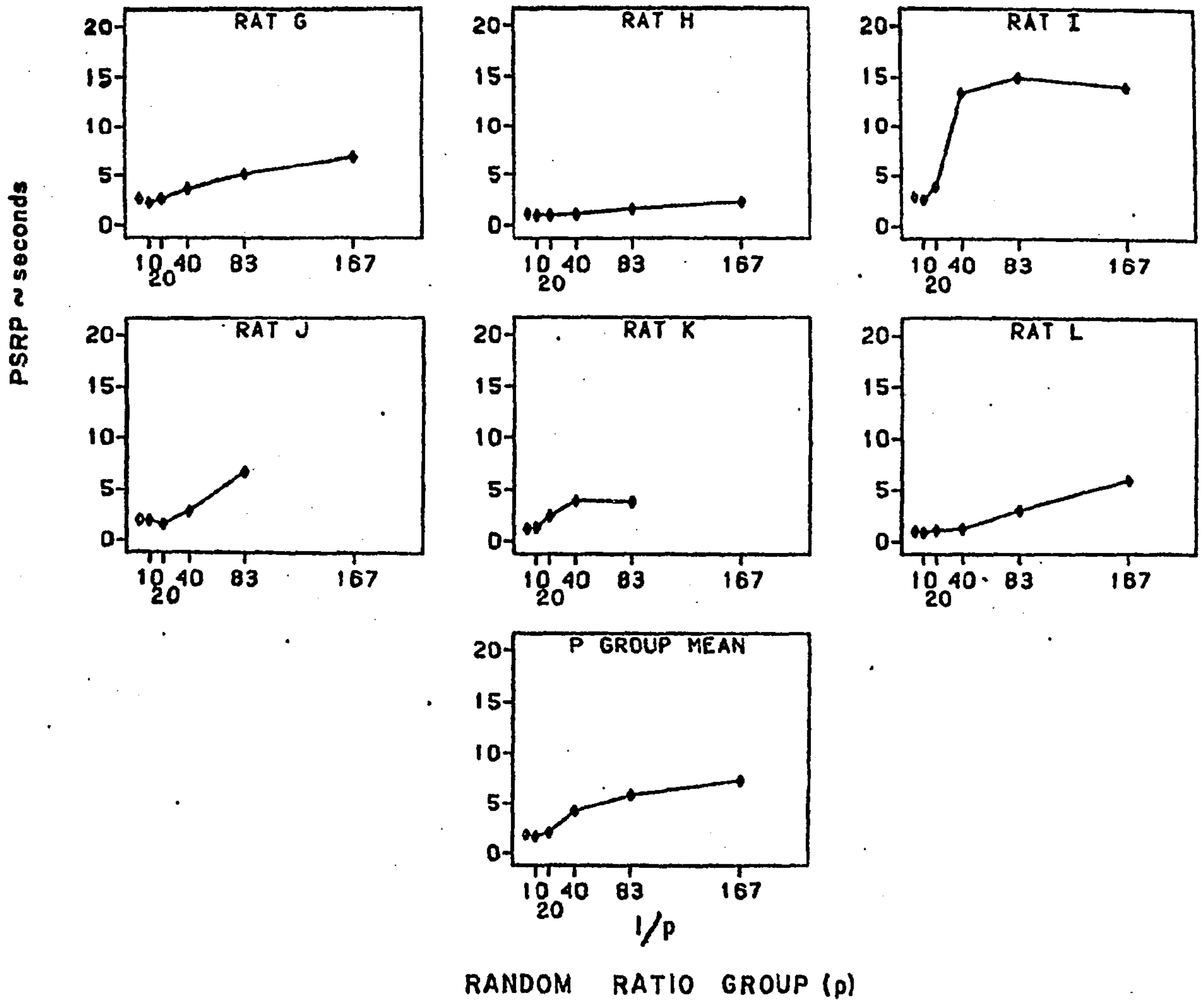
Mean post reinforcement pause functions for T and P groups are shown in Figures 5 and 6 respectively. All T-Group animals show increases in PSRP through RI 120 sec, although to varying degrees. Except rat D, no T-group subject showed a substantial change in mean pause when the schedule was shifted from RI 120 sec to RI 240 sec and one rat, A, actually revealed a small decline. During the recovery phase, PSRP returned to its original level for all subjects except rat D for whom it declined only part way back to its initial low level. For P-Group animals, the pause data are quite different. All but one of the subjects revealed only a small increase in mean pause as

Figure 5. Post reinforcement pause (in seconds) for each T-Group subject and for the group mean as a function of T/p. Each point represents the mean taken from the last 4 days at the condition. Rat D's last point is off scale; its value is 44. The disconnected point offset to the left of the function indicates redetermination of the first (T/p=15), condition.



RANDOM INTERVAL GROUP (T)

Figure 6. Post reinforcement pause (in seconds) for each P-Group subject and for the group mean as a function of 1/p. Each point represents the mean taken from the last 4 days at the condition. Missing points are due to conditions where no reinforcements were obtained. The disconnected point offset to the left of each function indicates redetermination of the first (1/p=10), condition.

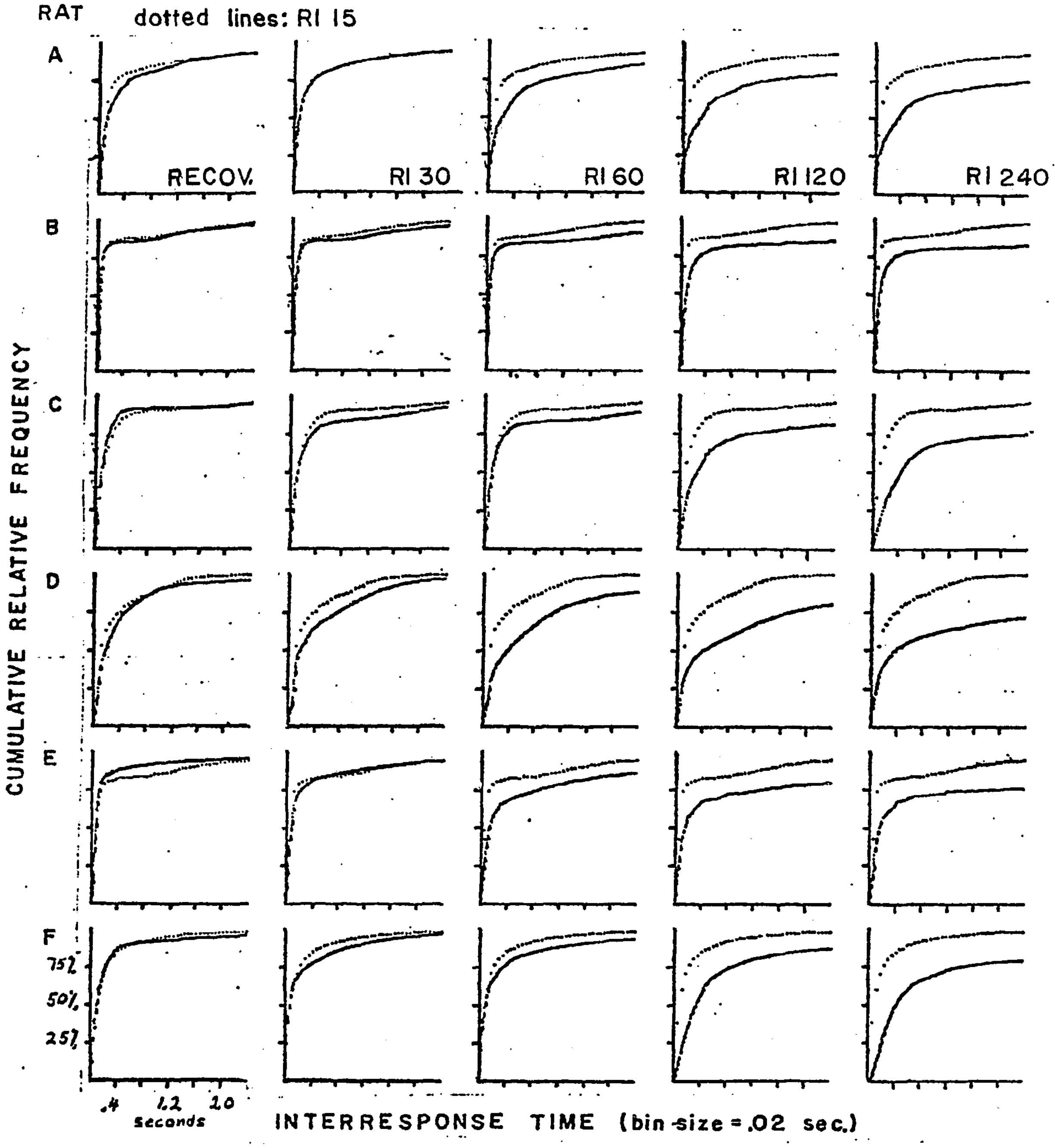

PSRP ~ seconds
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
P GROUP MEAN
0
5
10
15
20
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

the probability of reinforcement declined. The exception, Rat I, had a large increase in PSRP at RR 40 but showed no further change at RR 83.3 or RR 166.6. Recovery data at RR 10 revealed little systematic difference from initial RR 10 performance. The PSRP functions for both T and P groups are in general agreement with those found by other investigators under similar conditions although frequently larger pause durations are observed (cf. Farmer, 1963; Felton and Lyon, 1966; Farmer and Schoenfeld, 1967).

