INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the original text directly from the copy submitted. Thus, some dissertation copies are in typewriter face, while others may be from a computer printer.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyrighted material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each oversize page is available as one exposure on a standard 35 mm slide or as a 17" × 23" black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. 35 mm slides or 6" × 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

Accessing the World's Information since 1938

300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA

Order Number 8816351

Partial reinforcement and resistance to extinction

Mellon, Robert Charles, Ph.D.

The University of North Carolina at Greensboro, 1987

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

PARTIAL REINFORCEMENT AND RESISTANCE TO EXTINCTION

by

Robert Charles Mellon

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
1987

Approved by

Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Dissertation Adviser

Committee Members Susan Mullys Keane

P. Scott Lawrence

Timothy D. Johnston

John E. King

October 30, 1987
Date of Acceptance by Committee

October 27, 1987
Date of Final Oral Examination

MELLON, ROBERT CHARLES, Ph.D. Partial Reinforcement and Resistance to Extinction. (1987) Directed by Dr. Richard L. Shull. 93 pp.

Schoenfeld (1950) proposed that manipulations of rates of reinforcement have two conflicting effects on resistance to extinction. Leaner schedules reinforce behavior less frequently, which results in less resistance to extinction. But leaner schedules also reinforce more different movements, or response forms, resulting in increased resistance to extinction. Experiment 1 tested whether partial schedules indeed maintain a wider range of response forms. In a multiple schedule, pigeons' sequences of 6 keypecks were partially reinforced in one context and continuously reinforced in a second context. Partial schedules tended to maintain a wider range of response forms than continuous schedules, but produced responding that was less resistant to extinction, suggesting that if the reinforcement of a wider range of response forms enhanced resistance, that effect was weaker than a conflicting effect of less frequent reinforcement. Two additional experiments tested the effects in extinction of the reinforcement of a wider range of response forms in the absence of differences in rates of reinforcement. In Experiment 2, a multiple schedule was arranged; in one context, 6-peck sequences were reinforced only if they differed in form (sequence) from the previously-reinforced sequence. In the other, redundant 6-peck sequences could be reinforced. Responding was more resistant to extinction when variability in form was required. It seemed likely, however, that the two contingencies had produced different levels of proprioceptive discrimination, due to differences in the relation of response-produced stimuli and reinforcement during training. Experiment 3 entailed a manipulation of ranges of forms in the absence of such differences. Keypecking was reinforced in two alternating contexts; in one a single key was presented, and in the other two keys were presented. Rates of responding in extinction declined in the two contexts at similar rates, suggesting that differences observed in Experiment 2 were not due to the manipulation of ranges of response forms per se, but to correlated differences in proprioceptive control. Where observed, paradoxical strength-enhancement by less frequent reinforcement appears to be a discriminative phenomenon. In general, more frequent reinforcement produces responding that is more resistant to extinction.

ACKNOWLEDGMENTS

I gratefully acknowledge the support of the UNCG Graduate School, the New York University-Bellevue Hospital Internship Program, and the Center for Developmental Psychobiology, University Center at Binghamton, State University of New York. Mr. Frank Russell provided valuable help in programming, and Ms. Carmen Ruiz assisted with the data analysis. Russell, Ruiz, and Mrs. Luann Russell kindly provided many forms of sustenance. I thank the members of my advisory committee, Drs. Keane, King, Lawrence, Johnston, and Turkat, for their guidance and support. Most importantly, I wish to acknowledge the wonderful generosity of my teachers, Dr. Aaron J. Brownstein and Dr. Richard L. Shull.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This paper is concerned with an apparent exception to an otherwise general statement of the relationship between the rate of reinforcement of operant behavior and the rate of change in behavior when reinforcement is subsequently withheld. Generally, the higher the rate of reinforcement, the more persistent is responding in extinction (e.g., Nevin, 1979; 1987). The exception, so surprising as to be labeled "paradoxical," is widely known as the "partial reinforcement effect in extinction." Simply put, fewer responses appear in extinction after continuous reinforcement, in which every instance of a response is reinforced, than after partial reinforcement, in which only a portion of responses are reinforced. If the resistance to extinction of behavior increases with its rate of reinforcement, why should the highest rate, continuous reinforcement, result in less resistant behavior?

The partial reinforcement effect in extinction is a very old phenomenon that plays an important role in contemporary explanations of behavior. For example, an introductory textbook on behavior modification states that "...extinction is much quicker after continuous reinforcement (in which each response was previously reinforced) than after intermittent reinforcement (in which responses were reinforced only occasionally). This means that if you try to extinguish a behavior that has been reinforced intermittently, you must be prepared for extinction to take longer." (Martin and Pear, 1978, p. 48). What we might call the "principle of partial reinforcement in extinction" is cited often in behavioral formulations of clinical cases in which the presumed reinforcers of a persistent target behavior appear infrequently; for example, when a pathological gambler continues to bet though he seldom wins. It is the purpose of the present paper to test an attempt to reconcile the effects of continuous and intermittent schedules with the more general and perhaps more fundamental effects of intermittent schedules differing in rates of reinforcement.

Behavior is ever changing and therefore not easily analyzed into meaningful units. In the analytic tradition of Guthrie (1952) and Skinner (1938), among others, a distinction is made between isolated movements, or responses, and classes of movements that are related to each other principally because their effects on the environment are similar. Such classes of movements or responses have been called acts, or more recently and more widely, operants. For example, in the case of a pigeon trained to peck a lighted disk with food reinforcement, many responses of distinct appearance result in food. The pigeon might peck with its eyes open or closed, with the right or left side of its beak, with its wings spread or not spread, *et cetera*. These responses differ in form, but the forms share the property of operating the lighted disk and producing food. For understanding the relationship between acts or operants and parameters of reinforcement, it would be convenient if we could ignore non-defining differences in response form.

In an attempt to analyze the partial reinforcement effect in extinction in the terms of more general principles, Schoenfeld (1950) argued that although it may often be appropriate to ignore differences in form that do not bear an obvious relation to reinforcing consequences, to understand the partial reinforcement effect one must take into account the relation of a schedule of reinforcement to the various movements or response forms that make up a generic class like keypecking. He suggested that continuous and partial schedules provide reinforcement of different ranges of response forms, and that the range of reinforced forms of an operant affects responding in extinction. The present series of experiments was designed to test this notion. As will be detailed below, an analysis of the results revealed that manipulations of the ranges of reinforced forms of operants at best weakly influence the resistance to extinction, and probably do so via a discriminative mechanism. Generally, more frequent reinforcement produces greater resistance to extinction than less frequent reinforcement, whether the richer schedule is a richer partial schedule or a CRF schedule.

Schoenfeld's (1950) analysis of the partial reinforcement effect stemmed from observations that the variability of response forms decreases in a series of regular reinforcements, and increases in extinction. These observations were elegantly substantiated by Antonitis (1950). A rat was placed in a chamber with a 50 cm horizontal slot in one wall and a feeding mechanism on another. If the subject thrust its nose through any part of the slot, a photobeam was broken and food was immediately presented. The positions of successive nose-thrusts were recorded, and at first the responses were distributed unsystematically across the slot. Then, under continuous reinforcement, most of the responses came to be distributed over a small section of the slot. Finally the food presentations were discontinued, and the position of subsequent nose-thrusting again became more varied.

As noted, Schoenfeld argued that in the case of partial versus continuous reinforcement it is important to take into account the various movements, responses or response forms that make up a generic class like nose-poking or keypecking. Such "sub-categories" of responding are relatively easy to discern with a spatially-distributed manipulandum like Antonitis used, and though they are more subtle in the single response-key or lever-press situation, Schoenfeld argued that their detection might be the key to understanding the seeming paradox of partial and continuous reinforcement. Each of an animal's responses is unique, and responses have numerous properties. Although food is contingent upon a generic property of responding, it follows responses that also have varying formal properties, which define sub-categories. Schoenfeld suggested that the partial reinforcement effect might be based on the fact that partial schedules arrange for the reinforcement of more sub-categories of responding than do continuous schedules.

"In [continuous] reinforcement," he argued, "there is a greater probability after each response that the same or a closely similar response will be emitted to be reinforced once more. In [partial] reinforcement, extinction following a reinforcement weakens the prior response form until its strength is not greater than some other forms or sub-categories; extinction lowers the strength of stronger sub-categories to the level of weaker ones, in this way continually expanding the number or range of equally strong sub-categories from which one will finally procure reinforcement" (1968 republication, p. 260). Thus, the increased variability of response forms in extinction means that more sub-categories will be reinforced under partial reinforcement, due to scheduled periods of extinction, than under continuous reinforcement schedules. But because there are more sub-category responses, there will be a lower rate of reinforcement per sub-category response under partial schedules than under continuous schedules. Thus, each of the sub-categories maintained under continuous reinforcement should be stronger than the individual sub-categories maintained under partial reinforcement. However, it is reasonable to assume that the strength of each sub-category is a negatively accelerated function of the rate of reinforcement of that sub-category (e.g., Catania and Reynolds, 1968). If so, a lower rate of reinforcement for each of many sub-categories could bring about a greater total resistance to extinction (sum of all sub-category strengths) than a high rate of reinforcement for each of a few sub-categories. Thus partial reinforcement appears, paradoxically, to maintain more resistant keypecking, because it incidentally arranges for the reinforcement of more variants of keypecking. Knowing the absolute numbers or ranges of variants that have independent strengths under partial and continuous reinforcement is not critical for making predictions of resistance to extinction.

Schoenfeld's molecular analysis of the effects of partial and continuous reinforcement appears to be consistent with the effects of other schedules of reinforcement on responding in extinction. For example, it is well established that, given equal arithmetic mean rates of reinforcement, schedules that provide reinforcement after variable time intervals produce responding that appears to be more resistant to extinction than do schedules that provide reinforcement after fixed time intervals. The effect seems to be dependent upon the degree of variability in the duration of the intervals (cf., Mellon and Shull, 1986). For Schoenfeld, the apparently greater resistance shown by responding maintained by variable-interval as opposed to fixed-interval schedules is due to the fact that variable-interval schedules condition more sub-categories of responding, by virtue of their occasional imposition of longer periods of nonreinforcement. "Thus," he wrote, "the superiority of the geometric series may be ascribed to the greater response variability occurring in the longer intervals [of the geometric series] which are not present in the arithmetic series" (1968 republication, p. 260). In other words, aperiodic reinforcement enhances resistance because it arranges the reinforcement of more response forms.

A controversy exists over whether, as the sub-category analysis of the partial reinforcement effect requires, partial schedules actually maintain more varied forms of responding than continuous reinforcement (CRF) schedules do. The finding that the range of forms of an operant decreases with regular reinforcement is well established (Antonitis, 1951; Ferraro and Branch, 1968; Guthrie and Horton, 1946; Notterman, 1959; Skinner, 1938; Vogel and Annau, 1973). Also well established is the observation that when continuously-reinforced behavior is extinguished, increased variability is seen in measurable aspects of response form (Antonitis, 1951; D'Amato and Siller, 1962; Eckerman and Lanson, 1969). Taking these findings together, it would seem reasonable to expect that partial schedules, which reinforce a smaller percentage of responses than CRF schedules but a larger percentage than extinction schedules, should produce intermediate levels of response variability. The effect of partial reinforcement on the observed range of response forms, however, has not appeared to be as consistent as the effects of CRF and extinction.

Herrnstein (1961) employed a horizontally-oriented, 10-location response surface (colloquially known as a long key) in order to compare directly the response-location variability generated by CRF and partial reinforcement schedules. For two weeks pigeons' keypecks were reinforced continuously when directed to any location on the long key. Then the schedule was changed from continuous to partial (variable-interval) reinforcement. Contrary to expectations based on Schoenfeld's account, the location of the pigeons' responding became more stereotyped under partial reinforcement. However, the effects of the two schedules in Herrnstein's experiment might have been confounded by their order of presentation. It might be the case that responding tends to move towards stereotypy with successive reinforcements whether presented on a partial or a continuous basis, albeit at different rates and with different endpoints. In Herrnstein's study, responding might have become even more stereotyped if CRF had been maintained. Herrnstein observed a marked increase in stereotypy on the first exposure to partial schedules, suggesting that partial schedules induce stereotypy more rapidly than CRF schedules do. However, Ferraro and Branch (1968) exposed long-key responding to several blocks of continuous and partial reinforcement in different orders of presentation, and found that variability in response location increased under variable-interval (VI) reinforcement when VI reinforcement followed CRF, while the variability of forms decreased whenever CRF followed VI reinforcement. Also generally consistent with the Schoenfeld analysis were the findings of a long-key study by Eckerman and Lanson (1969) who examined the effects of CRF and several partial schedules differing in average rates of reinforcement. They found that variability in the location of keypecking was greater when reinforcement was provided on a fixed- or random-interval schedule rather than on a CRF schedule. However, when comparing the variability of response forms produced by partial schedules that differed in average time between reinforcements, Eckerman and Lanson did not find reliable differences.

While the general pattern of the results reviewed here is consistent with the requirements of a sub-category analysis of the partial reinforcement paradox, it seemed prudent to test the generality of the pattern, particularly with different preparations. The findings of two recent studies (Schwartz 1982b; 1986) to be described below would appear to indicate that partial reinforcement has <u>no</u> differential effect on the variability of response forms. The general procedure of the present experiment was similar to Schwartz's. In the present experiment, pigeons were confronted with two lighted response keys. Six keypecks, evenly distributed in number over the two response keys, produced a food presentation. That is, three pecks to the left key coupled with three pecks to the right resulted in food. The three left and three right pecks could occur in any order; Left-Right-L-R-L-R, LLLRRR, RLRLLR and any of 17 other evenly-distributed combinations resulted in a food presentation. A fourth peck to either key violated the requirement for food delivery and resulted in a blackout; the keylights and chamber lights turned off for 4 sec. For example, LLLRRL, RRRR, and LRLRRR all resulted in a blackout. In all there were 30 possible forms that would produce this consequence. The frequencies of occurrence of each of the 50 possible sequences were recorded to obtain a measure of the variability of response forms.

The reinforcement of sequences of keypecks followed a procedure used by Vogel and Annau (1973), who found that pigeons produce a wide and gradually narrowing range of response sequences when six evenly-distributed pecks produced reinforcement on a continuous basis (that is, on CRF). Thus, their procedure treated six pecks as a single response, and they found that variability in the form of this more complex response changed in a manner that was consistent with that of nose-poking and long-key pecking under CRF.

Schwartz (1982b, 1986) adapted the Vogel and Annau procedure for use with partial schedules by only occasionally reinforcing sequences of eight pecks that met the criterion of exactly four pecks to each key. He presented pigeons with a pattern of colored lights on an adjacent wall that changed in a manner that was correlated with the response sequence as it progressed. A timer defined a minimum delay interval between reinforcements, and the first evenly-distributed sequence of eight pecks that occurred after the given interval had elapsed produced food. Evenly-distributed sequences that were completed before the interval had elapsed returned the colored lights to an initial position and reset the peck count to zero. Unevenly distributed sequences (fifth peck to either key) resulted in a blackout.

To be consistent with the general pattern of comparisons of response variability reviewed above, there should have been a wider range of response sequences observed under partial reinforcement than were observed under CRF. Schwartz, however, did not observe such an effect with fixed-interval and fixed ratio schedules (1982b) nor with VI schedules (1986); he found no difference in the variability of forms under partial schedules compared with that observed under CRF. This finding seems inconsistent both with those in support of a sub-category analysis and with Herrnstein's results.

The behavior of Herrnstein's subjects grew more stereotyped with reinforcement, even when it was presented on a partial schedule. As noted, it may be generally true that responding tends to become more stereotyped in form under any schedule of reinforcement, with the principle effect of schedules being manifest in the time required to narrow the distribution of forms, and/or on the terminal variance of forms maintained by reinforcement. In the extreme, responding may become so stereotyped that extinction operations no longer increase variance in some properties of response form. The responding of Schwartz's subjects became neither more nor less stereotyped, as measured by the distribution of sequences, under partial reinforcement as compared to CRF. But these birds all had extensive training on CRF prior to the introduction of partial schedules. Perhaps as a function of this experience, the subjects' responding was highly stereotyped prior to exposure to partial schedules (most sequences were either LLLLRRRR or RRRRLLLL). While the integrity of the stereotyped 8-peck units in the face of a transition to a leaner schedule is impressive, it might not reflect the effect that such a transition might have had on less stereotyped responding. In fact, in another experiment in which subjects were given extensive exposure to CRF of 8-peck sequences (Schwartz, 1981) the response sequences did not become any more varied when placed on extinction. This would represent a dramatic exception to the well-established finding that the form of continuously-reinforced behavior becomes more varied under extinction, unless the extensive CRF training constrained the expression of variance in extinction to properties of responding other than the sequence of pecks. The same might have been true of variance produced by the partial schedules in his other experiments. But Schwartz's purpose was to demonstrate the potential integrity of complex response units in the face of environmental change, not to test the contribution of reinforcement schedules to the variance of response forms. Thus, for the present concern of testing the variability in the form of responding under continuous and partial schedules of reinforcement, Schwartz's procedure was modified somewhat.

Steps were taken in the present study to insure a higher degree of variability in form prior to the introduction of partial reinforcement. First, the stimulus lights that Schwartz had correlated with the production of the various sequences were omitted from this experiment; Vogel and Annau (1973) found that removing similar lights increased the variability of their subjects' 6-peck sequences. Second, and perhaps more importantly, we tried to limit as much as possible the amount of continuous reinforcement of 6-peck sequences prior to the introduction of partial reinforcement schedules. A fair amount of exposure (detailed below) to CRF proved to be necessary as the 6-peck sequences extinguished easily during training with changes in average rates of reinforcement that would have had only slight effects on the more typical single-key responding. Nevertheless, we were able to introduce partial schedules at a point in training where the sequence variability was far greater than that exhibited by subjects in Schwartz's studies when similar schedules were introduced.

To compare the variabilities of response form and, later, the resistances to extinction produced by CRF and VI schedules in a manner that was minimally confounded by the order of their presentation, brief, regularly alternating periods of schedule exposure were arranged. Two lighted keys were presented, both colored the same, either white or green. The keys were lighted with the first color for 1 min, then all lights were extinguished for 15 sec, then the second color came on for 1 min followed by another 15 sec blackout; this cycle was repeated until the end of the session. Evenly-distributed sequences were reinforced on a VI schedule when keys were white and on a CRF schedule when keys were green. Deviations from the even-peck-distribution requirement (that is, a 4th peck to either key) always resulted in a 4-sec blackout. After a number of sessions of exposure to the comparison schedules, a resistance to extinction test was conducted in which white and green keys were presented for alternating 1-min periods but all food presentations were withheld.