II. Variability under RI and RR Reinforcement Schedules

The measure of variability in not-R will be considered first. Figure 7 shows cumulative relative frequency distributions of interresponse times for T group subjects. There are 120 "bins" of .02 sec along each of the abscissae with the 121st bin holding all IRTs exceeding 2.4 seconds. The proportion of data falling into this overflow bin may be noted from the distance at its terminal point to the 100 % level on the ordinate. The dotted curves show the distribution under the initial exposure to RI 15 sec. To provide a reference level for comparison, they are plotted at all conditions for each rat. The experimental conditions represented by the solid curves paired with RI 15 are depicted in the following sequence: Recovery (RI 15), RI 30, RI 60, RI 120, and RI 240. All subjects show an increase in variability of interresponse time with increases in the mean interreinforcement interval. The onset and magnitude of this effect, however, vary from subject to subject. Rat F, for example, reveals little change in variability from RI 15 sec through RI 60 sec but then shows a substantial increase at RI 120 and a somewhat smaller increase at RI 240. Rat E's pattern is similar although his increase occurs at RI 60. The remaining rats show steady increases in IRT variability across experimental conditions. With respect to magnitude

Figure 7. Cumulative relative frequency distributions of interresponse times for each T-Group subject (rows) at each value of T/p (columns). The distribution obtained under exposure to the initial condition (RI 15 sec., dotted line) is plotted along with the distribution from each of the other conditions (solid lines). Depicted in the columns, left to right, along with RI 15 sec. are: recovery (RI 15 sec.), RI 30, RI 60, RI 120, and RI 240 seconds. Abscissae are comprised of 120 .02 sec. "bins", and a 121st overflow bin holding all interresponse times exceeding 2.4 secs. Hatch marks are located at every 20th bin on the abscissae; on the ordinates they are located at the 25th, 50th and 75th percentile levels.



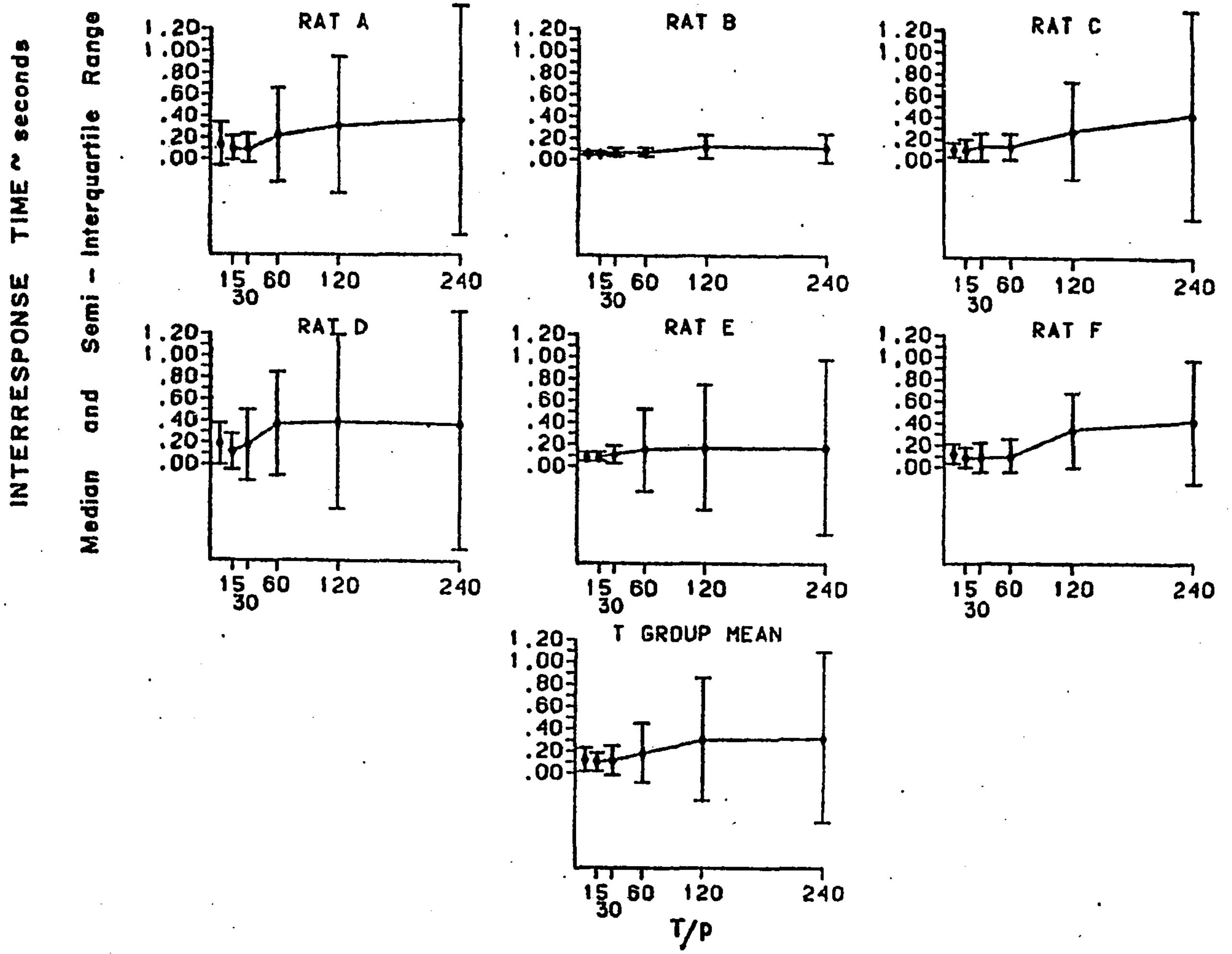
RANDOM INTERVAL GROUP

of total change in variability, the differences among subjects are not pronounced; although one rat, B, shows considerably less increase in variability than the others. Redetermination of RI 15 sec resulted in virtually complete recovery of the initial distribution for all animals.

A plot of medians and semi-interquartile ranges (SIQRs) taken from the preceding distributions is shown in Figure 8. The SIQRs, represented by the vertical bars, clearly reflect the changes in variability of the distributions as previously described. The median interresponse time for each rat shows a small increase across conditions. However, in view of the substantial decreases in response rate occurring across conditions, it is the relative stability of the median IRT rather than its tendency to increase which becomes striking. Redetermination of RI 15 sec resulted in recovery of the median IRT in all cases. initial exposure.

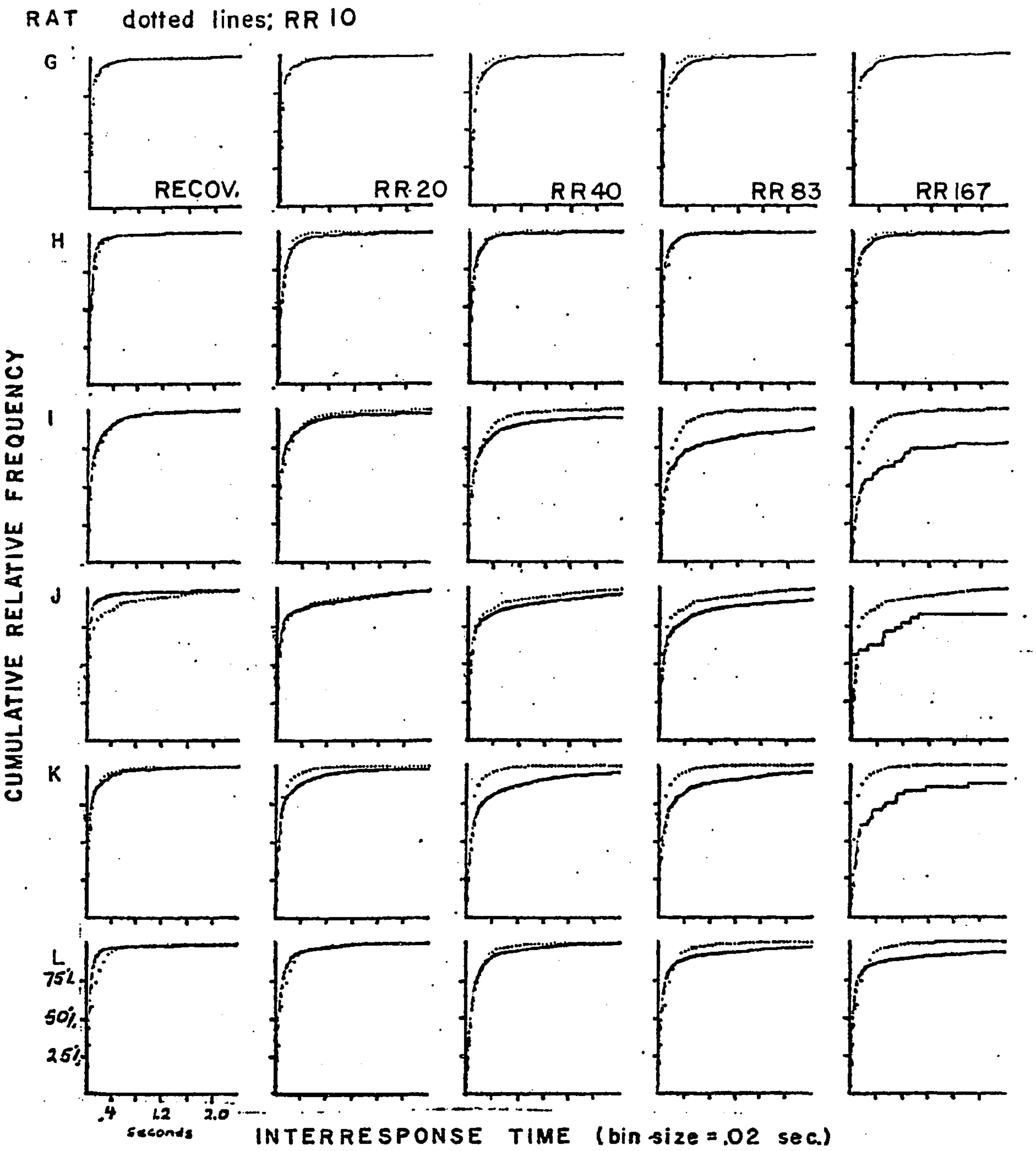
P-Group cumulative relative IRT frequency distributions are shown in Figure 9. These Random Ratio subjects show less of an effect on their IRT distributions than do the Random Interval subjects, across the range of well to poorly maintained behavior which occurred under both sets of schedules used in this study. Moreover, as long as responding did not collapse, (as it did under RR 166.6 for rats I, J, and K), only relatively small changes are seen in the form of the cumulative IRT distributions.

Figure 8. Medians and semi-interquartile ranges obtained from the cumulative interresponse time distributions of figure 7, for each T-Group subject, and the group mean of those medians and semi-interquartile ranges, obtained at each value of T/p. Offset to the left, and unconnected with the function is the median and semi-interquartile range under redetermination of the first (T/p=15), condition.



RANDOM INTERVAL GROUP (T)

Figure 9. Cumulative relative frequency distributions of interresponse times for each P-Group subject (rows) at each value of 1/p (columns). The distribution obtained under exposure to the initial condition (RR 10, dotted line) is plotted along with the distribution from each of the other conditions (solid lines). Depicted in the columns, left to right, along with RR 10 are: Recovery (RR 10), RR 20, RR 40, RR 83.3, and RR 166.6. Abscissae are comprised of 120 .02 sec "bins", and a 121st overflow bin holding all interresponse times exceeding 2.4 secs. Hatch marks are located at every 20th bin on the abscissae; on the ordinate they are located at the 25th, 50th and 75th percentile levels.

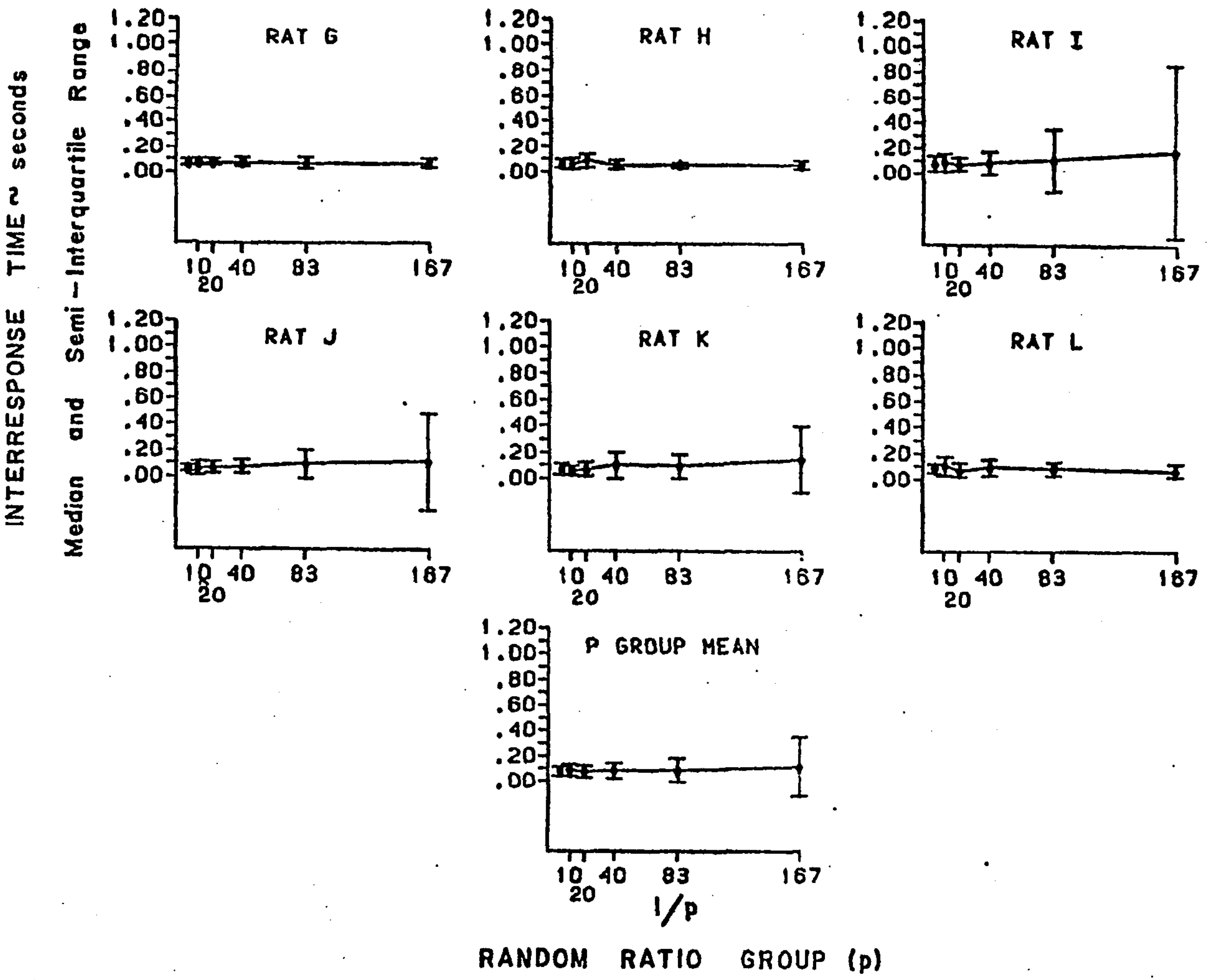


RANDOM RATIO GROUP

The semi-interquartile ranges of these distributions, depicted in Figure 10, contribute additional support to this observation. Rats G, H, and L reveal virtually no change in their SIQRs across conditions while the SIQR increases observed in rats I, J, and K do not occur until the point where responding becomes poorly maintained (see Figure 4). Median IRT was also largely unaffected by experimental conditions for this group. The relative invariance observed in these IRT distributions is consistent with what has commonly been observed under Fixed Ratio schedules, namely that the reductions in response rate with increases in the response requirement are not due to changes in the local rate, but rather to increases in amount of time spent not responding (Ferster and Skinner, 1957; Felton and Lyon, 1966). In summary, these data suggest that variability in behavior, that is variability in not-R, as reflected by variation in interresponse time distributions, increases systematically with increases in intermittency on RI schedules, but not on RR schedules. Moreover, across the range of well to poorly maintained behavior, variability in not-R is greater on RI schedules than on RR schedules.

When estimating overall variability of behavior under reinforcement schedules, the IRT distribution is perhaps the most comprehensive measure of overall schedule performance. However, because it is an index of

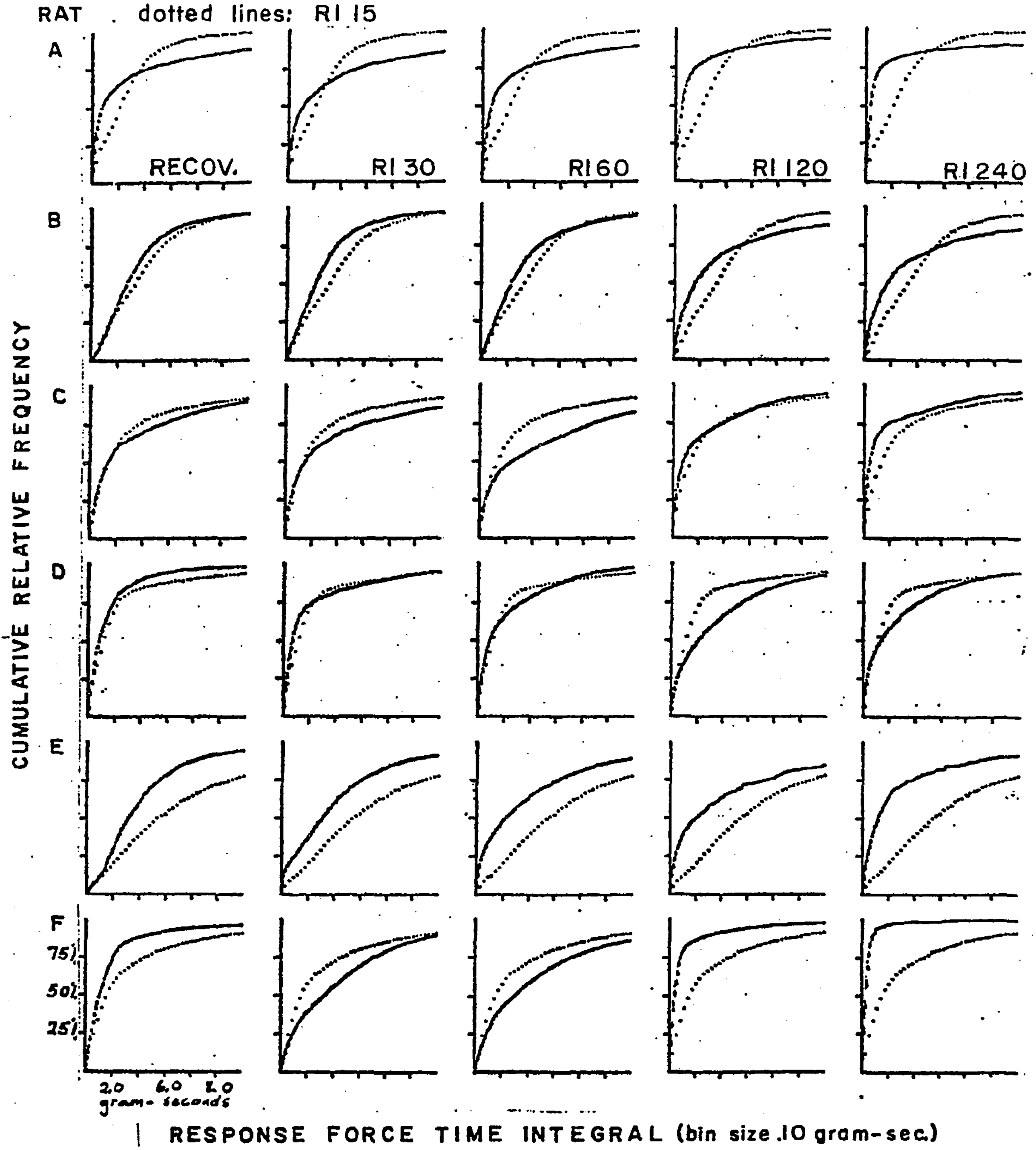
Figure 10. Medians and semi-interquartile ranges obtained from the cumulative interresponse time distributions of figure 7, for each P-Group subject, and the group mean of those medians and semi-interquartile ranges, obtained at each value of 1/p. Offset to the left, and unconnected with the function, is the median and semi-interquartile range under redetermination of the first (1/p=10), condition.