CHAPTER II

EXPERIMENT 1

Subjects

The subjects were 6 adult male pigeons (Palmetto Pigeon Plant). They were maintained throughout the experiment at approximately 80% of their free-feeding weights. They were individually housed and given continuous access to water and grit in their home cages. All subjects had served in previous experiments involving keypecking and food presentations in operant conditioning chambers, but none had prior experience with contingencies requiring even spatial distribution of responding over 2 keys.

Apparatus

A standard 2-key operant conditioning chamber was used (Lehigh Valley). The subjects' space was 30 cm long, 33 cm wide, and 34 cm high. Two translucent response keys were mounted 13.5 cm apart, center to center, and 24 cm above the floor of the chamber. They could be lighted white, green, or purple. When lighted, a sufficently forceful peck (approximately .2 N) turned off the keylights and the houselight for .25 s. The houselight, located on the front wall of the chamber above the response keys, provided low-level illumination and could be lighted either white or red. Centered below the keys, 24 cm above the floor, was a rectangular opening that gave access to mixed grain when the food hopper was raised. At those times, the feeder opening was illumunated with red light, the red houselight was illuminated, and the white houselight and the keylights were extinguished. An externally-mounted fan provided masking noise and ventilation.

Procedure

Pretraining. Throughout the pretraining period the number of food presentations varied for each of the subjects with their individual training requirements. Whenever keys were lighted during pretraining they were colored purple. Subjects were exposed to response-independent presentations of the keylights followed by food presentations (i.e., an autoshaping schedule) until each was pecking one of two purple keys. This took from 1 to 4 days and autoshaping was followed by six days of shaping. On day 1 subjects were presented with 4 sec access to grain only if they made a total of 3 pecks to either key or in any combination. The same contingency was in effect for the first half of day 2; in the second half the pecks had to be directed to the key that was less frequently pecked in the first half. Occasionally it was necessary to turn off the light of the preferred key to induce pecking of the other key. This treatment was repeated on day 3, by the end of which all subjects were reliably pecking both keys. On days 4 and 5, a peck had to be directed to each key to produce food; additional pecks to a given key prior to the required peck to the other key had no scheduled consequence. These conditions also prevailed on day 6 with the exception that a minimum of 3 pecks to each key were required. Six subjects of a pool of birds that reliably produced reinforcement on day 6 were randomly selected to serve in Experiment 1.

Schedule exposure. Subjects were then exposed to a multiple schedule of reinforcement. Daily sessions began with the chamber dark. The white houselight was illuminated as were the two response keys, both colored either white or green. The selection of key colors at the start of each session was random; the colors were then presented in regular alternation for periods of approximately 1 min throughout the daily sessions. Periods of exposure to the 2 conditions were separated by 15 sec intertrial intervals (ITIs) during which all lights were turned off. To keep the subjects' weights stable the number of 1-min response-key presentations was adjusted each day; generally, keys were presented either 26 or 36 times per session (13 or 18 of each color) but occasionally 0, 16, or 46 presentations were made. An equal number of green-key and white-key presentations were made in each session. On the first day of exposure to green and white keys, food reinforcement (3.5 sec access to red-lighted grain presented with the red houselight) was made contingent on the production of exactly 6 pecks evenly distributed over the 2 keys (3 pecks per key). Six evenly-distributed pecks produced food regardless of their order of appearance; a 4th peck to either key produced a 4-sec blackout. Green and white key presentations were scheduled for 60 sec exclusive of blackout and food presentation time, but they could not end during an active sequence. That is, if the schedule presentation timer reached 60 sec while the subject was engaged in a sequence, the keys retained their status until the sequence was completed. (The purpose of this was to avoid inadvertent nonreinforcement of parts of sequences). The only exception occurred when 60 sec elapsed between pecks in a sequence; whenever 60 sec of key exposure elapsed without a keypeck, the ITI and next key presentation ensued.

For at least 13 sessions, each sequence that satisfied the distribution requirement was followed by a food presentation, whether the keys were green or white. Then when responding appeared to be moving towards stereotypy (range: 13 to 21 sessions), a VI 15 sec average interfood interval was imposed on responding--only when keys were white. Interfood intervals were varied on a random basis after each white-key reinforcer, and the interval values for all VI schedules were based on an arithmetic progression. Evenly-distributed sequences that appeared prior to the end of an interval extinguished the keylights and the white houselight and illuminated the red houselight, which was otherwise only lit in the presence of food, for 2.5 sec. (It was hoped that the red houselight would serve a conditioned reinforcing function, like that ascribed to the more typical "feedback click", of strengthening the operant less than its correlated food presentation, but more than nothing. No independent assessment of this function was made). The VI schedule operative in the presence of white keys was increased over the next several days from 15 to 30 and finally to 60 sec. For 5 of the 6 subjects responding in the presence of white keys became highly disrupted on the VI 60 sec schedule, and so the schedule was returned to the 30 sec level for the duration of training. The number of sessions that the subjects were exposed to at each level of intermittency are presented in Table 1. Continuous reinforcement in the presence of green keys was maintained throughout this period. The frequencies of each of the 50 recorded sequences were monitored daily for each condition.

Resistance to extinction tests. After 13-15 sessions of exposure to VI schedules, a test was conducted of the relative resistance to extinction maintained by responding on VI and CRF schedules. In extinction sessions, alternating 1-min green and white key presentations continued as in the training sessions, with the exception that all scheduled presentations of food and/or red lights were replaced with the 4 sec blackout normally encountered after a 4th peck to a given key. Extinction sessions continued until no keypecks were observed for 10 min (5 min of green plus 5 min of white keylight presentations).

Results

First we will look at the obtained differences in rates of reinforcement for each subject across conditions and associated differences in rates of responding. Then we will consider whether VI and CRF schedules differentially affected the variability of response forms. Finally we will evaluate the relative resistance to extinction of responding under the comparison schedules.

The average number of food presentations and the average number of sequences per minute in the last 5 days of schedule exposure are presented, for individual subjects, in Table 2. The two columns to the left show the average time between food presentations under VI and CRF schedules, along with the ratios of average interfood times under these schedules. The interfood times depended both upon the final values of the VI schedules (VI 30 sec for all subjects but 1A; VI 60 sec for this bird) as well as on the subjects' rates of responding. The ratios of the interfood times under VI and CRF schedules ranged from 8.1:1 to 2.2:1. The response rate data are presented in the other two columns of this table. For each subject, they show the average number of evenly-distributed 6-peck sequences per minute over the average number of even plus uneven sequences per minute, along with the ratios of the two averages. Recall that 50 different sequences were recorded, 20 of which were composed of 3 pecks to each key. Thus if keypecking were truly random, the ratio of evenly-distributed sequences to total sequences would approximate .4. Nevertheless, this ratio does not indicate the degree of variability in responding because a ratio of .4 might be associated with either highly stereotyped or highly variable behavior. For all subjects, both the average rate of sequence production and the average rate of even sequence production was higher under CRF than under VI reinforcement. The ratios of even sequences to total sequences also tended to be higher under the CRF schedule than under VI reinforcement.

There is probably no single best measure of the variability of response forms, as there is no way of knowing in advance the size of functional response units. Two measures were applied; one was an analysis of collections of 4, 5, and 6 pecks and the other an analysis of collections of 1, 2, and 3 pecks. The statements of ordinal relations of the variability of response forms under the comparison conditions were consistent over the two measures for all subjects. Both measures were derived from calculations of the relative frequencies of the different sequences.

Figure 1 presents, for individual subjects, the relative frequencies of the 10 sequences most often observed in each condition. If responding were truly random, the relative frequencies of each of the 50 sequences would be expected to be approximately .02. The 10th most frequently-observed sequence approximated this level for all subjects. The proportions of the total responding represented by the top ten sequences in each condition were summed and are presented in Table 3 (top entries for each subject). If responding were random the top 10 sequences should approximate (.02 x 10) = .20 of total responding. For 5 subjects the top 10 sequences accounted for more of the total responding in the CRF condition than in the VI condition. By this measure, only subject 1E responded more variably under CRF than under VI reinforcement.

The second measure of response variability supported the generalization that partial schedules of reinforcement maintained a wider range of response forms than continuous schedules did. In Table 3 the lower entries for each subject indicate the average uncertainty, u, of responding under CRF an VI schedules. Uncertainty was calculated with the following equation:

$$u = \frac{\sum_1^8 (pi \log \ pi) - \left[\frac{\sum_1^2 ji \log_2 ji}{\log_2 (2)} \right]}{\log_2 (8)}$$

where ji equals the probabilities of left and right responses, and pi equals the probabilities of LLL, LLR, LRL, LRR, RLL, RLR, RRL, and RRR response sequences. This measure, which was adapted from Miller and Frick (1949) was designed to reflect the degree of sequential dependency in behavior. When all possible sequences of 3 pecks were approximately equal in probability, u approached 1.0. (Measuring relative frequencies of 3-peck sequences limited differences in the number of observations contributed by 4, 5, and 6-peck sequences). Although differences were small, uncertainty was higher, indicating more variable responding, under VI reinforcement than under CRF for all 6 subjects. Based upon a one-tailed sign test with a p of .02, the null hypothesis of no difference in u across conditions was rejected. Over the 6 subjects, the mean proportion of total responding represented by the top 10 sequences in each condition is presented in the lower margin of Table 3, along with the mean u over subjects in each condition. On average, VI reinforcement maintained a wider range of response forms than continuous reinforcement did.

Next we will consider the results of the resistance to extinction tests. In Figure 2 are presented the results of the extinction tests for the 6 subjects, which are identified by number. For each subject, the upper panel represents total responding in extinction (even plus uneven sequences) and the lower panel represents responses in extinction that were evenly distributed over the 2 keys. Response rates following CRF (crosses) and VI reinforcement (squares) are expressed as proportions of baseline (pre-extinction) rates during successive 10-min blocks of time in extinction. Baseline rates were calculated by averaging the relevant rates over the last 5 sessions preceding the extinction test. If one of the two conditions produced behavior that was more resistant to extinction, the response rate would decrease more slowly relative to its baseline rate. In other words, the response rate function with the flatter slope would be identified with the more resistant behavior. For example, the slopes of the CRF functions of subject 1B are flatter, indicating more resistant behavior. With the exceptions of subjects 1F and 1C (total sequences only) responding appears to have been more resistant after CRF training than after VI training.

A quantitative summary was derived from each function and also appears in Figure 2. The summary statistic, p, is the weighted mean proportion of the baseline response rate (Nevin, Mandell, and Yarensky, 1981) calculated by multiplying the proportion of baseline at each 10-min block of extinction by the number of minutes of extinction time, summing, and dividing by the total time in extinction. Formally,

$$p = \frac{\sum (xi\ pi)}{\sum (xi)}$$

where xi represents the value of the variable on the x-axis and pi is the proportion of baseline rate at that value. For example, suppose that after 10 minutes of extinction, the response rate expressed as a proportion of the baseline rate is .95, after 20 minutes it is .45, and after 30 minutes it is .16. The weighted mean proportion of baseline is

$$p = \frac{(10 \times .95) + (20 \times .45) + (30 \times .16)}{10 + 20 + 30} = .39$$

This statistic gives proportionally greater weight to the greater effect of longer periods of extinction, which may be more reliable. Assuming that the extinction operation generally reduces responding, the value of p ranges from 1.0, signifying that responding is unchanged by the extinction operation, to 0, indicating that responding is maximally disrupted throughout extinction.

When total sequences were measured, p was larger in extinction after after CRF than after VI reinforcement for all subjects except 1C and 1F. When evenly-distributed sequences alone were considered, p was larger after CRF for all subjects except 1F. Recall that the ratio of bird 1F's obtained average interfood intervals (VI:CRF) was only 2.2:1. In other preparations, differences in average interfood times as small as this have not produced reliable differences in resistance to extinction (cf., Mellon and Shull, 1986).

The other subject whose data contradicted the general trend, 1C, had obtained the second smallest difference in interfood times between conditions (VI:CRF=3.3:1). As noted, for this subject continuous reinforcement produced greater resistance when evenly-distributed sequences were measured alone, but p was greater after VI reinforcement when total sequences were calculated. The rate of total sequence responding of 1C was higher over much of the extinction test than it was during the baseline period, especially following VI reinforcement, resulting in a p of 1.14 for responding in that condition and the improbable conclusion that response strength increased in extinction. If contributions to the weighted average of response rate at any point of extinction is limited to that of behavior unaffected by extinction (i.e., if the ceiling of pi is 1.0) the p of the total sequences of 1C would be .96 after partial reinforcement, somewhat closer to the p of .87 after CRF.

The sampling distribution of p differences is not known, but the magnitude of the differences in p for subjects in Experiment 3 were consistent with our visual scan of the functions and were similar to those obtained in other preparations where reinforcement rates were manipulated (e.g., Nevin, Mandell, and Yarensky, 1981). Typically, no differences in p have been observed when the reinforcement histories of comparison conditions were similar. When total sequences were measured, the average p across the 6 subjects was .6 after CRF training and .48 after VI training. When only evenly-distributed (reinforcable) sequences were measured, the average p was .45 after CRF training and .28 after VI training.

The absolute numbers of keypecks, evenly-distributed sequences, and total sequences produced by each subject in extinction are presented in Table 4, along with the average rates of even and total sequences per minute of extinction time, shown in ratio in the fashion of Table 2. All 6 subjects pecked the keys more times and produced more evenly-distributed sequences after continuous reinforcement than after VI reinforcement. Subjects 1F and 1C produced more total sequences in extinction following VI reinforcement. Taken together the relative and absolute measures of responding in extinction support a generalization that CRF produced responding that was more resistant than partial reinforcement did, except when the average rates of reinforcement in VI and CRF conditions were similar (3.3:1 or less in ratio).

Discussion

In Experiment 1, the VI schedules employed tended to maintain a wider range of response forms than did CRF schedules. However, if this difference enhanced the resistance of partially-reinforced behavior, its impact was not sufficient to produce the effect that the textbooks describe as "paradoxical." To the contrary, partially-reinforced behavior tended to be less resistant to extinction than continuously-reinforced behavior. The leaner VI schedules tended to maintain responding that was lower in rate, more varied in form, and less resistant to extinction than responding maintained by the richer CRF schedule. In other words, the effect of partial reinforcement on responding in extinction was not paradoxical with respect to the more general relation between rate of reinforcement and resistance.

The results of the measures of variability of response forms across conditions seem different from those obtained by Schwartz (1982b; 1986) who employed a similar procedure and found no differences in the ranges of forms maintained by continuous and partial schedules. A likely basis for the different outcome is that the subjects in Schwartz's studies had extensive histories of continuous reinforcement of sequence responding prior to exposure to partial schedules, resulting in highly stereotyped responding, while exposure to partial schedules began much earlier in training in the present study. The present finding, that responding is more varied in form under partial reinforcement, is consistent with those of the majority of cited investigations of this issue using different methods.

The results of the resistance-to-extinction tests might be taken as support for the position that the paradoxical partial reinforcement effect is neither robust nor generally obtained (Nevin, 1987 in press); I will return to this interpretation later. On the other hand, it might be argued that the paradoxical effect was not obtained in Experiment 1 because the putative CRF schedule was actually a fixed ratio schedule, as 6 keypecks were required for reinforcement. Taking this view, the comparison schedules were FR 6 ("CRF") and FR 6 with an added VI requirement ("VI"). Thus in Experiment 1 the leaner of two intermittent schedules resulted in less resistant responding. The "partial reinforcement principle", it might be argued, makes its paradoxical prediction only when comparing the effects of intermittent reinforcement and a "true" CRF, not when comparing two intermittent schedules differing in average rates of reinforcement. But even the continuous reinforcement of individual keypecks can be thought of as requiring at least three responses; orienting to, approaching, and pecking the key. This interpretation would seem to limit the predictive power of the "paradoxical principle" to preparations involving the continuous versus partial reinforcement of very simple properties of behavior. This limitation would seem to cast serious doubt on the validity of the paradoxical principle as an account of such complex behavior as pathological gambling. For by restricting the use of the term "CRF" to cases in which virtually every movement is reinforced, virtually all of the complex human behavior that is of interest to the clinician would have to be considered to be intermittently reinforced and therefore within the predictive domain of the "nonparadoxical partial reinforcement principle"; that is, the principle that states that higher rates of intermittent reinforcement result in more resistant responding.

If the partial reinforcement effect is indeed limited to comparisons of the effects of partial reinforcement and CRF, the "paradoxical principle" would have limited utility as an account for why behavior is persistent despite infrequent reinforcement. Partial reinforcement might account for behavior being more persistent than other behaviors maintained by <u>continuous</u> reinforcement, but it would fail to account for why the behavior is stronger than other behaviors maintained by <u>richer partial</u> schedules. For example, appeal to the paradoxical principle might be legitimate for accounting for the (actually unlikely) case of paradoxically greater persistence of a gambler who rarely wins (i.e., a lean intermittent schedule) compared to that of a gambler who wins every time (CRF). But it would not account for the more likely case of the paradoxically greater strength of a gambler who rarely wins (lean intermittent schedule) when compared to that of a gambler who occasionally wins (richer intermittent schedule). As has been noted, leaner partial schedules consistently produce behavior that is less resistant to extinction than richer partial schedules.

Schoenfeld's account of the paradoxical partial reinforcement effect is consistent with the non-paradoxical results of Experiment 1, because it specifies two conflicting effects of manipulations of rates of reinforcement on resistance to extinction. Leaner schedules reinforce behavior less frequently, which results in weaker resistance to extinction. But leaner schedules also tend to reinforce more response forms, which results, according to this view, in increased resistance to extinction. The second effect on resistance to extinction is presumably weaker than the first because it makes its presence known inconsistently and only in unusual cases like comparisons of CRF and intermittent reinforcement, possibly because the differences in ranges of reinforced forms are larger than for comparisons of two levels of intermittent reinforcement. [Recall that Eckerman and Lanson (1969) found reliable differences in the ranges of forms produced under CRF and intermittent reinforcement, but no reliable differences in the ranges of forms produced under different levels of intermittent reinforcement]. The possible resistance-enhancing effect of reinforcing a wider range of response forms on partial schedules cannot be assessed from the results of Experiment 1 independently of the more obvious resistance-weakening effect of less frequent reinforcement.