INTERRESPONSE TIME ~ seconds
Median and Semi-Interquartile Range
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
P GROUP MEAN
1.20
1.00
.80
.60
.40
.20
.00
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

variability in behavior more or less exclusive of the response class, it provides only part of the data relevant to an assessment of behavioral variability on reinforcement schedules. Direct measurement of some property of the response selected for reinforcement is necessary as an index of variability to supplement the interresponse time measure of not-R variability. Variability within the response class may be assessed along several dimensions; those used in this study were time integral of response force and response duration.

Figure 11 shows the cumulative relative frequency distribution of response force time integral for T-group subjects. Bin size is .10 gram-second with integrals exceeding 12 gram-seconds falling into the overflow category. The most obvious feature of these data is the idiosyncratic nature of variability changes occurring among these animals. Moreover, there is a clear lack of systematic change in response variability occurring with increases in intermittency. In spite of individual divergences, however, there are a few effects common to these animals. In most cases, (excepting D and possibly B), variability of the RFTI distribution is less under RI 240 than under RI 15 sec. Moreover, in all cases but B, variability passes through a maximum before reaching the final reduced level. Another result in common is the fact that variability under recovery is frequently greater than

Figure 11. Cumulative relative frequency distributions of response force time integrals for each T-Group subject (rows) at each value of T/p (columns). The distribution obtained under exposure to the initial condition (RI 15 sec., dotted line) is plotted along with the distribution from each of the other conditions. Depicted in the columns, left to right, along with RI 15 sec. are: Recovery (RI 15 sec.), RI 30, RI 60, RI 120, and RI 240 seconds. Abscissae are comprised of 120 .10 gram-second "bins", and a 121st overflow bin holding all response force time integrals exceeding 12 gram-seconds. Hatch marks are located at every 20th bin on the abscissae; on the ordinates they are located at the 25th, 50th and 75th percentile levels.

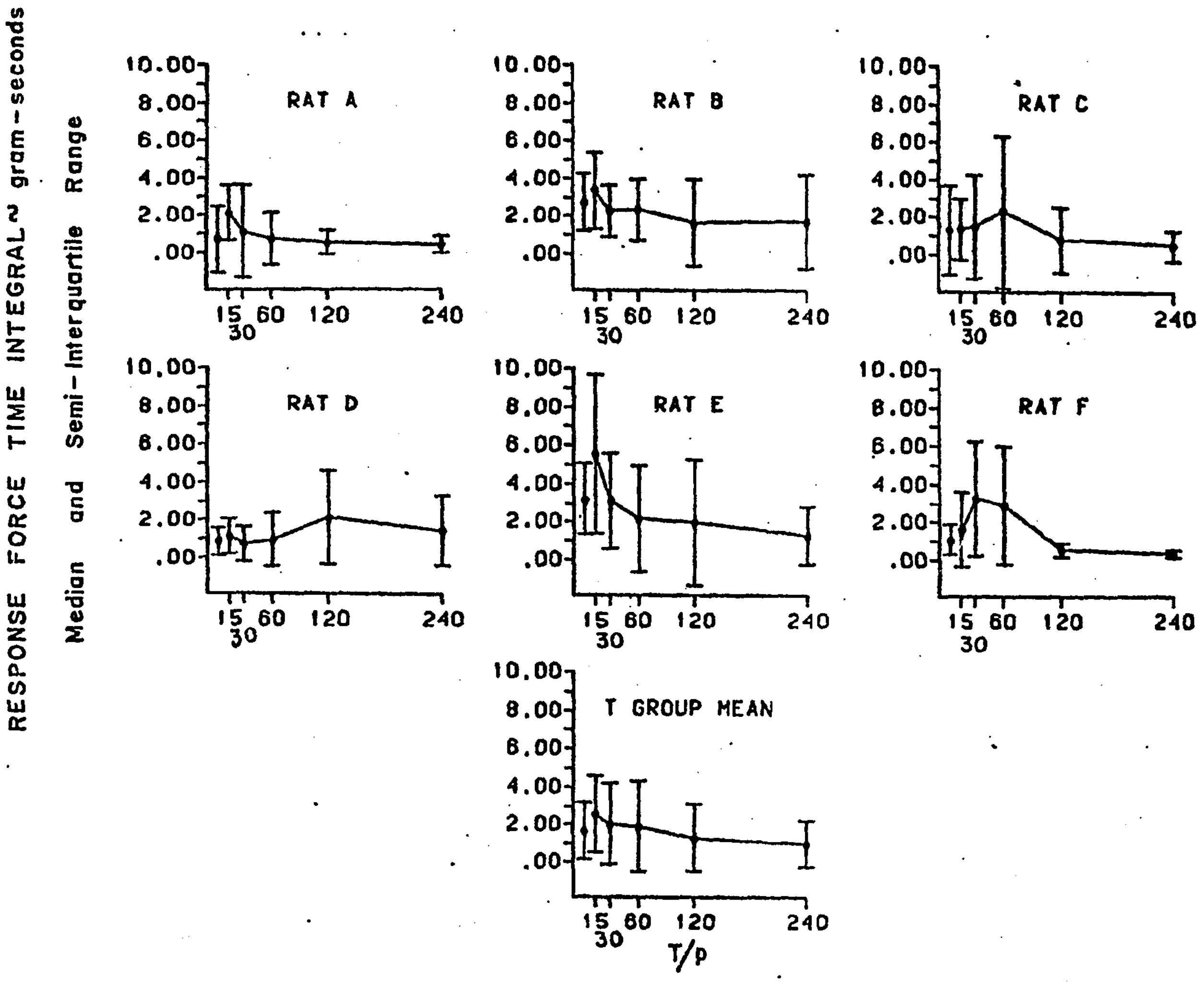


RANDOM INTERVAL GROUP

it was under the final condition (RI 240 sec) (exceptions B and D), and frequently less than under the initial condition (RI 15) (exceptions A and C). The Antonitis (1951) finding of reduced variability with reconditioning is thus not paralled by these results. Median and SIQR plots, Figure 12, help to underscore the above observations and in addition point out another similarity among animals -- median RFTI under RI 240 sec is usually slightly lower than under initial RI 15 sec and median RFTI under recovery is usually higher than under RI 240 but lower than under initial RI exposure. Taken together, these observations suggest that mean interreinforcement time and amount of training are both able to affect "efficiency" of responding on interval schedules. It should also be noted, however, that these effects are not pronounced. In previous research in which this question was addressed, Notterman and Mintz (1965) using FI schedules of 30, 60, and 120 sec. found no differential effect of interval length or extent of training on mean integral. Similarly, Millenson et al. (1961) working with response duration across FI schedules of 15, 30, 60, 120, and 240 sec., did not find consistent effects of training or of FI length on median duration.

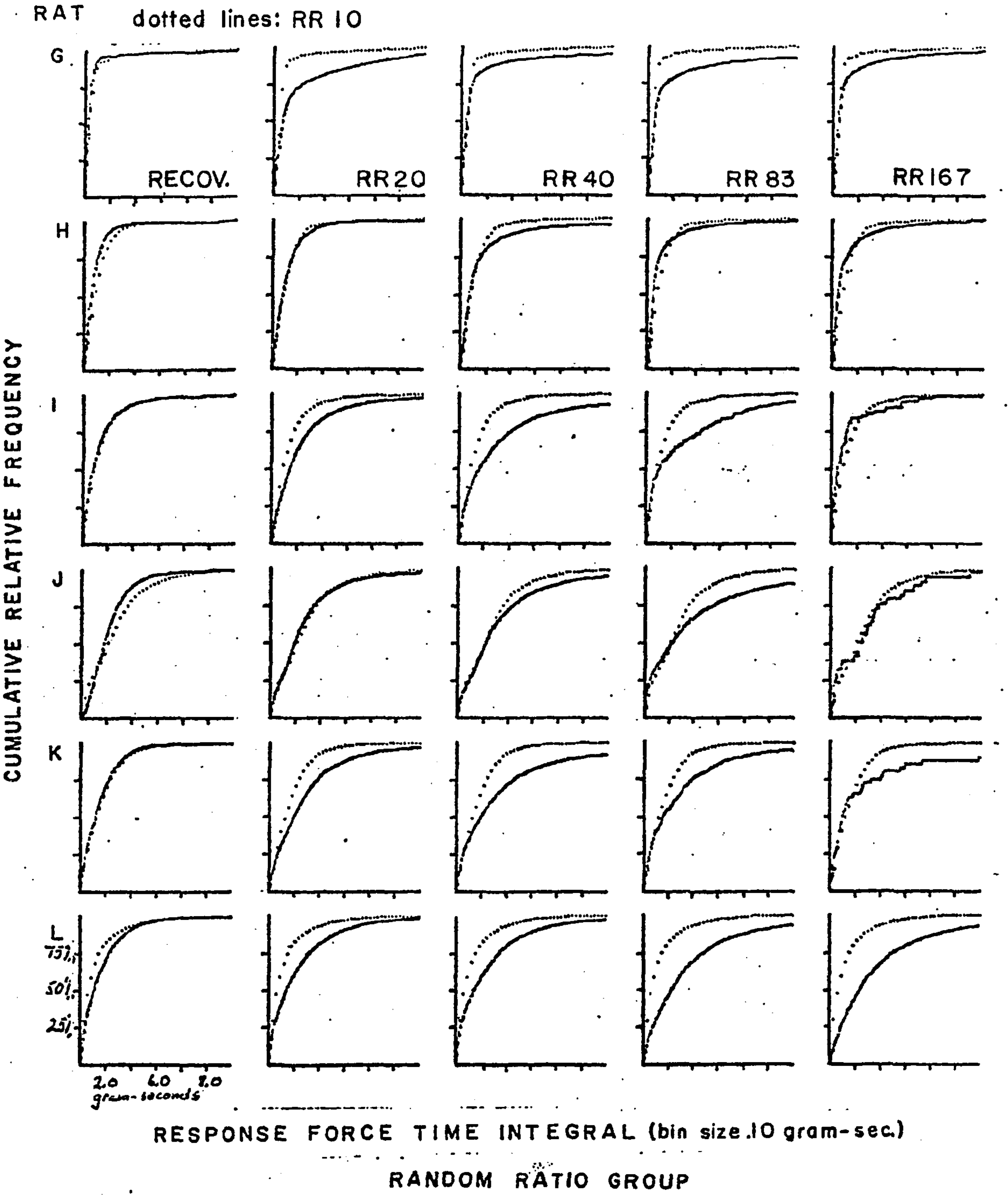
Group P response force time integral distributions are shown in Figure 13. These animals are in somewhat better agreement with one another than are the T group animals on this measure. With the exception of rats G and

Figure 12. Medians and semi-interquartile ranges obtained from the cumulative response force time integral distributions of figure 11, for each T-Group subject, and the group mean of those medians and semi-interquartile ranges, obtained at each value of T/p. Offset to the left, and unconnected with the function, is the median and semi-interquartile range under redetermination of the first (T/p=15) condition.



RANDOM INTERVAL GROUP (T)

Figure 13. Cumulative relative frequency distributions of response force time integrals for each P-Group subject (rows) at each value of 1/p. (columns). The distribution obtained under exposure to the initial condition (RR 10, dotted line) is plotted along with the distribution from each of the other conditions. Depicted in the columns, left to right, along with RR 10 are: Recovery (RR 10), RR 20, RR 40, RR 83.3, and RR 166.6. Abscissae are comprised of 120 .10 gram-second "bins", and a 121st overflow bin holding all response force time integrals exceeding 12 gram-seconds. Hatch marks are located at every 20th bin on the abscissae; on the ordinates they are located at the 25th, 50th, and 75th percentile levels.


RAT
dotted lines: RR 10
G
H
I
J
K
L
RECOV.
RR20
RR40
RR83
RR167
CUMULATIVE RELATIVE FREQUENCY
75%
50%
25%
2.0
6.0
8.0
gram-seconds
RESPONSE FORCE TIME INTEGRAL (bin size .10 gram-sec.)
RANDOM RATIO GROUP

H whose rate and IRT data were little affected by the changing p values, one sees greater variability under the lower p values than under the highest. However, after their initial shifts, these distributions do not, for the most part, reveal continuing change. Return to the initial condition resulted in recovery of the initial distribution in all cases. Figure 14 shows the median and SIQR data taken from these plots. They confirm the above observations with regard to the distributions. In contrast to the T Group data, medians were not seen to differ across conditions and were not generally lower under recovery than under initial RR 10 exposure.

Figures 15 and 16 show response duration distributions and functions of median and SIQRs for T group subjects. Figures 17 and 18 show corresponding data for P group subjects. All of the generalizations drawn from the RFTI data are fully supported by these duration data; differences between them which do occur are almost always in the same direction. One exception, rat A, whose RFTI data revealed a possible maximum in SIQR at RI 30 sec, shows a steady decrease in variability of duration across experimental conditions. The relation between duration and force was previously examined by Notterman and Mintz (1965). They found that under CRF, extinction, and reconditioning, and regardless of changes in response criteria, correlations of duration and peak force

Figure 14. Medians and semi-interquartile ranges obtained from the cumulative response force time integral distributions of figure 13, for each P-Group subject, and the group mean of those medians and semi-interquartile ranges, obtained at each value of 1/p. Offset to the left, and unconnected with the function, is the median and semi-interquartile range under redetermination of the first experimental condition.