Experiment 2 was an attempt to dissociate these factors to evaluate the independent contribution of variance in the form of operants to their resistance to extinction. This required a manipulation of the range of forms reinforced while keeping other factors, particularly rates of reinforcement, as consistent as possible across conditions.

A type of contingency was employed that differentially reinforced responding that was varied in form. Not surprisingly, this type of contingency has been investigated by Schoenfeld and his associates (Schoenfeld, Harris, and Farmer, 1966) but it has not been used to test his view of the relation between sub-categories of responding and resistance to extinction. The contingency involves (1) identifying a range of forms of responses that produce a common reinforcer and (2) making reinforcement contingent, not only on the occurrence of the response, but also on variance in the identified dimension of form. The gradual shifting of the form of responding under such a contingency toward a target form is commonly known as shaping.

Several investigators (e.g., Schwartz, 1982a; Page and Neuringer, 1985) have adapted such "variability" contingencies to the type of sequence responding that was established in Experiment 1. In a typical procedure, _n_ keypecks are only followed by food if they (1) are evenly distributed over the two keys and (2) if the sequence of left-key and right-key pecks differs from the last sequence that was reinforced. The fact that pigeons satisfy these requirements more accurately than computer-based random response generators suggests that variability in form is a reinforcable dimension of responding (cf., Page and Neuringer 1985). In other procedures the even-distribution requirement has been omitted. That is, pigeons made sequences of _n_ pecks, with the only requirements for reinforcement being the number of pecks and that the sequence of pecks on two available keys differed from the last reinforced sequence. In one study, more than .7 of subjects' 8-peck sequences satisfied this less demanding requirement, even when reinforcement was made contingent, after extensive training, upon the production of a sequence that differed from each of the last 50 reinforced sequences (Page and Neuringer, 1985).

In the present experiment, a 6-peck, even-distribution requirement was used in the hope of producing a relatively large degree of stereotypy in one of two experimental conditions. The challenge was to produce greater variability in the other condition while keeping other reinforcement parameters non-differential. The procedure adopted was as follows. At the start of daily sessions pigeons were placed in a dark chamber. Then the houselight was illuminated along with two response keys, which were colored white. (Later in the session the keys would be colored green; the two colors were presented in regular alternation after every third food presentation). As in Experiment 1, any 6 pecks that were evenly distributed over the two white keys were followed by food, and a 4th peck to either key resulted in a brief blackout. For later use, we kept track of the number of sequences that occurred before food was produced. After the reinforcer presentation, the white keylights and the houselight were again illuminated. This time, in addition to the even-distribution requirement, the sequence had to differ in form from the previously-reinforced sequence before it was followed with food. Thus if LRLRLR was the first sequence to be reinforced, it was followed by a blackout if it recurred during the second opportunity. LRLRRL, on the other hand, would produce food, as would 18 other evenly-distributed, nonredundant variants. Again for later use, we kept track of the number of sequences that preceded food on this second opportunity. A third presentation of the white keys ensued and, like before, even sequences had to differ from the most recently-reinforced sequence before they produced food; thus, if LRLRLR appeared it would now be reinforced, while LRLRRL would not. The number of sequences that preceded the third food was also recorded, and the three recorded numbers were used to determine the parameters of reinforcement in the ensuing green-key context.

After the 3rd reinforcer in the presence of the white keys, all lights were extinguished for a 15-sec ITI. Then the houselight was illuminated and the keys were lighted green, and in this context three consecutive foods were also obtained. But when the keys were green, any evenly-distributed 6-peck sequence was eligible for reinforcement; to produce food, they were not required to differ in form from any previously-reinforced sequence. Previous investigations have revealed that when sequences are required to vary in form (as they were in the present study when keys were white) they tend to be more varied in form than when they are allowed but not required to vary (as was the case when keys were green). Thus by requiring variability when keys were white and not when keys were green, we hoped to create a difference in the ranges of forms observed under the two conditions, and then test for a difference in resistance to extinction.

One added requirement was necessary to provide a test of the independent contribution of the ranges of response forms to resistance to extinction, because it seemed likely that more sequences and more time would tend to precede reinforcement when variability in form was required (white keys) than when it was not (green keys). To reduce probable rate of reinforcement differences across conditions, the number of sequences that preceded the first, the second and the third reinforcers when keys were white were used to establish a minimum number of sequences to precede the first, second, and third reinforcers, respectively, in the ensuing green-key context. For example; if, when keys were white, a subject made 3 sequences before the first food was obtained, 4 sequences before the second, and 2 sequences before the third food was obtained, then when the green keys were presented, the subject was required to make at least 3 sequences before the first food was presented, at least 4 before the second and at least 2 before the third. In other words, responding in the white-key condition established minimum response-to-reinforcer ratios when keys were next lighted green. When keys were green, the first evenly-distributed 6-peck sequence that satisfied its associated ratio requirement was followed by food; it was not required to differ in form from any previously-reinforced sequence. Uneven sequences "counted" in both conditions; when keys were white they increased the ensuing green-key ratio, and when keys were green they satisfied the ratio requirement--though of course they were never directly followed by food presentations, only by blackouts. Even sequences that preceded the satisfaction of the ratio requirements in the green-key context were also followed by blackouts. Again, the point was to keep the rates of reinforcement in the two conditions as close to equal as possible, while creating a difference in the ranges of reinforced forms, to assess any independent contribution of this difference to resistance to extinction.

CHAPTER III

EXPERIMENT 2

Subjects

Six pigeons were selected randomly for participation in Experiment 2 from a pool of subjects described in Experiment 1. They were housed and maintained in the fashion of Experiment 1.

Apparatus

The apparatus was identical to that employed in Experiment 1.

Procedure

Pretraining. The subjects were trained to peck 2 purple-lighted response keys via the pretraining procedure of Experiment 1.

Schedule exposure. After pretraining the subjects were exposed to a multiple schedule of reinforcement. Daily sessions began with the chamber dark. Then the houselight was illuminated along with two white response keys. Conditions associated with the white keys were operative until three foods were collected; the third presentation was followed by a 15-sec ITI during which all lights were extinguished. The keys were then lighted green, and conditions associated with green keys were operative for three food presentations followed by an ITI. Keylight colors and their associated conditions were presented in regular alternation. The number of 3-food schedule presentations varied from day to day so that weights were maintained at 80% of the free feeding level; generally either 30 or 45 foods were obtained in each condition.

Food reinforcement consisted of 3.5 sec of access to red-lighted grain coupled with the illumination of the red houselight.

White-key conditions: The first evenly-distributed 6-peck sequence produced each day was always reinforced. After the first reinforcement, only evenly-distributed sequences that differed from the last sequence reinforced in the presence of white keys produced food. Evenly-distributed sequences that were redundant in form with the last reinforced sequence were followed by a 2.5 sec blackout. A 4th peck to either key produced a 4 sec blackout. These conditions were operative in the presence of white keys for the first 25 sessions of schedule exposure. During the last 10 days conditions were the same except that even sequences produced food only if they differed from the last 2 sequences reinforced in the presence of white keys (LAG 2). Thus there were two requirements for reinforcement of responding in the presence of white keys: (1) even distribution of a 6-peck sequence that (2) differed in form from the last sequence (later the last two sequences) reinforced in the white-key context.

Green-key conditions: The number of sequences (even plus uneven) required to obtain each of a group of 3 foods in the presence of white keys were recorded. These numbers established a minimum number of sequences (even plus uneven) required for the presentation of each of the 3 foods in the ensuing green-key context. The only other requirement for reinforcement was the even distribution of 6 pecks over the two response keys; they could occur in any order and could be redundant in form with any previously-reinforced sequence.

Evenly-distributed sequences that occurred prior to the satisfaction of the minimum number of squences required were followed by a 2.5 sec darkening of the white houselight and a 2.5 sec lighting of the red houselight, which was otherwise only lighted in the presence of food. It was hoped that the red houselight would serve a conditioned reinforcing function and increase stereotypy in the presence of green keys. After 10 days of schedule exposure the 2.5 sec red houselight presentations were replaced with a 2.5 sec blackout to avoid contamination of the extinction tests by different rates of conditioned reinforcement, if indeed the red houselight was serving this function. (This change appeared to have no effect on response rates or on distributions of forms, and will not be discussed further). A 4th peck on either key resulted in a 4 sec blackout. Thus there were two requirements for the reinforcement of responding in the presence of green keys: (1) even distribution of a 6-peck sequence and (2) production of at least the same number of sequences that preceded a previous reinforcement in the presence of white keys. Again, the purpose of this second requirement was to keep the interreinforcement times and the ratios of responses to reinforcements as close to equal as possible in the two conditions.

Resistance to extinction tests. After a total of 35 days of exposure to the green-key "stereotypy" condition and the white-key "variability" condition, a test was conducted of the relative resistance to extinction that they produced. In the extinction sessions subjects were presented with green and white keylights for alternating 1 min periods, with all sequences (even and uneven) resulting in a 4 sec blackout only. The 1 min presentations of the two key colors were timed exclusive of blackout periods and they were separated by a 15 sec ITI blackout. As in Experiment 1, the 1 min exposure to a given schedule could not end during an active sequence, and whenever 60 sec elapsed without a keypeck the ITI and next key color presentation ensued. Extinction sessions continued until no keypecks were observed for 10 min (5 min of green plus 5 min of white key presentations) or until the 90th key-color presentation, whichever came first.

Results

Experiment 2 was designed to directly assess the contribution of the number or ranges of forms that responding takes to the resistance to extinction of operants. In the typical comparison of resistance under partial and continuous reinforcement, two factors of possible relevance to resistance to extinction may vary--the rate of reinforcement or number of responses per reinforcer, and a correlated difference in the ranges of forms of reinforced responding. The procedure employed here was designed to manipulate the ranges of forms independent of the rates or ratios of reinforcement.

When keys were white a given evenly-distributed sequence was never reinforced twice in succession, and later a sequence was not reinforced if its form was redundant with that of the last two reinforced sequences in that context. On the other hand, when keys were green any evenly-distributed sequence could produce any or all of the scheduled reinforcers regardless of redundancy in their form. Subjects were required to make at least as many sequences when keys were green as they had made when keys were white, so that, as an equal number of reinforcers were presented in the two conditions, the rates of reinforcement and the ratios of responses to reinforcement would be close to equal across conditions. First presented will be the differences in response rates and ratios across conditions, followed by an evaluation of differences in the ranges of forms across conditions, and finally, of relative resistance to extinction.

In the first two columns of Table 5 are presented the average times between food presentations during the last 5 days of exposure to "variability" (white-key) and "stereotypy" (green-key) contingencies, along with the ratios of the two averages. In the next two columns are the average ratios of sequences (even plus uneven) to reinforcement under the two conditions, which are, in turn, presented in ratio. Where differences in average interfood time were present, they were higher in the stereotypy condition than in the variability condition. The differences were modest, ranging, in ratio, from 1:1.8 to 1:1.1. Thus the largest obtained interfood time ratio in Experiment 2 was smaller than the smallest ratio for subjects in Experiment 1 (subject 1F; 2.2:1 for VI and CRF average interfood times). Recall that a reliable difference in resistance to extinction across conditions was not observed for this subject in Experiment 1. Differences in the ratios of responses per reinforcer under the variability and stereotypy contingencies corresponded to the differences in average interfood times. Differences in the ratios of the number of evenly-distributed sequences per reinforcer across conditions also corresponded to the average interfood time comparisons and are not presented.

Also shown in Table 5 are the average response rates (sequences per min) during the last 5 days of exposure to variability and stereotypy conditions. Entries in the two rightmost columns represent, for each subject, the average number of evenly-distributed 6-peck sequences per minute over the average number of even plus uneven sequences per minute, along with the ratio of the two averages. Response rates tended to be similar in the two conditions; across subjects they were higher under the (somewhat leaner) stereotypy contingency as often as they were under the (somewhat richer) variability contingency. Thus the rates of responding under the comparison conditions provided additional evidence that the modest differences in obtained rates and ratios of reinforcement did not differentially affect the strengths of responding.

As in Experiment 1, if responding were truly random, we would expect the ratios of even sequences to total sequences to approximate .4. Although Table 5 shows that the ratios were somewhat higher than .4 for two subjects and lower than .4 for two subjects, they appeared to be similar for each subject under variability and stereotypy contingencies. Again, the ratios of even to total responses do not reflect the variability of responding. As in Experiment 1, to determine the relative degree of variability in response form produced by the two conditions, the relative frequencies of all sequences observed were calculated and analyzed in two ways.

Figure 3 presents, for each subject, the relative frequencies of the 10 sequences that were most often observed during the last 5 days of exposure to each contingency. If responding were truly random the relative frequencies of each of the 50 possible sequences would be expected to approximate .02. The proportion of the total responding represented by the top 10 sequences in each condition were summed and are presented in Table 6 along with the results of tests of uncertainty (u).

For 5 of the 6 subjects the top 10 sequences accounted for more of the total responding in the stereotypy condition than in the variability condition. By this measure, only subject 2E responded more variably in the presence of green keys. Based on the u statistic, 5 of the 6 birds including 2E responded more variably (higher u) under the variability contingency. Subject 2C showed a higher uncertainty, indicating more varied responding, under the stereotypy contingency. A one-tailed sign test with a p of .10 failed to reject the null hypothesis of no difference in u across conditions.

The magnitude of differences in the variability of response forms under the two conditions did not appear to be related in any obvious way to differences in rates of reinforcement across conditions. The variability contingency was least effective in maintaining more varied responding for the subjects that had obtained a relatively large (2C; 1:1.5) and a small (2E; 1:1.1) ratio of average interfood times under variability and stereotypy contingencies.

To summarize the results to this point, a procedure that was designed to generate a difference in the variability of response forms across conditions was inconsistently effective. It produced differences that were observed consistently over two measures of variability for 4 of 6 subjects. Obtained differences in interfood time did not appear to have any consistent effect on either rates of responding or on the variability of responding under the two conditions across subjects. Now we will turn to the results of the resistance to extinction tests.

The results are presented in Figure 4. For each subject, the upper panel represents total responding in extinction and the lower panel represents evenly-distributed sequence responding in extinction. Response rates following variability (squares) and stereotypy (crosses) training are expressed as proportions of baseline (pre-extinction) rates during successive 10-min blocks of time in extinction. If one of the conditions produced behavior that was more resistant to extinction, the response rate would decrease more slowly relative to its baseline rate, and the associated function in Figure 4 would be the flatter one. Subject 2D, for example, provides a clear case of differential resistance, with the flatter slopes, and more resistant responding, following variability training. In general, the variability contingency resulted in more resistant responding; the least clear case was that of subject 2A.

The weighted mean proportion of baseline rate, p, was also calculated for responding in each condition and is presented in Figure 4. For all 6 subjects p was higher, indicating more resistant responding, after training on the variability contingency than after training on the stereotypy contingency. Again, the sampling distribution of differences in p is unknown, but the magnitude of differences in resistance to extinction across the conditions of Experiment 2 is large relative to those obtained in a substantial number of comparisons of schedule effects. When total sequences were measured, the average p across the 6 subjects was .59 after variability training and .37 after stereotypy training. When evenly-distributed sequences were measured, the average p was .45 after variability training and .24 after stereotypy training.

Like the variability of forms, the magnitude of difference in resistance to extinction under the two conditions did not appear to be systematically related to obtained differences in average interreinforcement times. The difference in p across subjects was smallest for subject 2A, the bird that had obtained the largest difference (1:1.8) in average interfood time across conditions. The magnitude of difference in resistance was also relatively small for a subject (2E) that had obtained a small difference (1:1.3) in average interfood times across conditions.

Thus, for all subjects, the variability contingency produced responding that was similar in rate, but more resistant to extinction, compared to that produced by the sterotypy contingency. The magnitude of differences in resistance to extinction in the two conditions across subjects was not ordered in any obvious way with respect to pre-extinction differences in average interfood times. Additionally, the effect was not correlated with intrasubject differences in the rates of responding across conditions prior to extinction. But of greater relevance to the purpose of this experiment was the finding that resistance to extinction across conditions was also not well ordered with respect to the degree of differences in the variability of response forms under the variability and stereotypy contingencies. In fact, 2 subjects (2C and 2E) showed differences in resistance to extinction despite the fact that the variability contingency had failed to produce a reliably wider range of response forms than the stereotypy contingency did. Responding was always more resistant to extinction after training under the variability contingency, even when the contingency had not produced more varied responding. Thus the magnitude of the effect of the contingency manipulation on responding in extinction was not well ordered with respect to obtained differences in average interfood times nor to differences in the variability of response forms.

One factor that seems to make intuitive and theoretical sense did appear to be related to the individual differences in the magnitude of resistance effects. However, this factor's influence was assessed after the fact, in a correlational fashion with a small sample, so the analysis is somewhat speculative. Recall that the variability contingency placed two requirements on responding; reinforced forms had to be evenly-distributed across the keys, and otherwise nonredundant in their distribution. Subjects differed in the degree to which they encountered the second half of this contingency. This was because redundant sequences had to occur before they could be differentially nonreinforced, and subjects differed in the number of redundant sequences they produced.

Figure 5 shows, for each subject, the proportion of evenly-distributed sequences that were nonreinforced because they were redundant in form with a previous sequence, during each session of training on the variability contingency. The four subjects that showed larger differences in resistance to extinction across conditions had at least one session during which more than half of the evenly-distributed sequences produced under the variability contingency were redundant and nonreinforced. The two subjects that showed smaller differences in resistance to extinction had less contact with the requirement of nonredundancy of form. Subject 2A produced the smallest proportion of redundant sequences and the smallest difference in resistance to extinction across conditions. The proportion of redundancy was rising for 2E at the end of training but had never reached .5; this subject showed the second-smallest differences in resistance to extinction. Of the 4 subjects that produced more redundant sequences and larger differences in resistance to extinction, only 2D and 2F were still making a large number of redundant sequences at the end of training; however, the magnitude of differences in resistance to extinction did not seem to be dependent upon the degree of redundancy at the end of exposure, as subjects 2B and 2C produced relatively few redundant sequences during the last 5 days of training and showed large differences in resistance to extinction. Thus larger numbers of nonreinforced redundant sequences were predictive of larger differences in resistance to extinction, whether the highest level of redundancy appeared early or late in training.