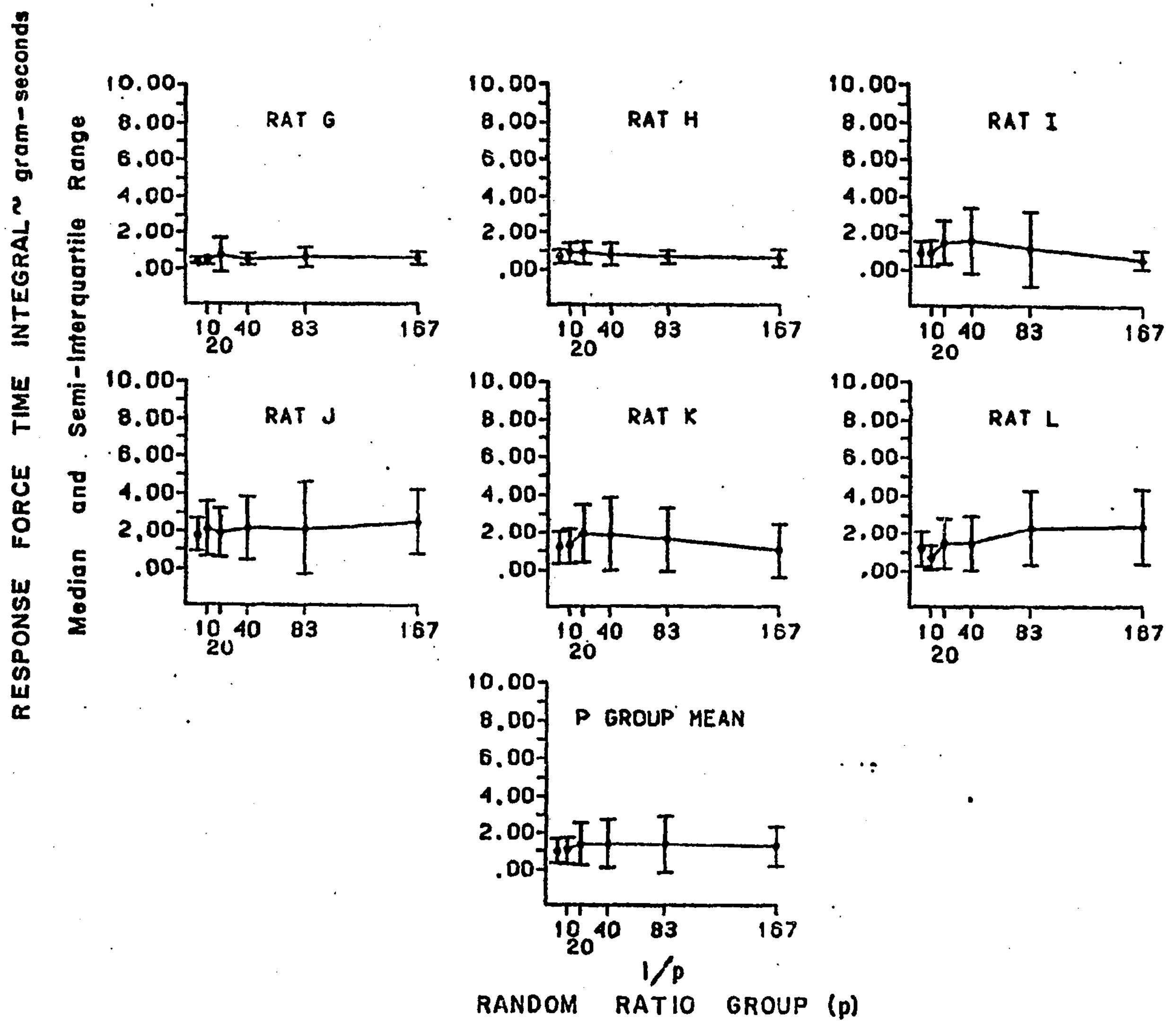
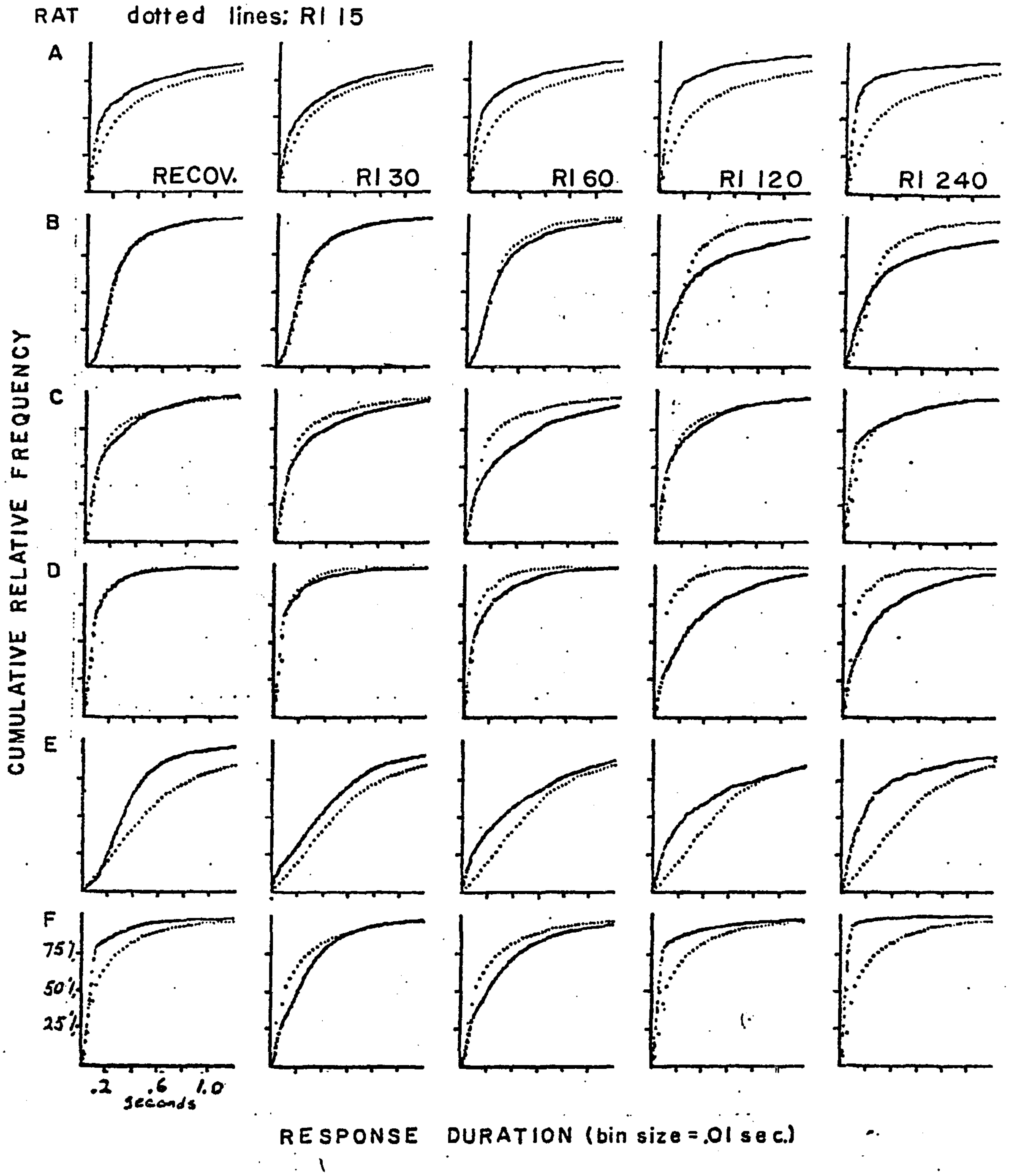
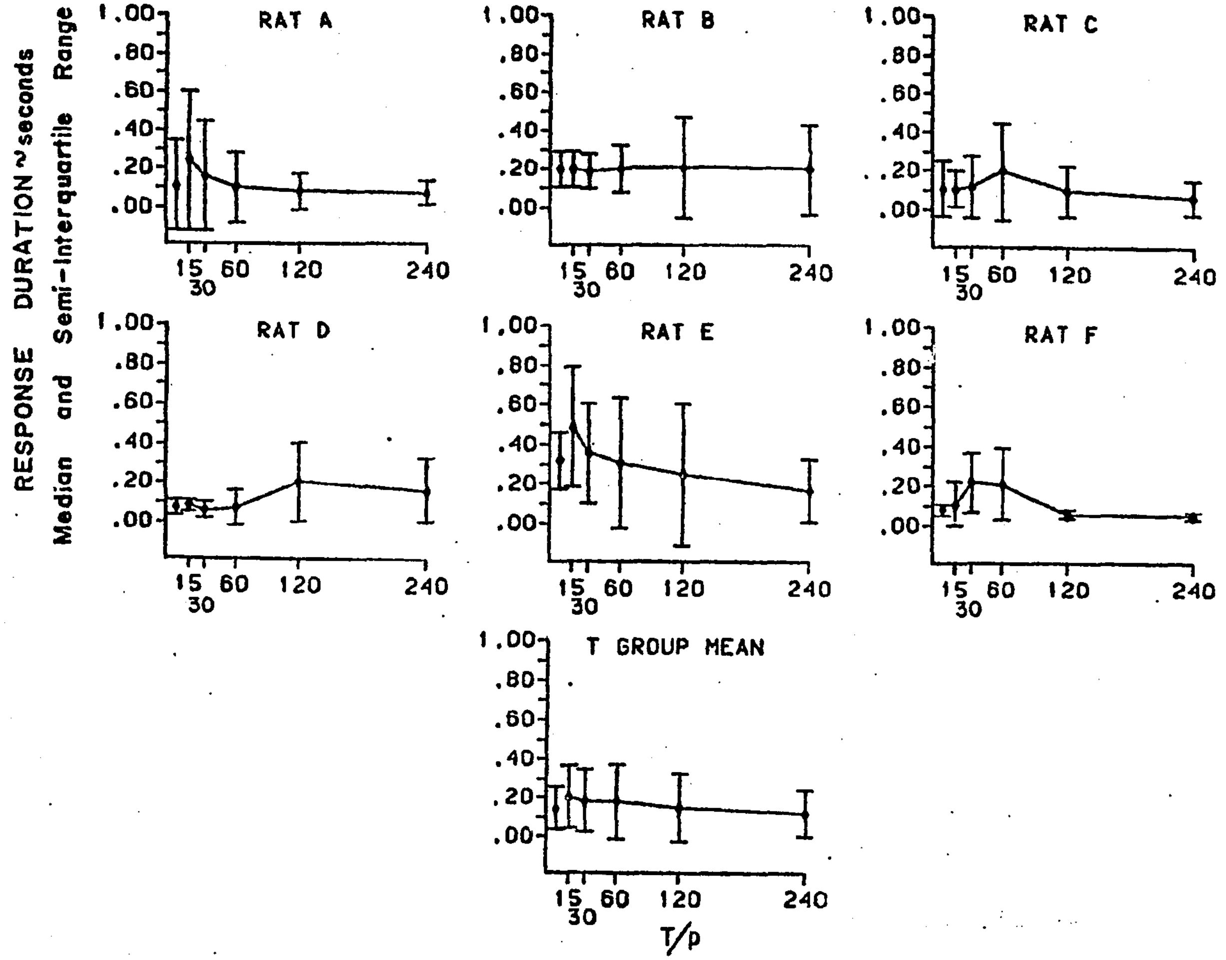

RESPONSE FORCE TIME INTEGRAL ~ gram-seconds
Median and Semi-Interquartile Range
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
P GROUP MEAN
10.00
8.00
6.00
4.00
2.00
.00
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

Figure 15. Cumulative relative frequency distributions of response durations for each T-Group subject (rows) at each value of T/p (columns). The distribution obtained under exposure to to the initial condition (RI 15 sec., dotted line) is plotted along with the distribution from each of the other conditions (solid lines). Depicted in the columns, left to right, along with RI 15 sec. are: Recovery (RI 15 sec.), RI 30, RI 60, RI 120, and RI 240 seconds. Abscissae are comprised of 120 .01 sec "bins", and a 121st overflow bin holding all response durations exceeding 1.2 secs. Hatch marks are located at every 20th bin on the abscissae; on the ordinate they are located at the 25th, 50th, and 75th percentile levels.