In summary, in the green-key context of Experiment 2 evenly-distributed 6-peck sequences were reinforced even if they were redundant in form, and in the white-key context they were reinforced only if they were nonredundant. The "variability" contingency produced responding that was more variable on each of two measures than responding under the "stereotypy" contingency for 4 of 6 subjects. Differences in average interfood times did not appear to exert systematic effects upon either the rates of responding prior to extinction or upon the relative resistances to extinction. The degree of difference in the variability of forms across conditions was also not systematically related to differences in rates of extinction; responding was more resistant after "variability" training whether it was, in fact, reliably more variable or not. While responding was more resistant to extinction after variability training for all 6 subjects, the magnitude of the differences in resistance across subjects seemed to be correlated with whether, at some point during training, a large proportion of the evenly-distributed sequences produced under the variability contingency were redundant and therefore nonreinforced.

Discussion

In Schoenfeld's view, reducing the rate of reinforcement of operant behavior has two conflicting effects on its resistance to extinction. The reinforcement of fewer responses tends to decrease resistance to extinction, but longer periods of nonreinforcement produce a wider range of reinforcable response forms, which tends to increase resistance to extinction. Observed resistance is a summation of the conflicting effects of the rate manipulation, and the latter effect is presumably weaker or at least less frequently detected. A case in point might be Experiment 1, where VI schedules tended to produce behavior that was more varied in form, yet less resistant to extinction, than CRF scedules did.

Experiment 2 was designed to produce two levels of variance in reinforced response forms while minimizing differences in rates of reinforcement. The purpose was to test for an independent contribution of a difference in the ranges of forms to resistance to extinction. The results were generally supportive of Schoenfeld's account; in all cases in which the contingency manipulation produced a difference in ranges of response forms, responding was more resistant when it was more varied in form.

However, in two cases responding was more resistant to extinction after training on the contingency that was designed to produce a wider range of forms, even though the expected difference in ranges of forms was not readily apparent. It is unlikely that the differential resistance to extinction is attributable to the modest differences in rates of reinforcement across conditions. Another possibility is that the contingency manipulation affected the development of discriminative stimulus control. This interpretation parallels discrimination or generalization-decrement accounts of the partial reinforcement effect in extinction (e.g., Skinner, 1938).

Discrimination accounts of the partial reinforcement effect differ in detail, but all point out that partial reinforcement schedules not only arrange for less frequent reinforcement than continuous schedules, but also necessarily reinforce responding in different stimulus contexts. Under partial schedules, periods of nonreinforcement of responding are part of the context in which responding is reinforced. This is not true under continuous schedules. Also, proprioceptive stimuli correlated with responding more reliably precede reinforcement under continuous schedules than under partial schedules. Plus, if partial reinforcement maintains a greater diversity of response forms, their proprioceptive correlates would be expected to be more diverse than those correlated with responding under continuous schedules. The greater diversity of proprioceptive stimuli under partial reinforcement might result in either a wider range of events functioning as discriminative stimuli or, if proprioceptive stimulation was diffuse enough, the result might be an overall weakening of discriminative control by the stimulus correlates of responding.

Discrimination accounts maintain that all extinction procedures involve changes in stimuli that might have entered into discriminative relations, and such changes tend to be greater after continuous than after partial reinforcement. As noted, under partial schedules, and not under continuous schedules, periods of nonreinforcement are part of the context in which responding is reinforced. Conditions of extinction are by definition periods of nonreinforcement, and thus entail the presentation of contextual events in the presence of which partially-reinforced responding has been reinforced and continuously-reinforced responding has not. The result might be a relative enhancement of the apparent strength of responding after partial reinforcement, only because the extinction procedure entailed an unequal removal of stimuli, other than reinforcers, that were relevant to the maintenance of responding. Procedurally, this would be analogous to changing the color of the response key associated with continuous reinforcement at the start of extinction, and not changing the color of the key associated with partial reinforcement. No one would be surprised that partial reinforcement resulted in responding that appeared to be more resistant to extinction than continuous reinforcement did; nor would they be likely to attribute this effect to differences in rates of reinforcement prior to extinction.

Proprioceptive discriminative stimuli would also be expected to change differentially in extinction after partial and continuous reinforcement. As responding becomes less frequent through the course of extinction, the stimulus correlates of responding also appear less frequently. If responding is under the discriminative control of such stimuli, this would result in a further weakening of responding. Transitions to extinction tend to result in the production of a wider range of response forms regardless of the maintaining schedule of reinforcement. If partial reinforcement results in discriminations under the control of a wider range of proprioceptive stimuli than does CRF, the stimuli correlated with the wider range of forms that appear in extinction would be more similar to those previously correlated with partial reinforcement than to those previously correlated with continuous reinforcement. Again, the result would be that partially-reinforced responding would appear to be more resistant to extinction, where extinction entails an unequal withdrawl of maintaining stimuli. Similarly, if partial reinforcement reduces or prevents the development of discriminative control by proprioceptive stimulation while such control develops more fully under CRF, anything that reduced the rates of responding equally under both schedules would remove more of the discriminative stimuli controlling continuously-reinforced responding, resulting in responding that appears to be weaker under the typical extinction procedure.

Schoenfeld (1950) contended that discrimination and response-based accounts of the partial reinforcement effect are logically equivalent. For Schoenfeld, the effect is based upon the fact that partial schedules reinforce more different response forms, and for discrimination theorists, it is based upon the greater diversity of stimuli that accompany such responses, along with other differences that result in an unequal change in stimulation in extinction. Despite the apparent logical equivalence of these accounts, Schoenfeld favored the response-based one because it "has at least the merit of standing on a variable that can be measured and experimentally manipulated in a direct way, while the notion of varying stimulus conditions is, so far, entirely presumptive" (Schoenfeld, 1950, p. 260 of 1968 republication). But while it is true that the range of response-produced stimuli cannot be manipulated independently of the range of responses that produce them, the discrimination account may provide a more coherent description of the results of Experiment 2, especially where subjects showed a difference in resistance to extinction in the absence of observed differences in ranges of forms.

Under both the stereotypy and variability contingencies, one or two response sequences were observed more often than any other; we will call such sequences "dominant" and those less frequently observed "non-dominant". Across conditions, there existed a difference in the context of reinforcement of dominant sequences. Under the variability contingency, the reinforcement of a dominant sequence only followed the production of a non-dominant sequence; it never followed the production of the dominant sequence. Most likely, under the stereotypy contingency the reinforcement of the dominant sequence more often followed upon the reinforcement of the dominant sequence. This could have produced a difference in the degree to which the stimuli that accompany non-dominant sequences evoke responding; for on 100% of occasions under the variability contingency, they had been part of the context in which the dominant sequence had been reinforced.

In extinction, responding tends to become less frequent and more varied in form. That is to say, in extinction non-dominant sequences appear with increasing frequency. The stimuli that accompany these non-dominant sequences should tend to evoke more dominant sequences after variability training, because in that condition dominant sequences had only been reinforced in their presence. As extinction progresses, more of the stimuli that have been discriminative of reinforcement under the variability contingency would be generated. That is, there would be a smaller decrement in evocative stimuli in extinction, and thus responding would appear to be stronger after variability training. This effect could be orthogonal to differences in ranges of response forms across conditions, and therefore it might account for the observation of resistance effects in the absence of reliable differences in form variability. The discriminative account would be consistent with the correlation observed between the nonreinforcement of redundant forms and the magnitude of difference in resistance to extinction.

While it is possible that the variability contingency resulted in a wider range of response-produced events being discriminative of reinforcement, it is also conceivable that the variability contingency retarded or prevented the development of proprioceptive stimulus control. Unlike the stereotypy contingency, the variability contingency could have prevented successive contiguous presentations of proprioceptive events and reinforcement, which might be important for the development of control by events that are already more diffuse than the more typical lights and tones. It would seem reasonable to expect, in general, weaker discriminative control when a wider range of events are differentially correlated with reinforcement. With respect to the loss of discriminative stimuli in extinction, the implications of weaker stimulus control by response-produced events would be similar to that of control by a wider range of events. Extinction results in fewer responses and a wider range of forms, so proprioceptive events that have been correlated with reinforcement are lost. But if proprioceptive events had never gained much discriminative control over responding, responding in extinction would not be much affected by their loss.

A third and final experiment tested whether the reinforcement of a wider range of forms enhanced resistance to extinction when reinforcement is not conditional upon making a response of different form. The procedure involved exposure to a single VI 60-sec schedule of food reinforcement for keypecking that was operative throughout each session. Keypecking was reinforced on this schedule in two stimulus contexts, which were independently operative for alternating 1-min time periods throughout daily sessions. In one condition only a single, yellow, center-mounted response key was illuminated and operative, and in the other condition only two red keys, mounted to either side of the yellow key, were illuminated and operative. When the red keys were illuminated, pecks to only one of them could produce reinforcement, and the operative key either changed or did not change after each red-key reinforcement, on a random basis. Thus, the procedure employed a VI 60-sec schedule with alternating (1 yellow-key, 2 red-key) stimulus presentations. It was expected that each of the keys would be pecked often, making the rates of reinforcement in both 1-key and 2-key situations approximately equal to the schedule value (i.e., 1 food per 60 sec on average). After 25 days of exposure to these conditions, a resistance to extinction test was conducted, during which alternating 1-min stimulus presentations continued but no food reinforcement was presented.

The procedure of Experiment 3 was similar to that of Experiment 2 in that it was designed to produce a difference in the number of reinforced response forms across conditions, in the absence of functional differences in rates of reinforcement across conditions. The procedures differed in that in the condition of Experiment 3 in which more response forms were expected (2-key), there was no requirement that a given response form must differ from the previously-reinforced response in order to produce food. In Experiment 3, the probability of reinforcement of any response form increased equally in the two conditions as a function of the time since the last response.

CHAPTER IV

EXPERIMENT 3

Subjects

Subjects were 5 adult male pigeons, similar in experience to the subjects that served in Experiments 1 and 2. They were individually housed and given continuous access to water and grit in their home cages, and they were maintained throughout the experiment at approximately 80% of their free-feeding weights.

Apparatus

A 3-key operant conditioning chamber was used, the interior dimensions of which differed somewhat from those of the chamber used in the first two experiments. The subjects' space was 50 cm long, 40 cm wide, and 38 cm high. Three translucent response keys were mounted 24 cm above the floor. The two outside keys were mounted 20 cm apart center to center, and could be illuminated with red light; a third key was centered between these and could be illuminated with yellow light. When lighted, a sufficiently forceful peck (minimum pressure .2 N) produced a brief click from a relay mounted behind the front wall of the chamber. An overhead houselight located on the ceiling near the front wall provided low-level illumination. Centered below the keys, 10 cm above the floor, was a rectangular opening that provided access to mixed grain when the food hopper was raised. At those times, the feeder opening was illuminated and the keylights and houselights were darkened. An externally mounted fan provided masking noise and ventilation.

Procedure

Because of the pigeons' prior experience, no particular pretraining was needed. Keypecks were reinforced with 4 sec of access to grain after the passage of variable time intervals averaging 1 min (VI 60 sec). The interval values were based on a constant probability progression (Fleshler and Hoffman, 1962). Depending on the condition, to be reinforced the pecks had to be directed to a single, center key, or to one of two outside keys. In one condition the center key was lighted yellow and pecks to it produced food at the end of an interval; the outside keys were dark and inoperative. In the other condition the outside keys were lighted red and the center key was dark and inoperative. The variable-interval timer ran constantly, without regard to condition, except during food presentations. Thus, on average, the rate of food availability was constant over conditions. To maintain pecking on each of the two red keys, food was made available at the end of each interval for a peck to only one of the two keys; the operative key position was determined on a random basis ($p = .5$) with each food presentation. Each of the two conditions (1-key or 2-keys) were operative for 1 min, regularly alternating periods throughout the experiment, again, independent of the VI schedule of food reinforcement.

Each of 25 daily sessions began with the chamber and keylights dark. Then one of the two stimulus contexts was presented, based on a random selection; conditions then alternated regularly. Sessions continued until 40 or 60 reinforcers were presented, depending on the subjects' weights. The chamber was dark after the final food presentation. The 26th session was a test of resistance to extinction. The session began as usual, but after the 16th reinforcement, no more food was presented. Alternating, 1-min exposures to the two conditions continued until 10 min (5 min of exposure to each condition) elapsed without a response.

Results and Discussion

The response rates in the 1-key condition closely approximated the combined (left-key and right-key) rates in the 2-key (concurrent) context. Thus, the rates of reinforcement in the concurrent and single-key situations were also closely approximated. The results of the resistance-to-extinction tests are presented in Figure 6. Responding in the single-key (crosses) and concurrent (squares) contexts is expressed as a proportion of the baseline response rates during successive 5-min blocks of extinction time. The baseline rates were calculated by averaging the response rates over the 5 sessions preceding the extinction tests.

The weighted mean proportions of baseline response rates, p, are also presented in Figure 6. Because the rates of responding of several subjects were higher over some portion of extinction time than they were at baseline, the p statistic is probably a less reliable index of differential resistance in the present experiment than it was in the previous experiments. The statistic is based on the assumption that rates will generally be lower as extinction progresses. On the basis of p, 4 subjects showed more resistant responding in the concurrent condition and 1 subject showed stronger responding in the single-key condition. However, a visual scan of the data reveals that response rates tended to change at similar rates in the two conditions, with only subject 3B showing consistently stronger behavior in the concurrent context. Thus, when a difference in resistance to extinction was obtained in Experiment 3, responding appeared to be stronger after the reinforcement of a larger range of forms than after the reinforcement of a smaller range of forms. But in the majority of cases responding appeared to be equally resistant to extinction in the two conditions.

The results seem different from those obtained in Experiment 2. In Experiment 2 there were probable differences in the context of reinforcement of the most probable (dominant) sequences. Across the conditions of Experiment 3 the differential basis for the development of response-produced stimulus control seemed smaller, and reliable differences in resistance to extinction were not obtained. This might be taken as evidence that the differences in resistance to extinction in Experiment 2 were not due to the manipulation of ranges of response forms *per se*, but to correlated differences in discriminative control by response-produced stimuli and subsequent differences in the frequency of occurrence of relevant discriminative stimuli in extinction.

Alternatively, it might be argued that reliable differences in resistance to extinction were obtained in Experiment 2 but not in Experiment 3 because in the former study, where differences in ranges of response forms across conditions were obtained, they were larger than those obtained in Experiment 3. In other words, increasing the range of reinforced response forms might generally enhance resistance to extinction, but such differences must be larger than those produced in Experiment 3. But to maintain Schoenfeld's response-forms account of the paradoxical partial reinforcement effect which is typically observed with responding on a single key, one would have to argue that partial versus continuous reinforcement produces a larger difference in the ranges of single-key responding than were produced across the comparison conditions (single versus concurrent) of Experiment 3. To me this seems possible but improbable.

Taken together, the results of the present series of experiments support a view that while partial schedules tend to reinforce a wider range of response forms than continuous schedules, that difference makes, at best, a contribution to resistance to extinction that is not robust. Generally, more frequent reinforcement produces responding that is more resistant to extinction than less frequent reinforcement, whether the richer schedule is a richer partial schedule or CRF. Nevin (1987) has reached a similar conclusion from an extensive review of the partial reinforcement literature. Where observed, paradoxical effects of partial schedules would appear to reflect their impact on the development of discriminations of response-produced and temporal stimuli, not on the strength of responding *per se*.

As was noted in the introduction, the textbook version of the "paradoxical" partial reinforcement effect is often cited in analyzing clinical cases that might otherwise appear to be difficult to understand from a behavioral perspective. Appeal is made to this phenomenon in cases where what would seem to be the reinforcers of a problematic behavior pattern appear infrequently, yet the behavior is highly persistent. In such cases it is pointed out that infrequent reinforcement sometimes makes behavior more resistant to extinction than more frequent reinforcement. Many of these cases can be understood in behavioral terms without recourse to schedule effects through a closer examination of the many possible consequences of complex behaviors; the wagering of the pathological gambler, for example, is followed by many events other than the occasional monetary payoff. The present analysis indicates that "partial reinforcement effect" is a poor description of the relevant factors in any case, even when appeal to schedule effects is more appropriate.

Where observed, the paradoxical effect seems to be a discriminative phenomenon (see also Amsel, 1962; Capaldi, 1967; Keller and Schoenfeld, 1950; Skinner, 1938). To the extent that infrequent reinforcement increases the probability that success will follow failure, it should increase the evocative power of events associated with failure. To the same extent, it should decrease the evocative power of events associated with success. When success is no longer forthcoming, responding will persist because its evocative context is retained. Thus behavior should be persistent to the extent that it is evoked by failure. When its cause is hopeless we call the persistence pathological or eccentric; when it is not, the persistence reveals industry or courage. To the extent that the evocative events are redundant and the behavior evoked is novel, we are likely to call the persistent responding creative. A focus on the relation between reinforcement contingencies and response-produced contextual events might reveal a common mechanism underlying the otherwise paradoxical persistence often shared by artists and scientists and madmen.

Table 1

REINFORCEMENT SCHEDULE

Subject	CRF	VI 15	VI 30	VI 60	VI 30	TOTAL
1A	20	2	2	7	-	31
1B	13	3	2	2	5	33
1C	21	3	2	2	5	33
1D	20	3	2	2	6	33
1E	15	3	2	2	5	27
1F	15	2	2	2	6	27

TABLE 2

Subject	INTERFOOD TIME and RATIO			$\left(\frac{\text{EVEN SEQUENCES PER MINUTE}}{\text{SEQUENCES PER MINUTE}} \right)$ = RATIO	
	VI	CRF		VI	CRF
1A	73s	9s	8.1:1	$\frac{3.7}{9.0}=.41$	$\frac{6.7}{12.6}=.53$
1E	41s	10s	4:1	$\frac{4.6}{11.7}=.39$	$\frac{5.8}{13.7}=.42$
1B	38s	10s	3.9:1	$\frac{5.1}{10.9}=.47$	$\frac{6.2}{12.2}=.51$
1D	59s	16s	3.8:1	$\frac{2.2}{6.5}=.34$	$\frac{3.6}{8.4}=.43$
1C	40s	12s	3.3:1	$\frac{3.1}{7.1}=.44$	$\frac{4.8}{8.2}=.59$
1F	46s	22s	2.2:1	$\frac{2.3}{6.0}=.38$	$\frac{2.9}{7.3}=.40$

TABLE 3

Subject	VI	CRF
1A	.48 u=.967	.70 u=.854
1E	.70 u=.945	.63 u=.926
1B	.58 u=.878	.77 u=.803
1D	.42 u=.979	.48 u=.963
1C	.60 u=.912	.88 u=.675
1F	.50 u=.986	.58 u=.957
MEANS	.55 u=.945	.67 u=.863

Table 4

	KEYPECKS		SEQUENCES		EVEN SEQUENCES		$\left(\frac{\text{EVEN SEQUENCES PER MINUTE}}{\text{SEQUENCES PER MINUTE}}\right)$ =RATIO	
Subject	VI	CRF	VI	CRF	VI	CRF	VI	CRF
1A	805	1487	144	255	56	131	.75 3.4=.22	3.1 6.1=.51
1E	1442	1933	264	339	82	152	2.1 6.8=.31	3.9 8.7=.45
1B	307	686	54	125	21	37	.70 1.7=.39	1.2 3.9=.31
1D	702	1056	129	272	49	90	1.5 3.9=.38	2.7 8.2=.32
1C	1643	1890	348	328	53	169	1.2 7.7=.16	3.8 7.2=.53
1F	588	608	116	114	24	28	.73 3.5=.21	.85 3.5=.24

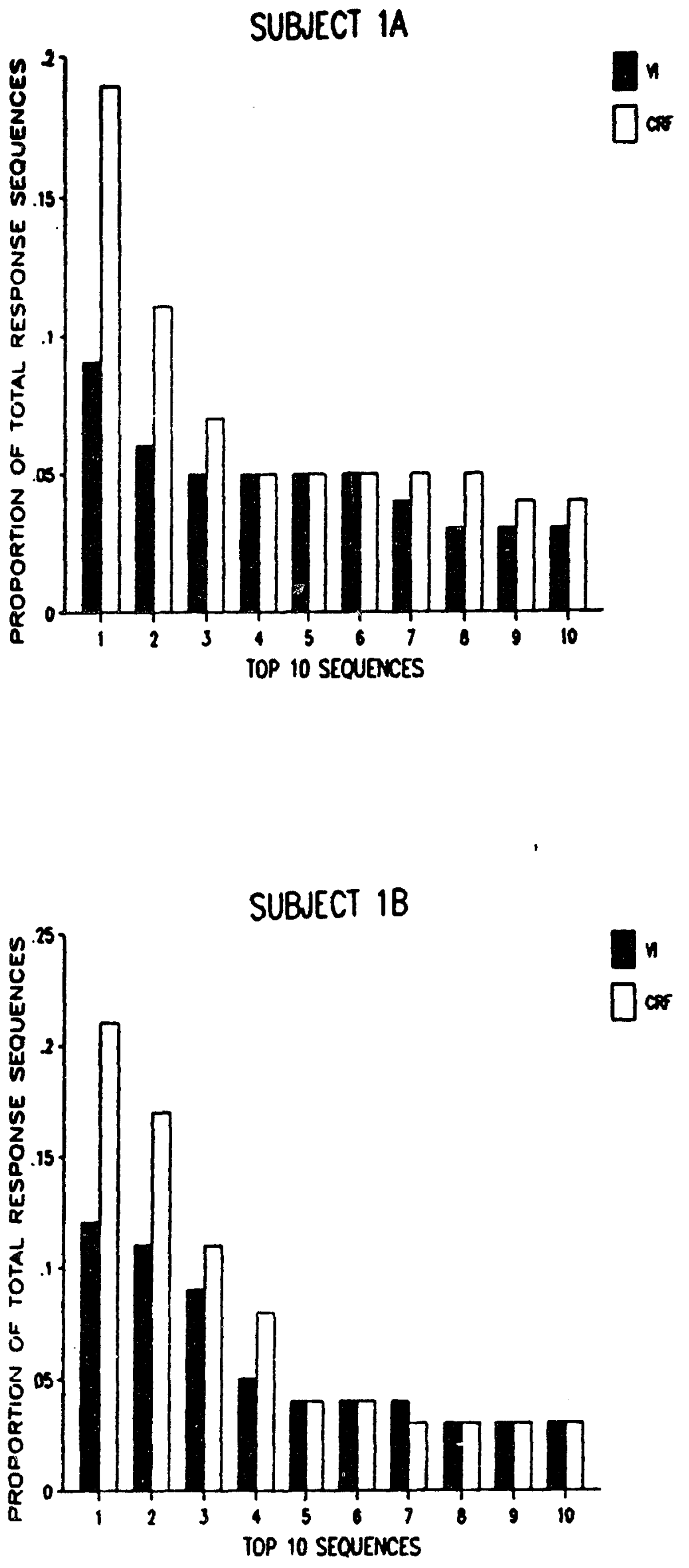
TABLE 5

	INTERFOOD TIME AND RATIO		SEQUENCES PER FOOD AND RATIO		$\frac{\text{EVEN SEQUENCES PER MINUTE}}{\text{SEQUENCES PER MINUTE}}$ = RATIO	
Subject	V	S	V	S	V	S
2A	27 s	48 s	2.4	4.0	$\frac{2.8}{5.7}$ =.49	$\frac{2.1}{5.0}$ =.42
	1:1.8		1:1.7			
2C	29 s	44 s	4.0	5.9	$\frac{2.8}{8.2}$ =.34	$\frac{3.0}{8.2}$ =.36
	1:1.5		1:1.5			
2D	25 s	36 s	4.3	5.7	$\frac{4.2}{10.2}$ =.41	$\frac{3.6}{9.6}$ =.38
	1:1.4		1:1.3			
2F	44 s	59 s	5.7	8.7	$\frac{2.7}{8.6}$ =.31	$\frac{2.9}{8.3}$ =.35
	1:1.4		1:1.5			
2B	29 s	37 s	3.2	4.9	$\frac{2.7}{6.9}$ =.39	$\frac{3.5}{7.8}$ =.45
	1:1.3		1:1.5			
2E	31 s	35 s	3.2	4.4	$\frac{3.2}{7.0}$ =.46	$\frac{3.4}{6.9}$ =.49
	1:1.1		1:1.4			

TABLE 6

Subject	VARIABILITY	STEREOTYPY
2A	.49 u =.958	.68 u =.949
2C	.59 u =.955	.63 u =.966
2D	.73 u =.955	.95 u =.824
2F	.84 u =.907	.94 u =.798
2B	.39 u =.977	.41 u =.966
2E	.69 u =.912	.67 u =.899
MEANS	.62 u =.944	.71 u=.901

Figure 1



SUBJECT 1A

SUBJECT 1B

Figure 1

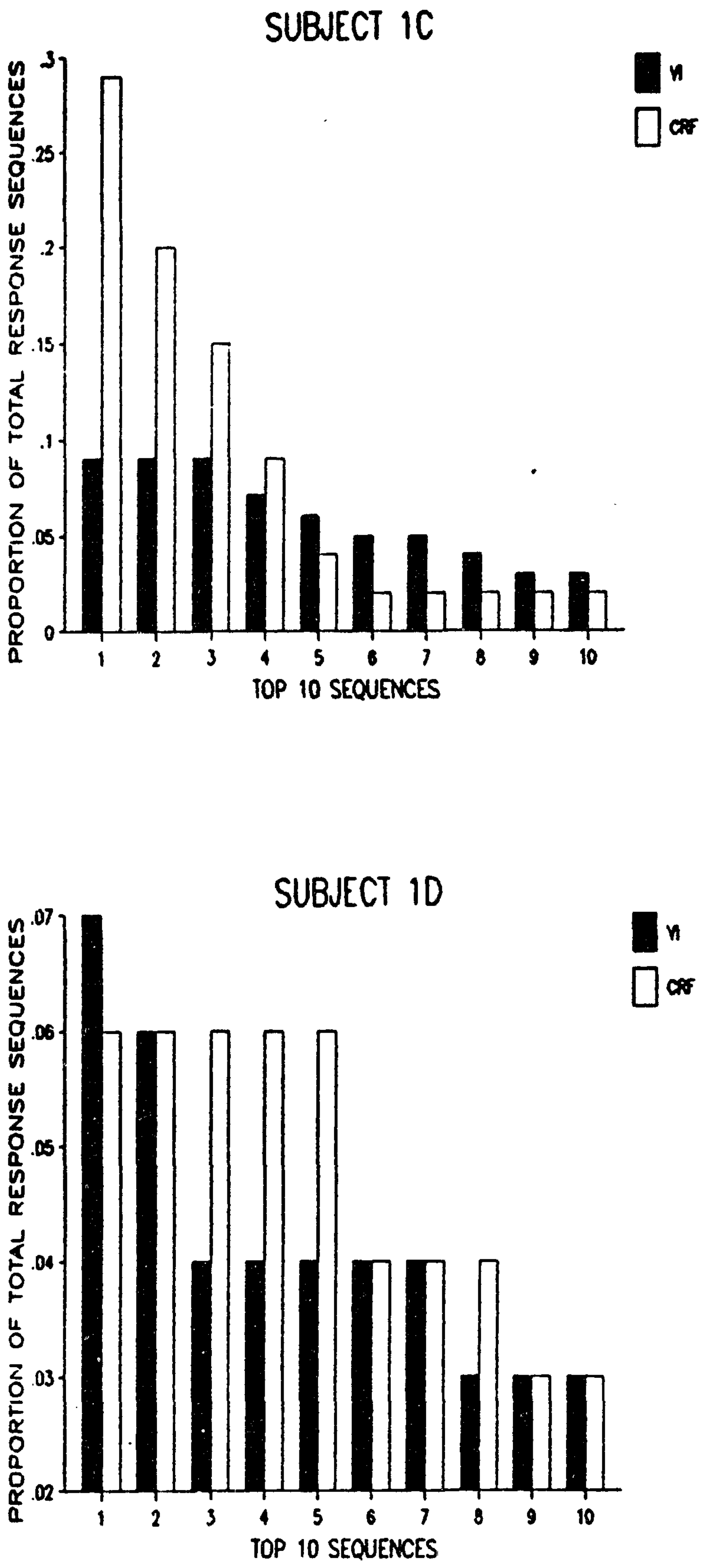
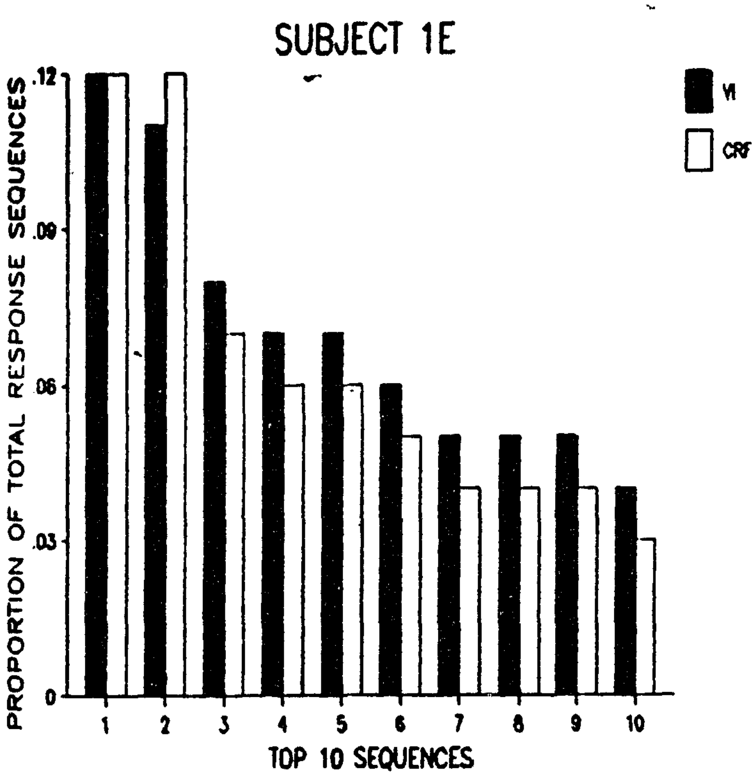

SUBJECT 1C
VI
CRF
PROPORTION OF TOTAL RESPONSE SEQUENCES
.3
.25
.2
.15
.1
.05
0
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES
SUBJECT 1D
VI
CRF
PROPORTION OF TOTAL RESPONSE SEQUENCES
.07
.06
.05
.04
.03
.02
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES

Figure 1


SUBJECT 1E

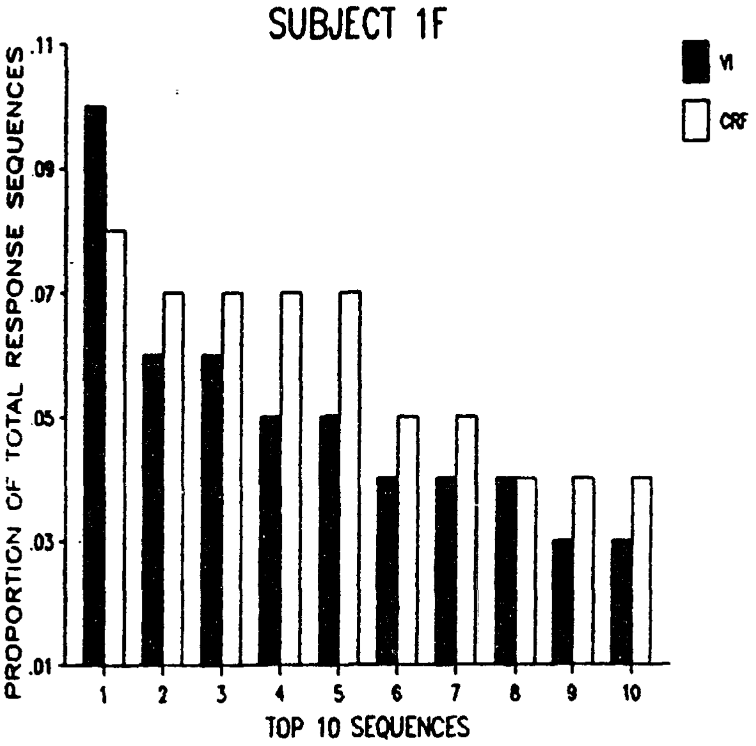

SUBJECT 1F

Figure 2

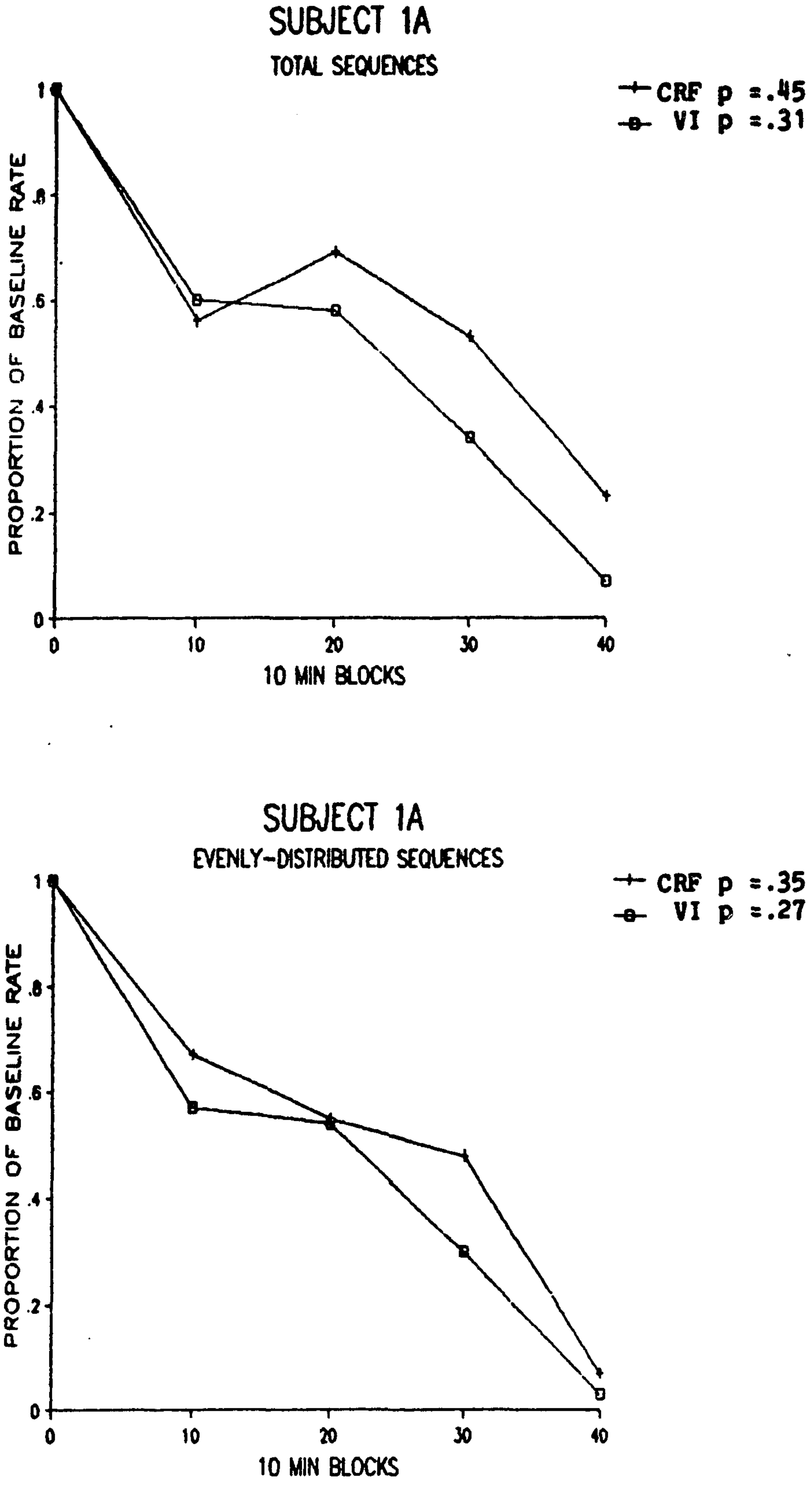

SUBJECT 1A
TOTAL SEQUENCES
CRF p =.45
VI p =.31
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
40
10 MIN BLOCKS
SUBJECT 1A
EVENLY-DISTRIBUTED SEQUENCES
CRF p =.35
VI p =.27
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
40
10 MIN BLOCKS