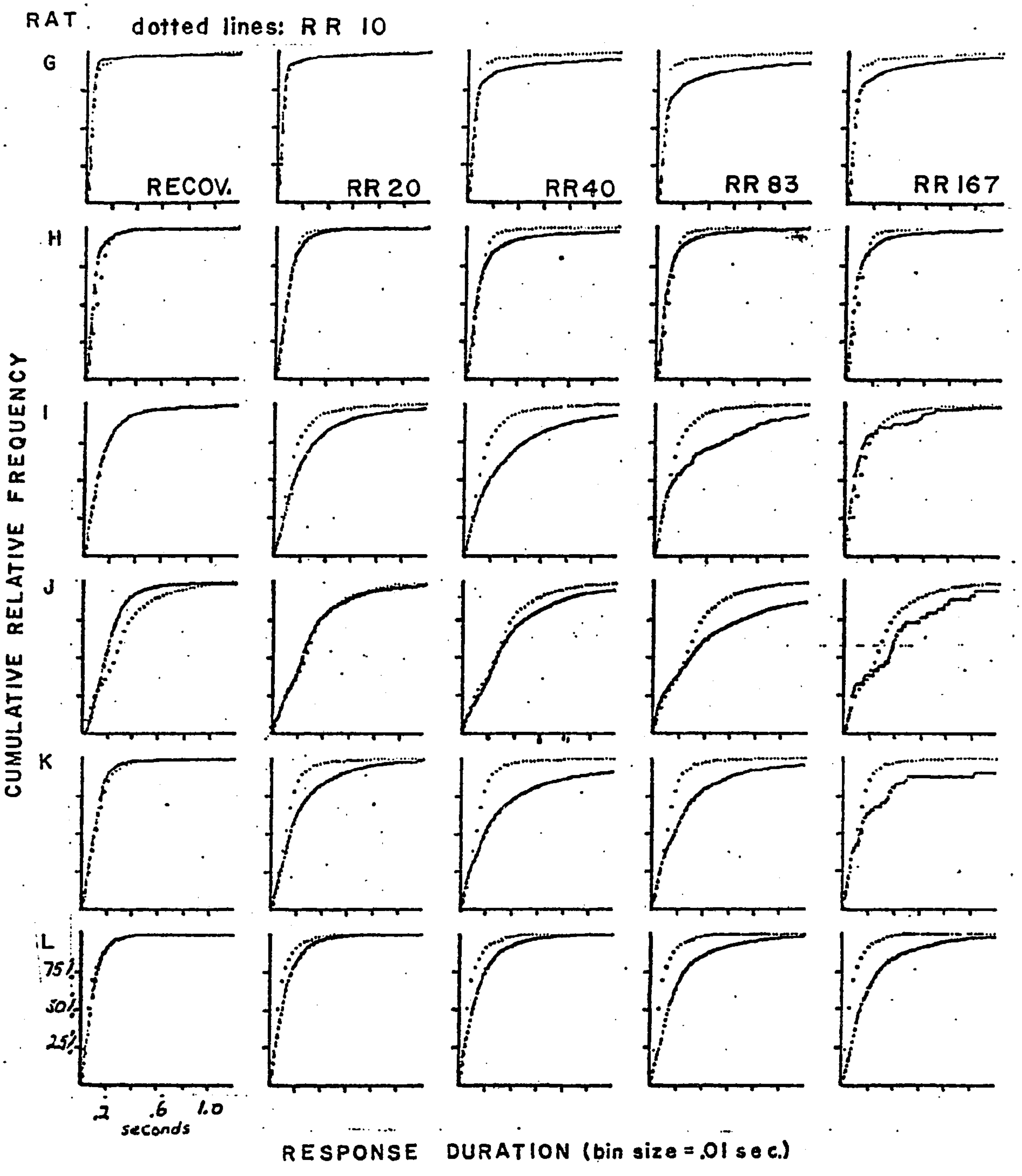
RANDOM INTERVAL GROUP

Figure 16. Medians and semi-interquartile ranges obtained from the cumulative response duration distributions of figure 15, for each T Group subject, and the group mean of those medians and semi-interquartile ranges, obtained at each value of T/p. Offset to the left, and unconnected with the function is the median and semi-interquartile range under redetermination of the first (T/p=15) condition.



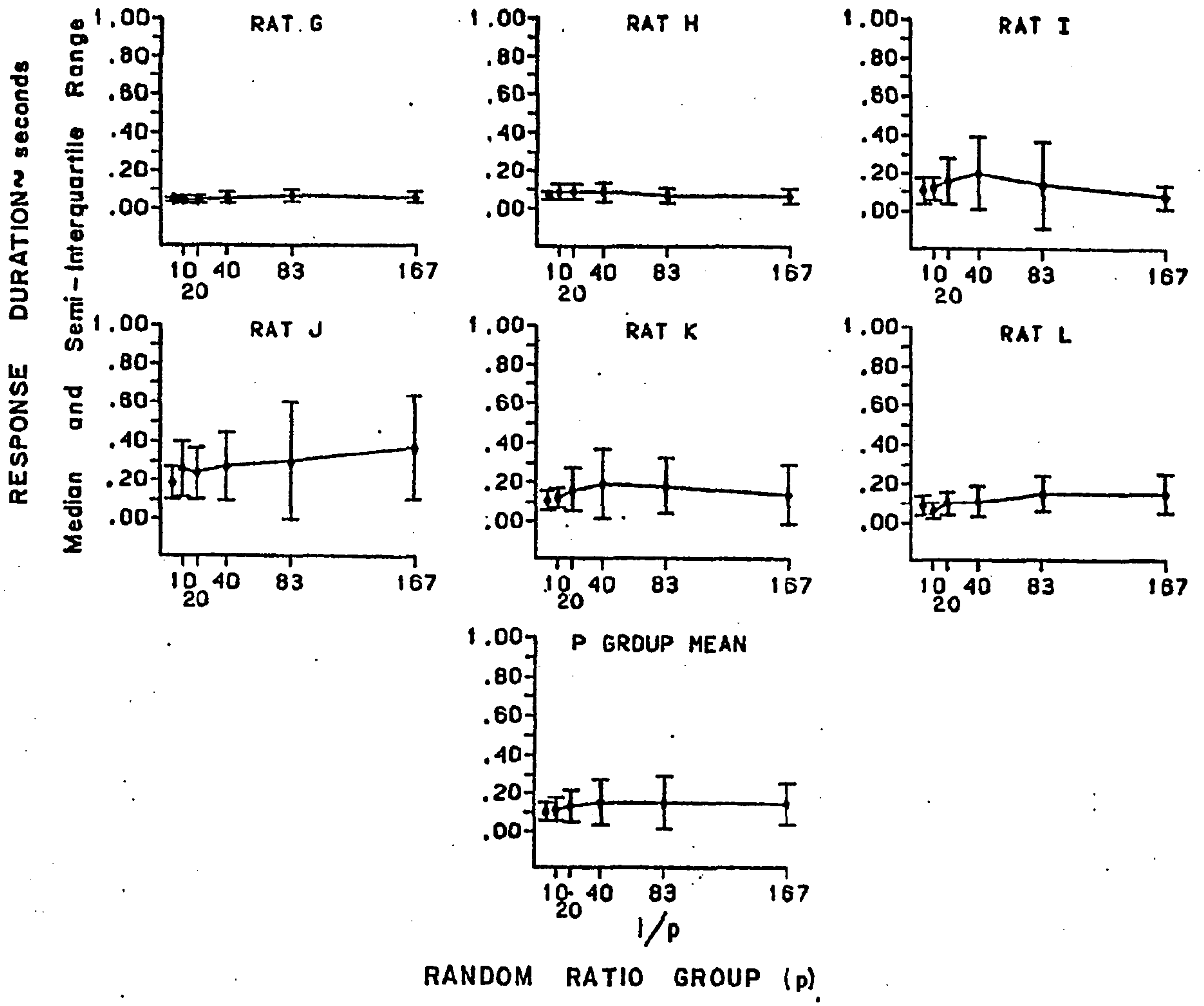
RANDOM INTERVAL GROUP (T)

Figure 17. Cumulative relative frequency distributions of response durations for each P-Group subject (rows) at each value of 1/p (columns). The distribution obtained under exposure to the initial condition (RR 10, dotted line) is plotted along with the distribution from each of the other conditions (solid lines). Depicted in the columns, left to right, along with RR 10 are: Recovery (RR 10), RR 20, RR 40, RR 83.3, and 166.6. Abscissae are comprised of 120 .01 sec. "bins", and a 121st overflow bin holding all response durations exceeding 1.2 secs. Hatch marks are located at every 20th bin on the abscissae; on the ordinate they are located at the 25th, 50th, and 75th percentile levels.



RANDOM RATIO GROUP

Figure 18. Medians and semi-interquartile ranges obtained from the cumulative response duration distributions of figure 17, for each P-Group subject, and the Group mean of those medians and semi-interquartile ranges, obtained at each value of 1/p. Offset to the left, and unconnected with the function, is the median and semi-interquartile range under redetermination of the first (1/p=10), condition.


RESPONSE DURATION~ seconds
Median and Semi-Interquartile Range
RAT G
RAT H
RAT I
RAT J
RAT K
RAT L
P GROUP MEAN
1.00
.80
.60
.40
.20
.00
10
20
40
83
167
1/p
RANDOM RATIO GROUP (p)

calculated on a response by response basis were extremely stable and hovered around the value .60. In the present study, duration was correlated on a response by response basis with the time integral of force. These Pearson r coefficients were almost above .90 and they show little variation either among subjects or conditions. They are thus consistent with Notterman and Mintz in this regard. The higher correlations occurring here may be attributed to the fact that time integral of force and duration are necessarily more interdependent than are peak force and duration and possibly also to the fact of the relatively extensive training these animals received. These correlations leave little doubt about the adequacy of duration data in representing dynamic response properties under these conditions.