Figure 2

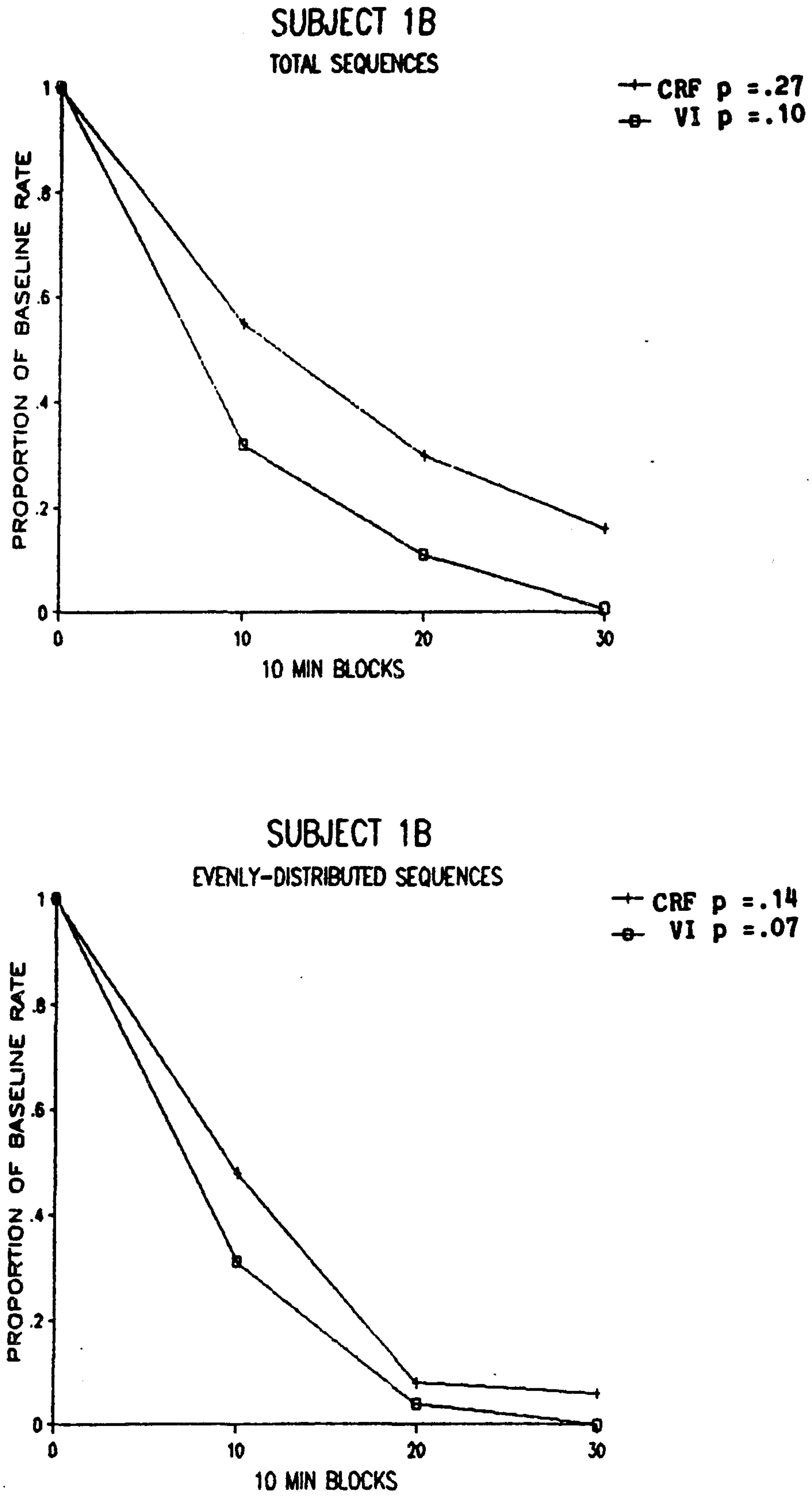
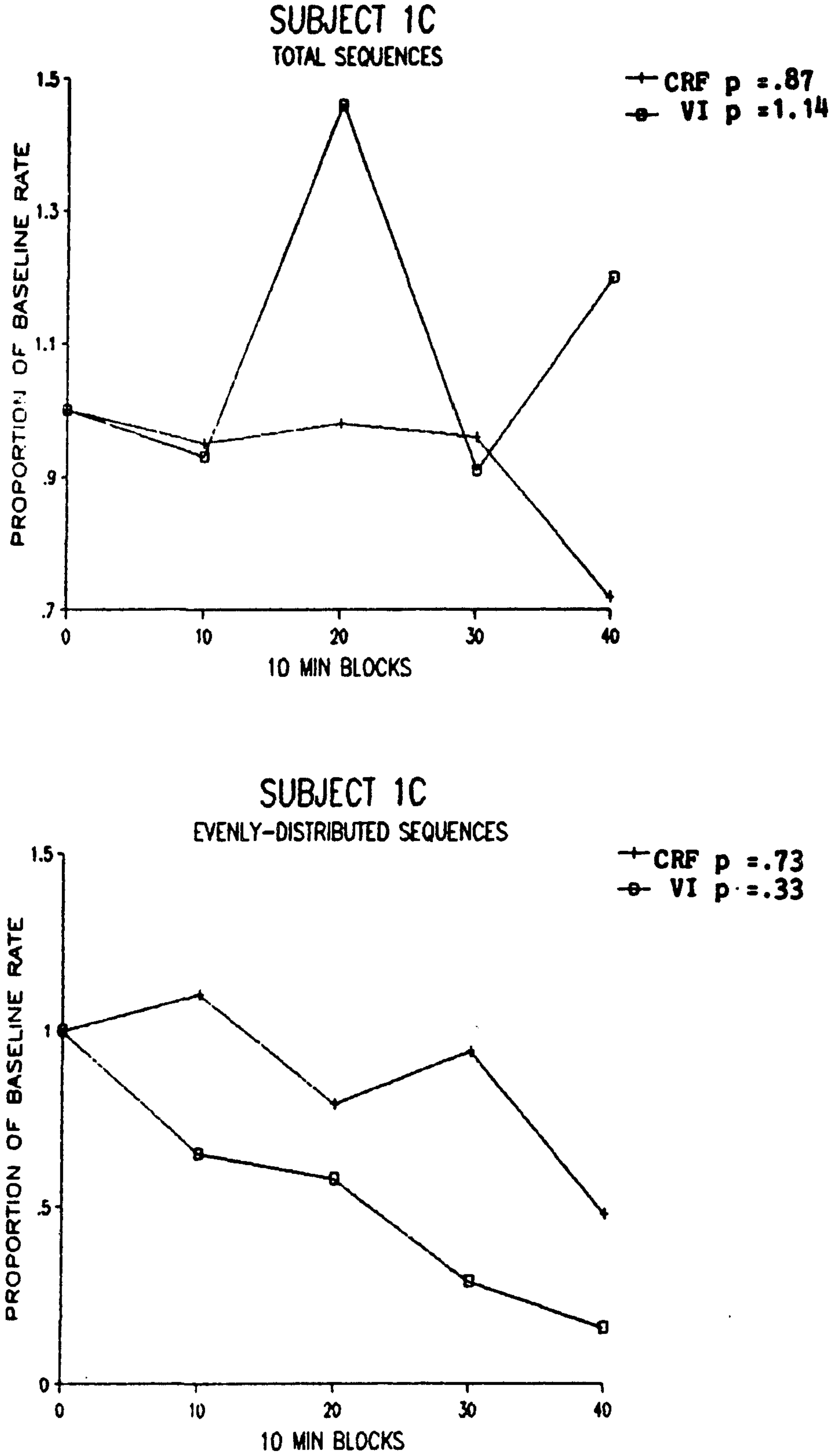

SUBJECT 1B
TOTAL SEQUENCES
CRF p =.27
VI p =.10
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
10 MIN BLOCKS
SUBJECT 1B
EVENLY-DISTRIBUTED SEQUENCES
CRF p =.14
VI p =.07
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
10 MIN BLOCKS

Figure 2



SUBJECT 1C
TOTAL SEQUENCES

SUBJECT 1C
EVENLY-DISTRIBUTED SEQUENCES

Figure 2

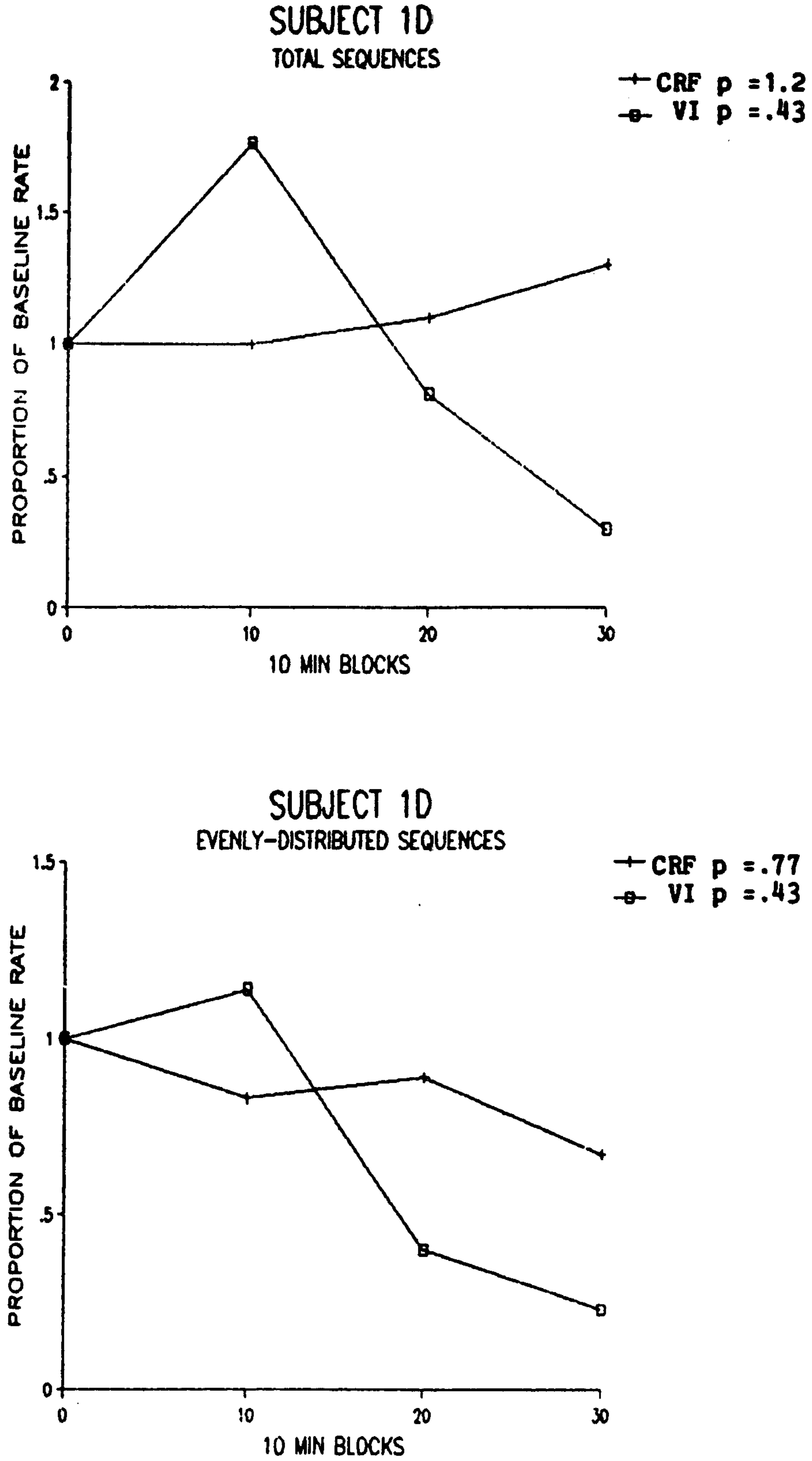
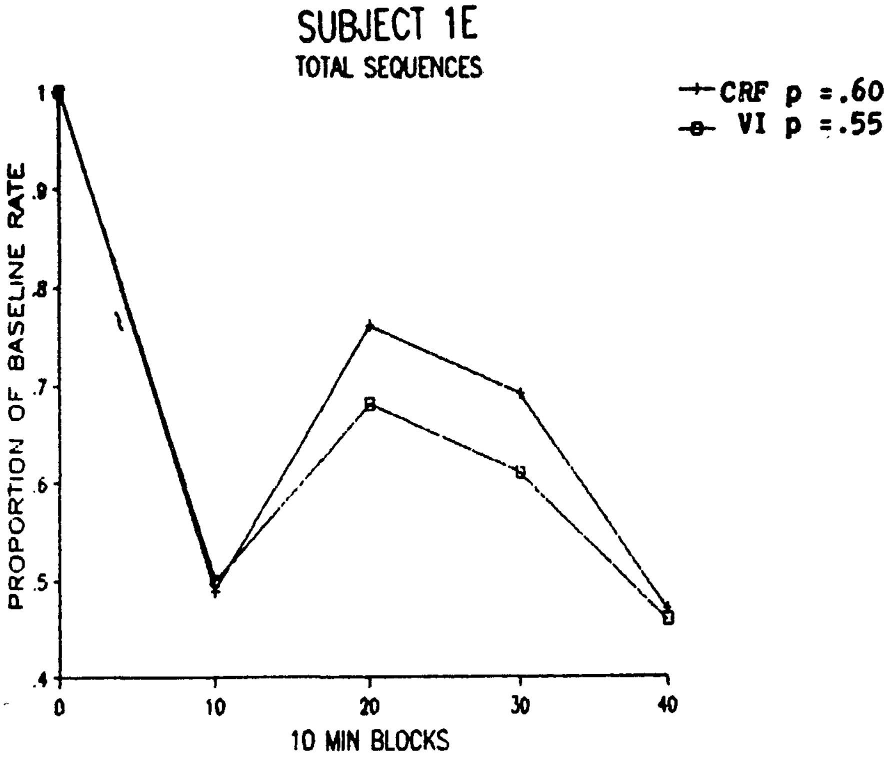

SUBJECT 1D
TOTAL SEQUENCES
CRF p =1.2
VI p =.43
PROPORTION OF BASELINE RATE
2
1.5
1
.5
0
0
10
20
30
10 MIN BLOCKS
SUBJECT 1D
EVENLY-DISTRIBUTED SEQUENCES
CRF p =.77
VI p =.43
PROPORTION OF BASELINE RATE
1.5
1
.5
0
0
10
20
30
10 MIN BLOCKS

Figure 2


SUBJECT 1E
TOTAL SEQUENCES
CRF p =.60
VI p =.55
PROPORTION OF BASELINE RATE
1
.9
.8
.7
.6
.5
.4
0
10
20
30
40
10 MIN BLOCKS

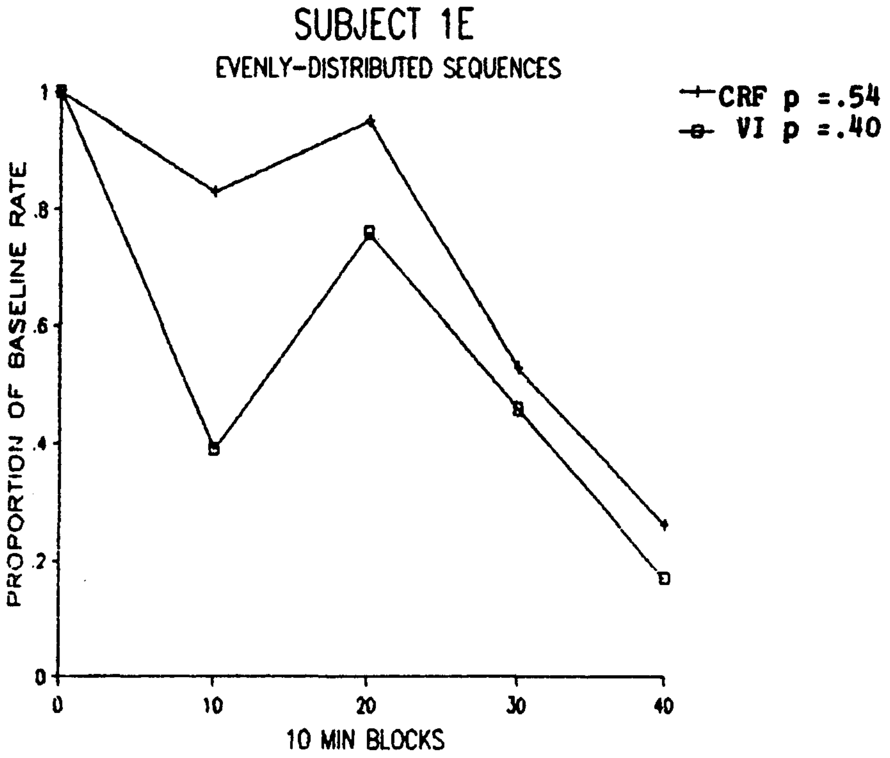
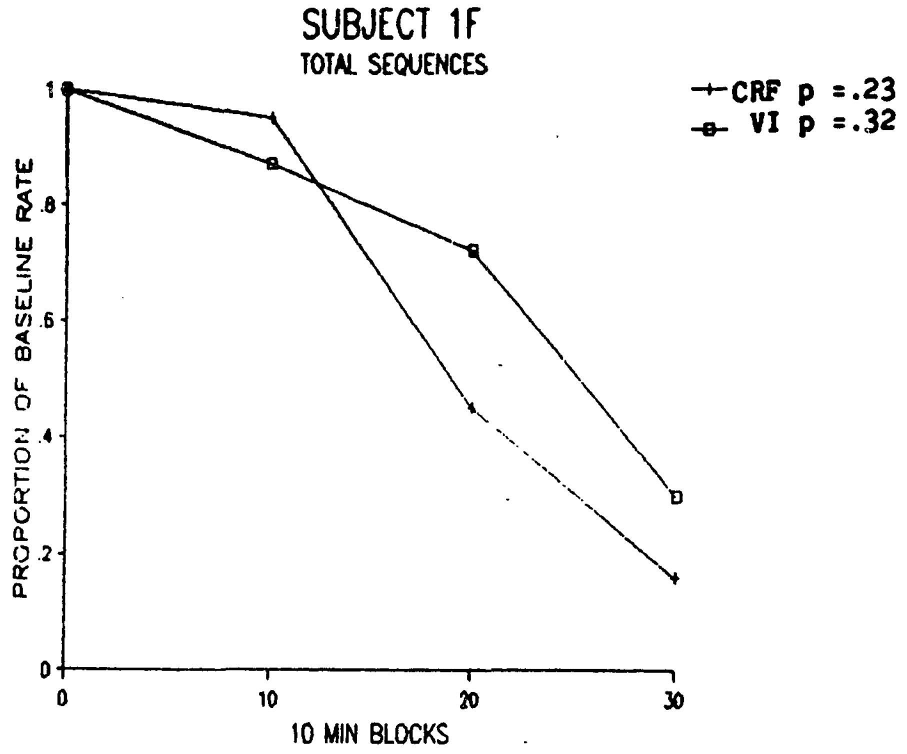
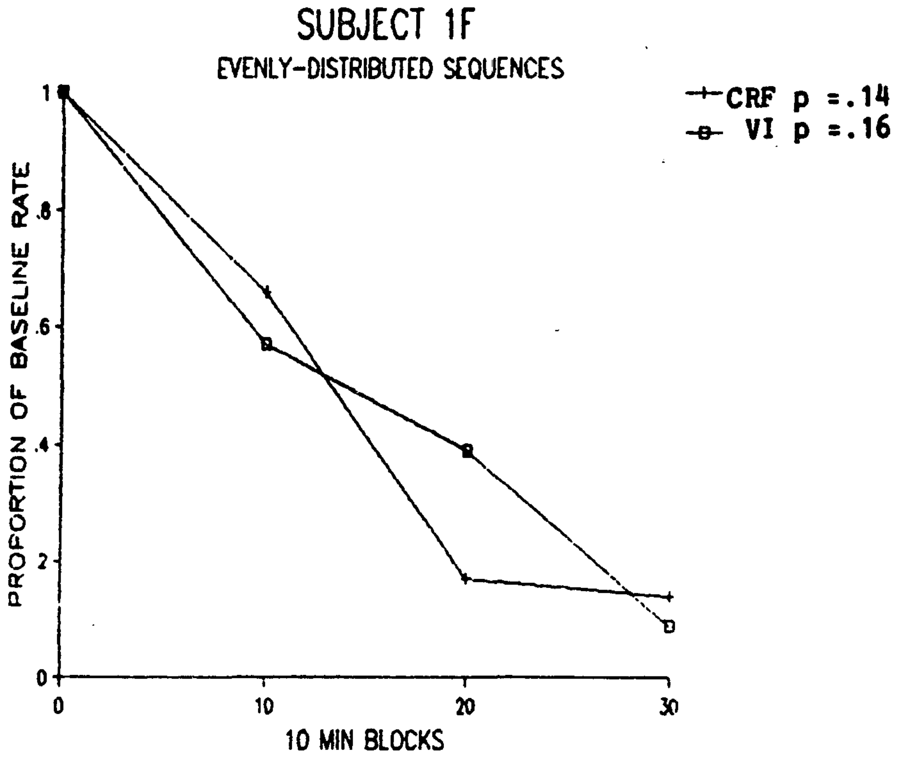