The concern with the duration - RFTI correlation is principally a methodological one. However, the correlation of the IRT with the RFTI (or the duration) terminating it is of more than methodological interest. Pearson r correlations for the IRT and the integral of the response terminating it were consistently low and usually negative. At no point did they exceed -.35 and they were typically less than -.15 for both T and P groups across all conditions. Although low, these correlations were quite uniform and therefore suggested the possibility that these variables may be non-linearly related. Visual inspection of the IRT-RFTI scatterplots confirms this possibility. Table 1 shows one such scatterplot. It is comprised of data accumulated over the last 4 days under RI 60 sec for rat B. Interresponse time is located on the abscissa which is comprised of 40 .04 sec bins. Time integral of force is located on the ordinate in 40 bins of .40 gram-seconds each. The overflow (41st) bins on the abscissa and ordinate hold all IRTs exceeding 1.6 sec and all integrals exceeding 16 gram-sec respectively. Each bin is allocated 3 digits on this table and therefore numbers appearing larger than 3 digits are actually in adjacent bins. This scatterplot shows quite clearly that short IRTs are commonly associated with both low and high RFTIs but that long IRTs are commonly associated only with low RFTIs. The relationship of IRT and RFTI shown here is typical of all subjects in this experiment, and moreover remains largely unaffected by changes in schedule parameters. These data are in agreement with those of Notterman and Mintz (1965) who obtained scatterplots of IRT and peak force for two animals under mixed Fixed Ratio, CRF schedules (alternating components). Despite the consistency of the relationship between IRT and force, little predictive power emerges since all combinations prevail except long IRTs and high forces. Insofar as the interresponse time may be regarded as an indicator of momentary response strength, this general lack of predictability is consistent with Skinner's

```
ANALYSIS RUN ON:   1/ 9/1981   VERB: MAINIG;SCATIG
RKB1:BJ0406.10    RKB1:BJ0506.10    RKB1:BJ0606.10    RKB1:BJ0706.10

SCATTERPLOT: INTERRESPONSE TIME VS. RESPONSE FORCE TIME INTEGRAL
ABSCISSA: INTERRESPONSE TIME (BIN SIZE=.04 SEC)    ORDINATE: RESPONSE FORCE TIME INTEGRAL (BIN SIZE=.40 GRAM-SEC)
PEARSON R (RAW DATA) FOR IRT--->GS =-0.06          PEARSON R (SCATTERPLOT DATA) FOR IRT--->GS =-0.28
N=  7700: PERCENT OF IRTS EXCEEDING 1.60 SEC=12.91   PERCENT OF RFTIS EXCEEDING 16.00 GRAM-SEC= 2.73
SX=13.25 SY= 4.63 DRMN= 1.43 GSMN= 3.76 SXB=13.79 SYB= 9.27 XIJMN= 7.90 YIIMN= 9.03
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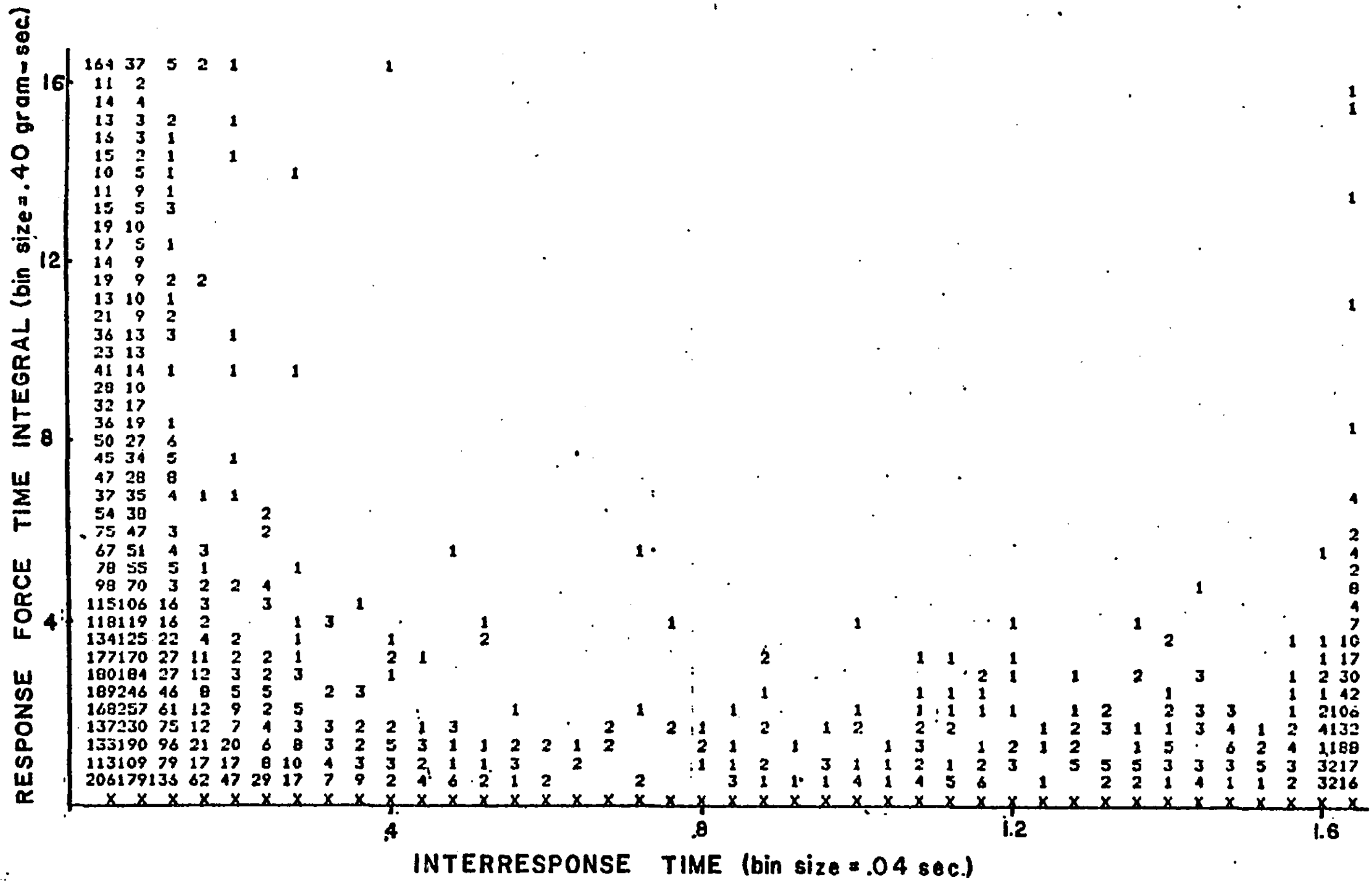

(1938) statements that "In operant behavior there are very slight, if any, changes in intensity [of the response] with changes in the strength of the reflex.", and, "The intensity of a response is only significant with respect to the differentiative history of the organism...", (1938, p.340). However, the fact that long IRTs were almost always followed by low intensities (RFTIs) in this experiment prevents the door from being completely closed on this matter.

General Discussion

The major findings of this experiment may be summarized as follows: (1) not-R variability, as reflected by distributions of interresponse times, increases as T/p increases on RI schedules, but is little affected by increases in 1/p on RR schedules, (2) R variability, when estimated from distributions of response force time integrals or from response durations, is not systematically related to changes in intermittency of reinforcement on either RI or RR schedules, (3) both R and not-R variability measures show, from their recovery data, that extended training itself does not have irreversible effects on variability, (4) response duration and response force time integral were highly correlated measures across all experimental conditions used in this study, (5) individual interresponse times were not highly correlated with the time integrals of force of the responses terminating them under any conditions used in this study, (although high forces were infrequently preceded by long interresponse times) and, (6) rate functions under both RI and RR schedules were similar in form to those previously obtained using standard apparatus.

The most important of the above findings is the failure to obtain a systematic relation between response variability and reinforcement intermittency. It is, in this regard, wholly consistent with the closely related Millenson et al. (1961) study. The present study does, however, bring into question Millenson's suggestion that duration per se is an inadequate indicator of response variability since, the RFTI measure used here also did not show systematic changes. The question of the measure selected for tracking changes in variability is an important one, however, and consideration of it may aid in clarifying some inconsistencies within the literature regarding variability and reinforcement schedules.

Bearing on the question of the appropriate dependent measure for following changes in variability of behavior is the distinction between quantitative (e.g. force, duration) and topographical (e.g. location) response measures as discussed by Ferraro and Branch (1968). They caution against regarding as equivalent findings obtained from these two types of measures because, (as mentioned earlier) response variants assessed along quantitative dimensions are not independently executable, nor are they free of possible differential reinforcement of their minimal values. Neither of these characteristics is true of response variants assessed along a dimension such as locus. dimension. Their caution is advisable, however, for another reason, namely, that quantitative response measures may track variability within the response class (R), more closely than measures using locus which seem to be more susceptible to influence from variability outside of the response class, (not-R). For example, the keypeck response of a pigeon or the nosing movement of a rat may depend for their loci, not only upon variation within such responses, but also upon the position of the animal within the test chamber. This being the case, it becomes clear that variability of behavior antecedent to the recorded response may influence the recorded variability of the response itself. In effect, variability in behavior outside of the response class (not-R) is sometimes attributed to variability in behavior within the response class (R). The observation of Eckerman and Lanson (1969) that the location of the food source relative to that of the response keys may affect the position of the bird after reinforcement is recognizable as a problem of this sort, where variability in not-R is influencing measured variability in R. Such interaction may occur to a lesser extent in experiments where variability in the response is not recorded in terms of locus, but rather along a quantitative dimension such as duration, force, or displacement. The distinction, however, is not clear cut because even with these measures, the boundary between R and not-R is not clear cut.

With regard to the findings of experiments using response locus, there appears to be general agreement that greater variability is observed on schedules of intermittent interval reinforcement compared with schedules of regular reinforcement. Herrnstein's (1961) discrepant result with respect to this finding is most likely due to the greater not-R variability obtaining under CRF as a result of his subject's returning to the opposite wall for food after each response under this schedule (cf. Eckerman and Lanson, (1969) who initially considered this reason for the discrepancy). Herrnstein's (1961) result therefore illustrates that the amount of influence of not-R variability in studies using response locus may be determined by exact procedural details of these experiments.

Distributions of IRTs in the present experiment indicate greater variability occurring in not-R with increases in intermittency on interval schedules. With respect to not-R variability under ratio schedules, the relative invariance in the IRT distributions of the present study suggests that not-R variability under ratio schedules does not increase with increases in ratio size. Such a finding is not inconsistent with the relative insensitivity of rate to changes in ratio requirement frequently found under these schedules.

Focusing upon experiments in which quantitative response dimensions have been used for dependent variables, the picture emerging is one of non-systematic effects on R variability with increases in intermittency on either interval or ratio schedules. Typically, however, interval schedules have been found to support more R variability than ratio schedules (including CRF).

With regard to the role of variability in the partial reinforcement effect, it it is noteworthy that the argument advanced in 1950 by Schoenfeld was explicit in delimiting its application to the case where successive conditionings and extinctions were not continued long enough for a discrimination to form. Under conditions of extended training, (e.g. the present study, or that of Millenson et al., 1961), it was suggested that stimulus factors would assume greater control of responding while response variability would become relatively less important. In view of this latter sometimes overlooked consideration, the Goldberg (1959) and Margulies (1960) experiments are most relevant to his original conjectures. The absence of systematic increases in response variability with increases in intermittency found here, does suggest, however, that response variability is not essential to the occurrence of heightened resistence to extinction following training on intermittent schedules.

In conclusion, the finding of increasing variability in the IRT distributions occurring with increases in intermittency (under interval schedules), in conjunction with the absence of systematic change occurring in either RFTI or response duration with these increases, suggests that the heightened "strength" of R observed following training on intermittent schedules is most likely attributable not to change in the properties of R itself, but rather to variations occurring in the behavior surrounding those Rs. The failure, in this study, to find a similar increase in the length of the not-R sequences accompanying R on the Random Ratio schedules would be consistent with a failure of these schedules to engender resistance to extinction comparable to that seen after training on interval schedules of equivalent temporal intermittency. From the above, it seems clear that a focus on R to the exclusion of not-R does not permit a complete account of behavioral variability under schedules of reinforcement.

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