SUBJECT 1E
EVENLY-DISTRIBUTED SEQUENCES
CRF p =.54
VI p =.40
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
40
10 MIN BLOCKS

Figure 2



SUBJECT 1F

TOTAL SEQUENCES



SUBJECT 1F

EVENLY-DISTRIBUTED SEQUENCES

Figure 3

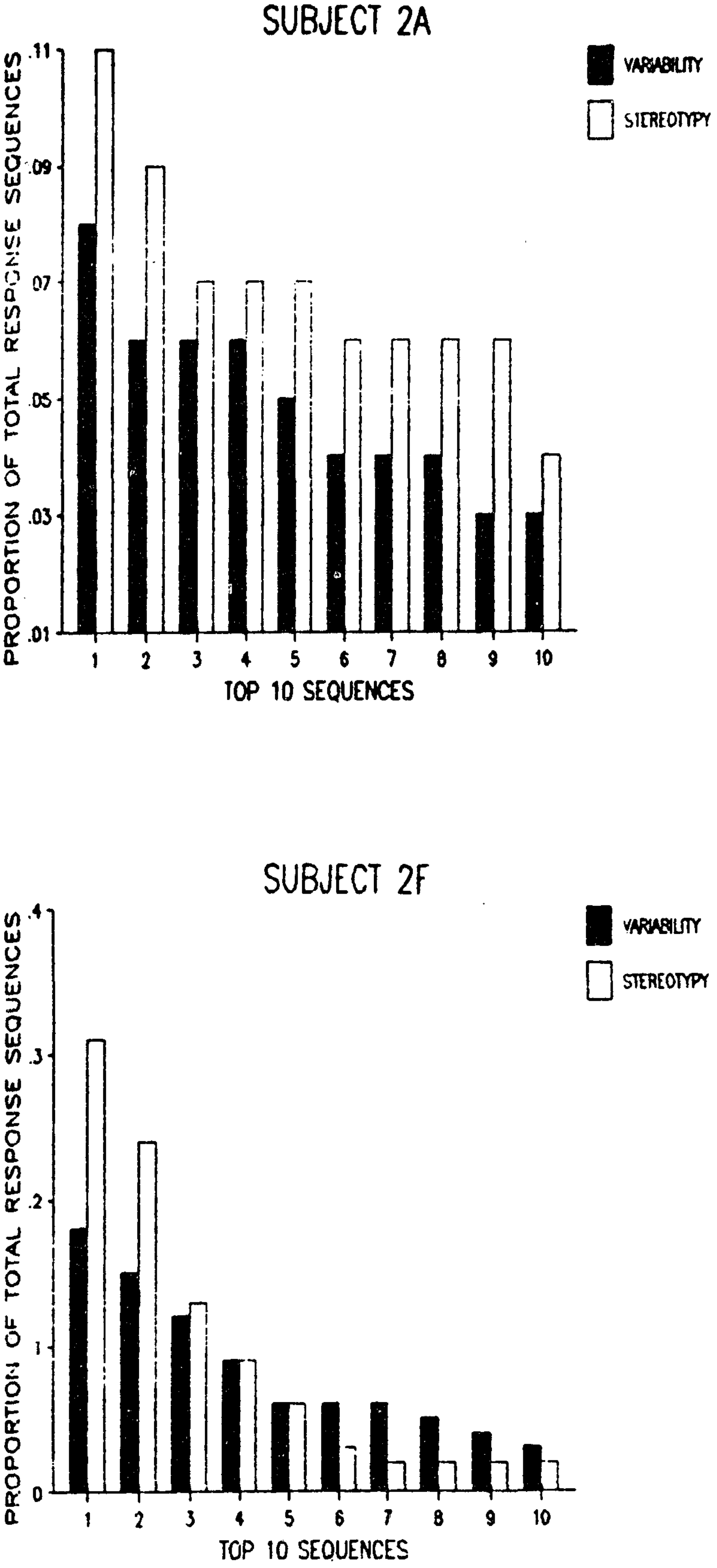

SUBJECT 2A
PROPORTION OF TOTAL RESPONSE SEQUENCES
.11
.09
.07
.05
.03
.01
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES
VARIABILITY
STEREOTYPY
SUBJECT 2F
PROPORTION OF TOTAL RESPONSE SEQUENCES
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES
VARIABILITY
STEREOTYPY

Figure 3

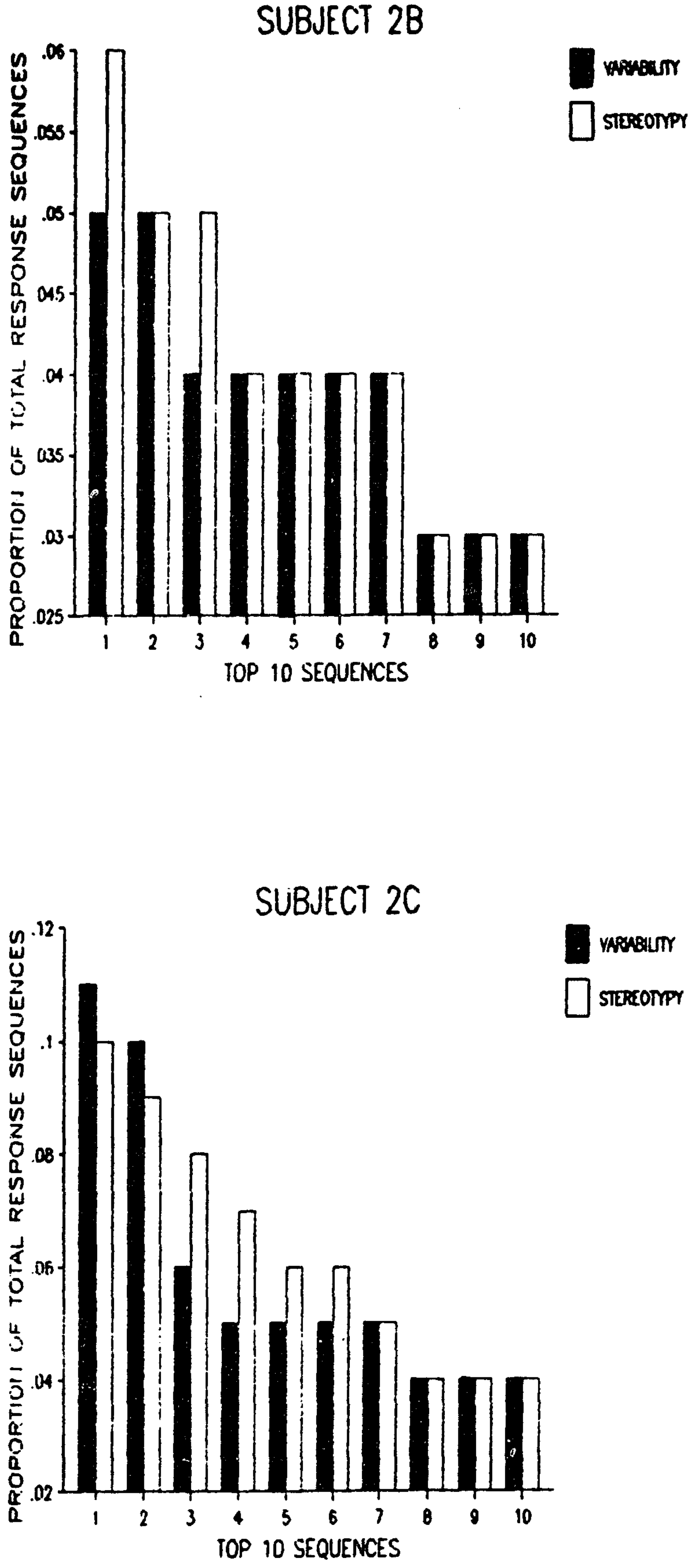
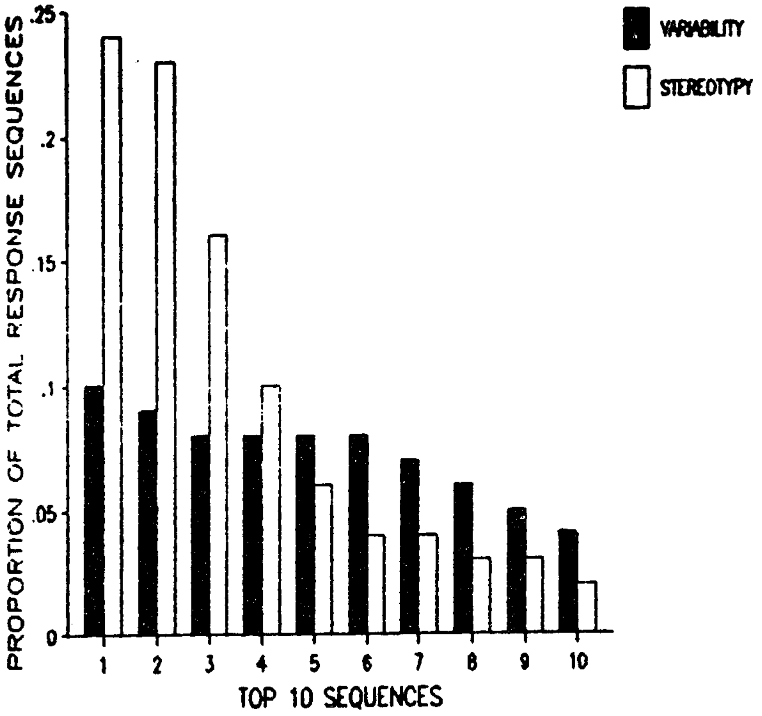
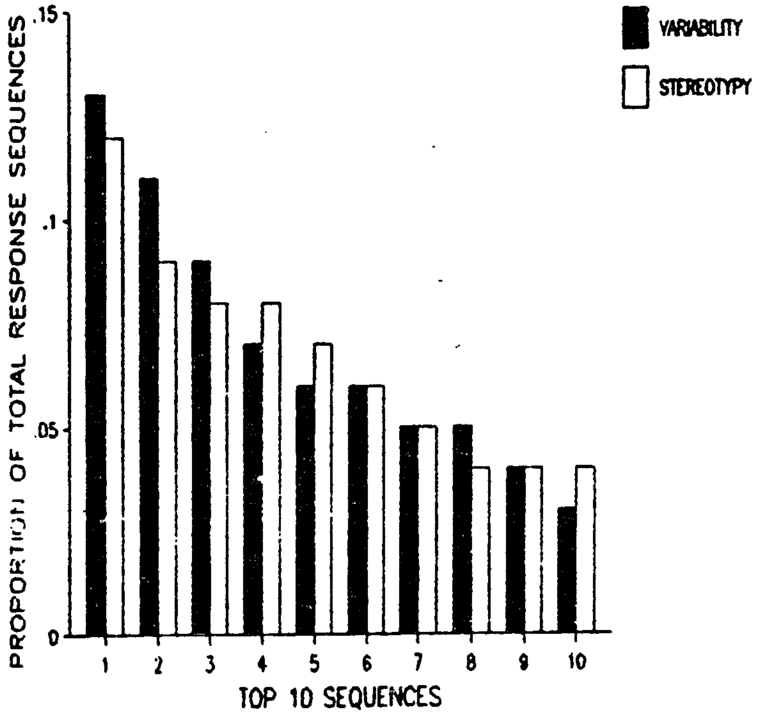

SUBJECT 2B
PROPORTION OF TOTAL RESPONSE SEQUENCES
.06
.055
.05
.045
.04
.035
.03
.025
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES
VARIABILITY
STEREOTYPY
SUBJECT 2C
PROPORTION OF TOTAL RESPONSE SEQUENCES
.12
.1
.08
.06
.04
.02
1
2
3
4
5
6
7
8
9
10
TOP 10 SEQUENCES
VARIABILITY
STEREOTYPY

Figure 3

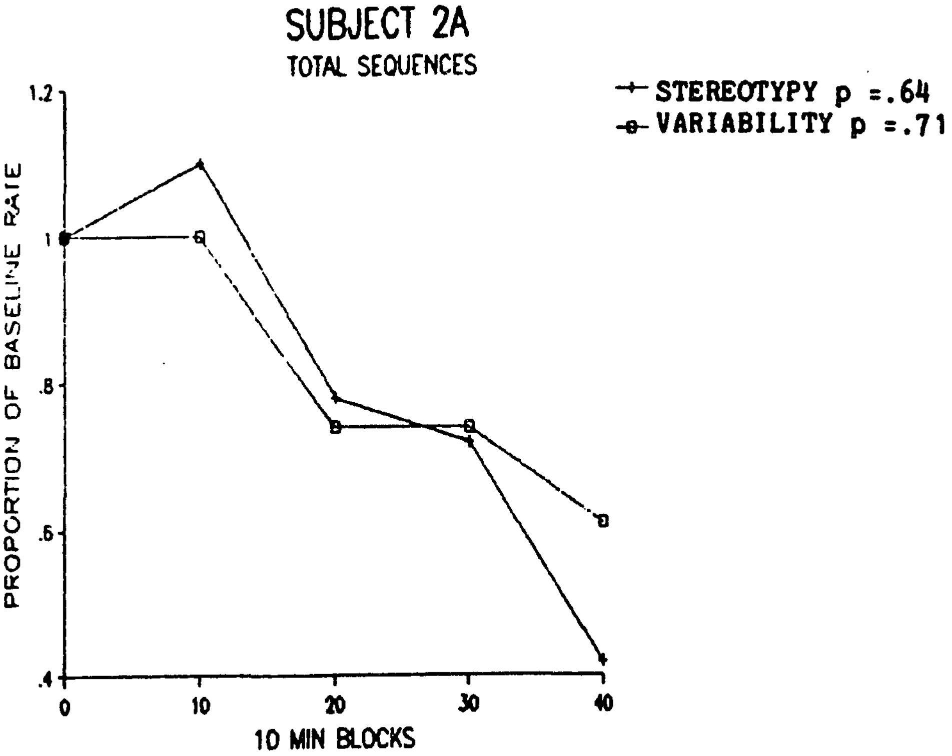


SUBJECT 2D



SUBJECT 2E

Figure 4


SUBJECT 2A
TOTAL SEQUENCES
STEREOTYPY p =.64
VARIABILITY p =.71
PROPORTION OF BASELINE RATE
1.2
1
.8
.6
.4
0
10
20
30
40
10 MIN BLOCKS

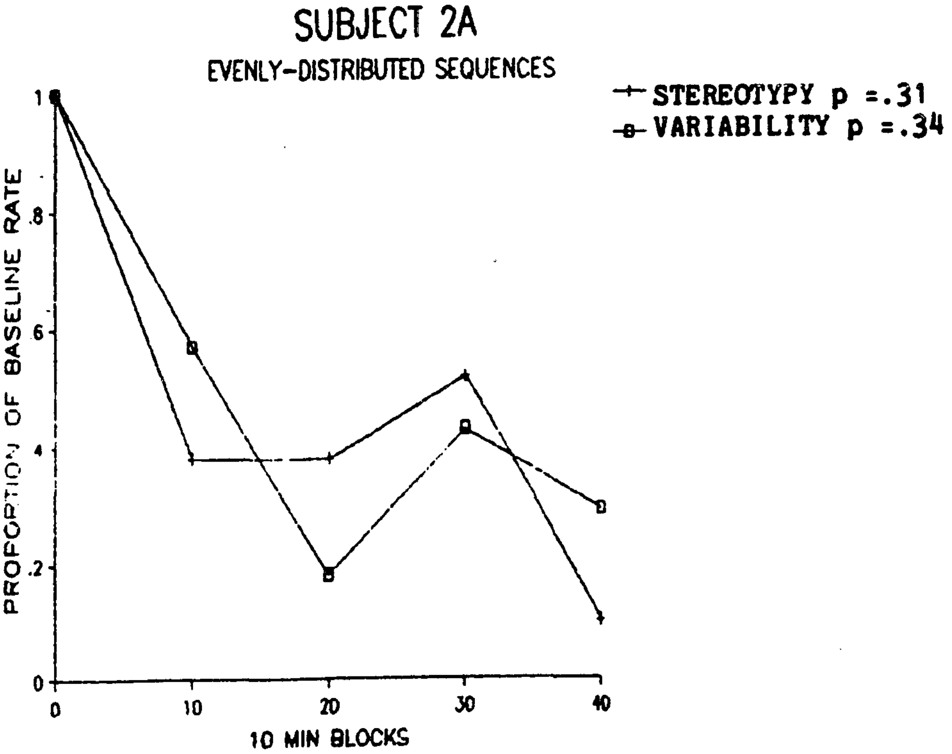
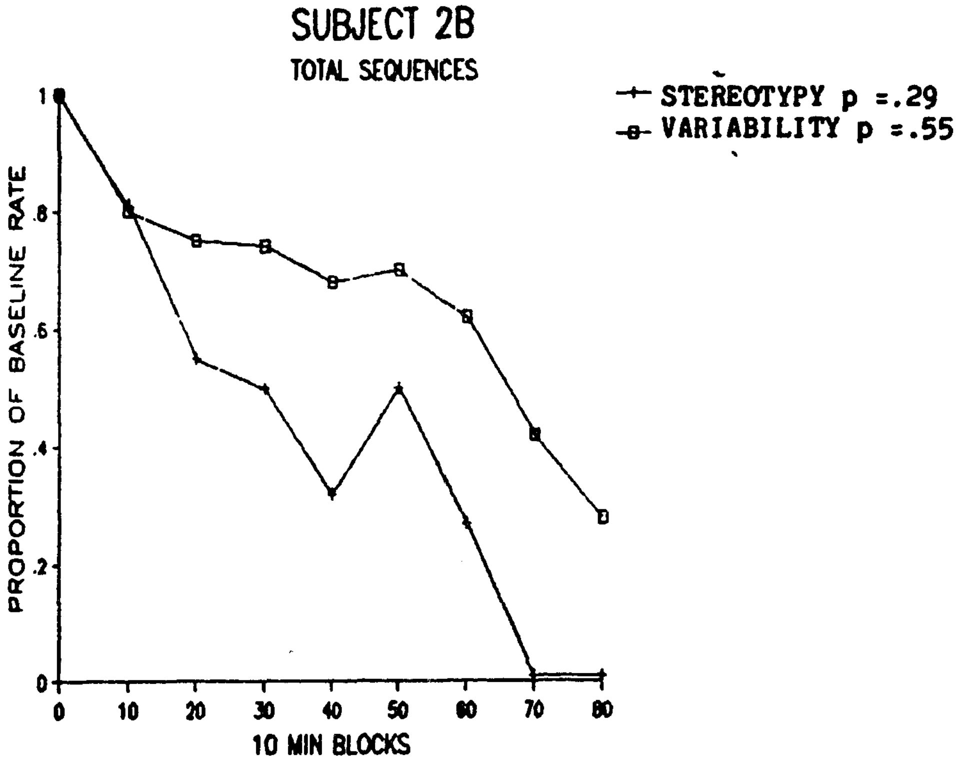
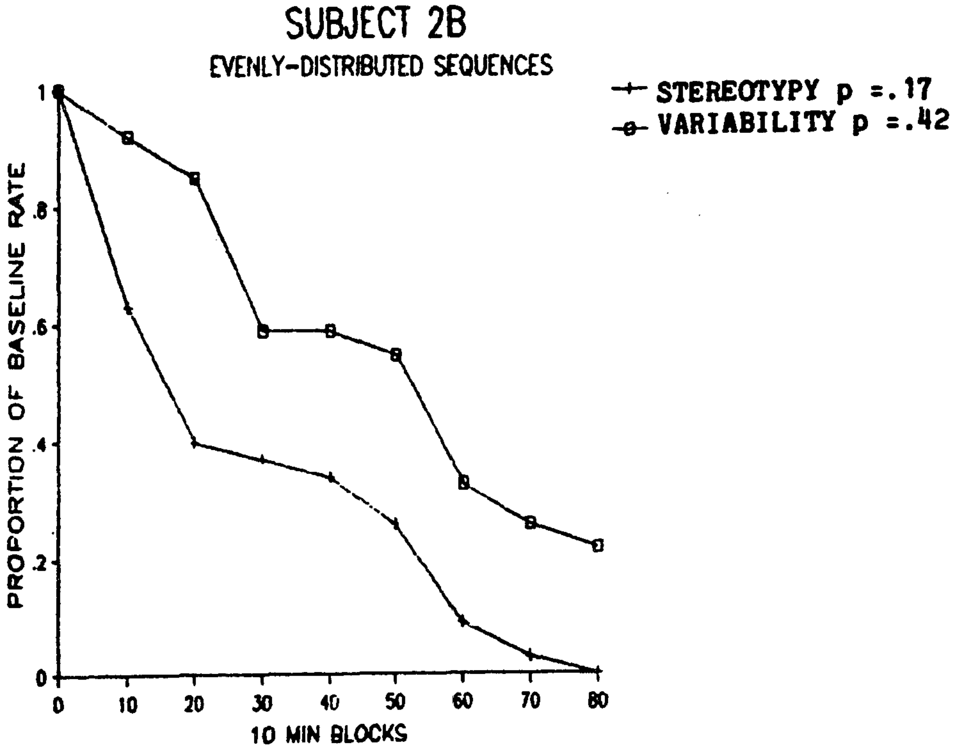

SUBJECT 2A
EVENLY-DISTRIBUTED SEQUENCES
STEREOTYPY p =.31
VARIABILITY p =.34
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
40
10 MIN BLOCKS

Figure 4



SUBJECT 2B

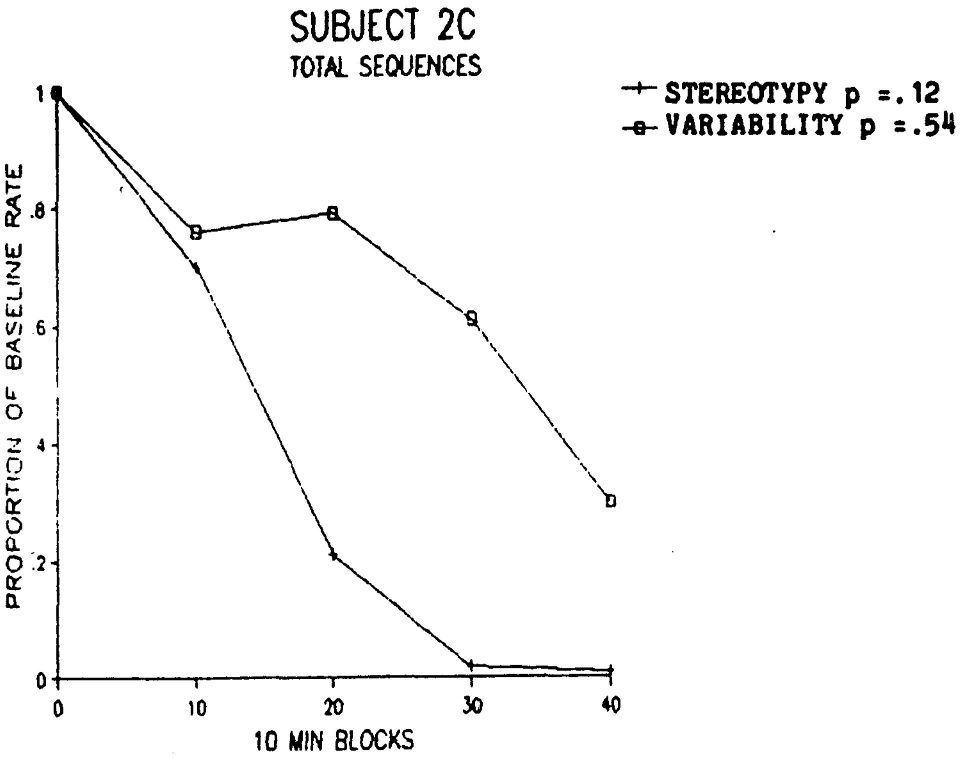
TOTAL SEQUENCES



SUBJECT 2B

EVENLY-DISTRIBUTED SEQUENCES

Figure 4


SUBJECT 2C
TOTAL SEQUENCES

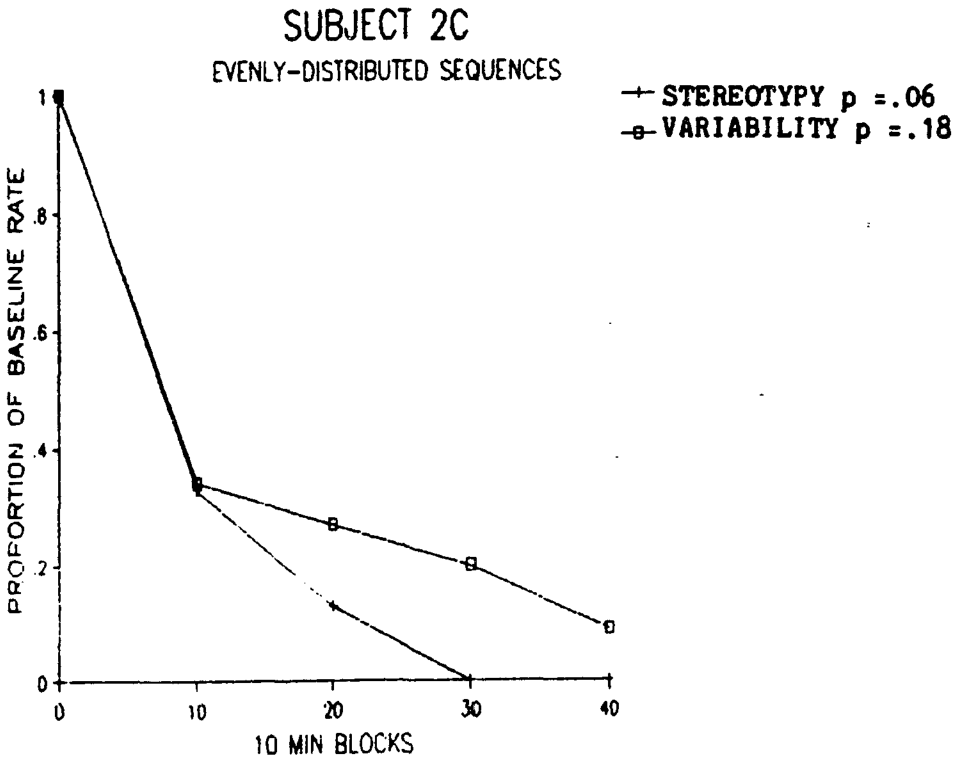
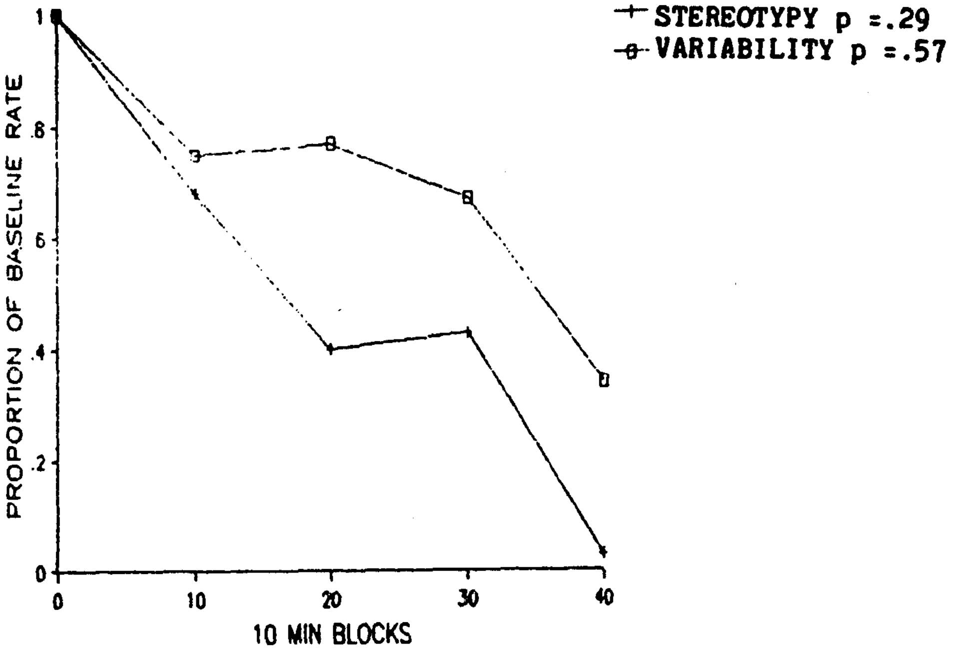

SUBJECT 2C
EVENLY-DISTRIBUTED SEQUENCES

Figure 4


SUBJECT 2D
TOTAL SEQUENCES

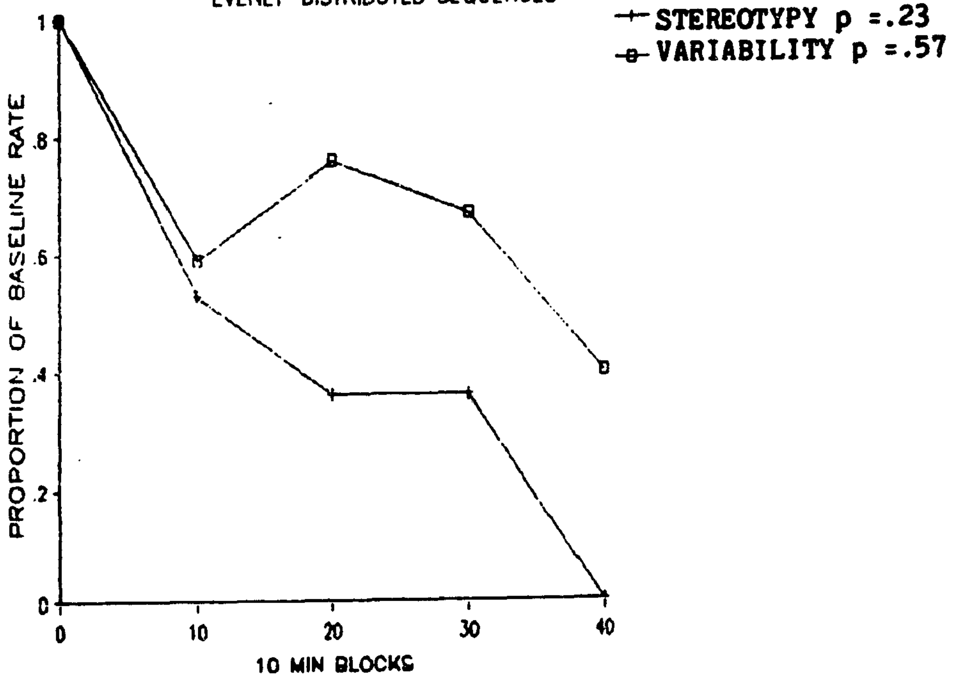

SUBJECT 2D
EVENLY-DISTRIBUTED SEQUENCES

Figure 4

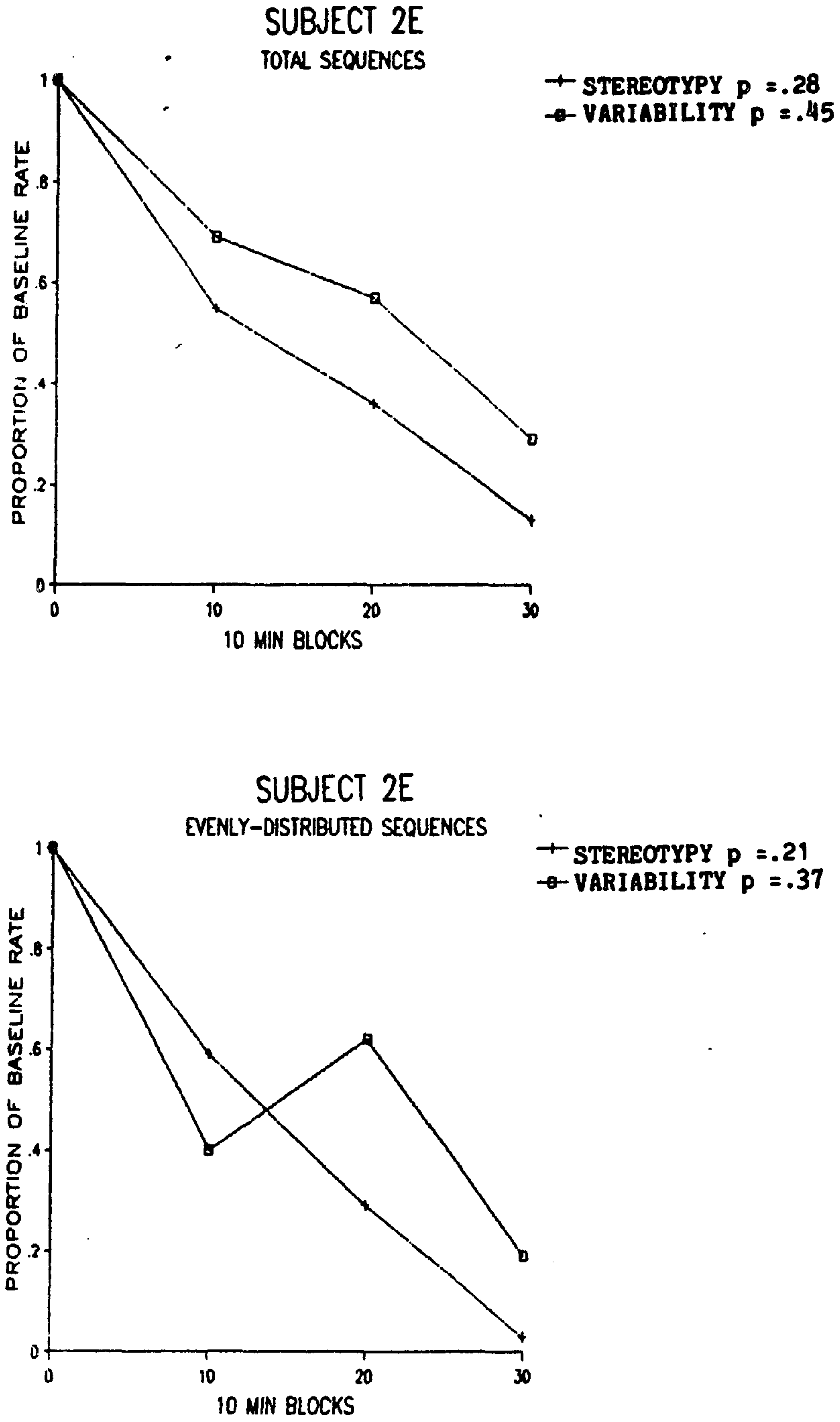

SUBJECT 2E
TOTAL SEQUENCES
STEREOTYPY p =.28
VARIABILITY p =.45
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
10 MIN BLOCKS
SUBJECT 2E
EVENLY-DISTRIBUTED SEQUENCES
STEREOTYPY p =.21
VARIABILITY p =.37
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
10
20
30
10 MIN BLOCKS

Figure 4

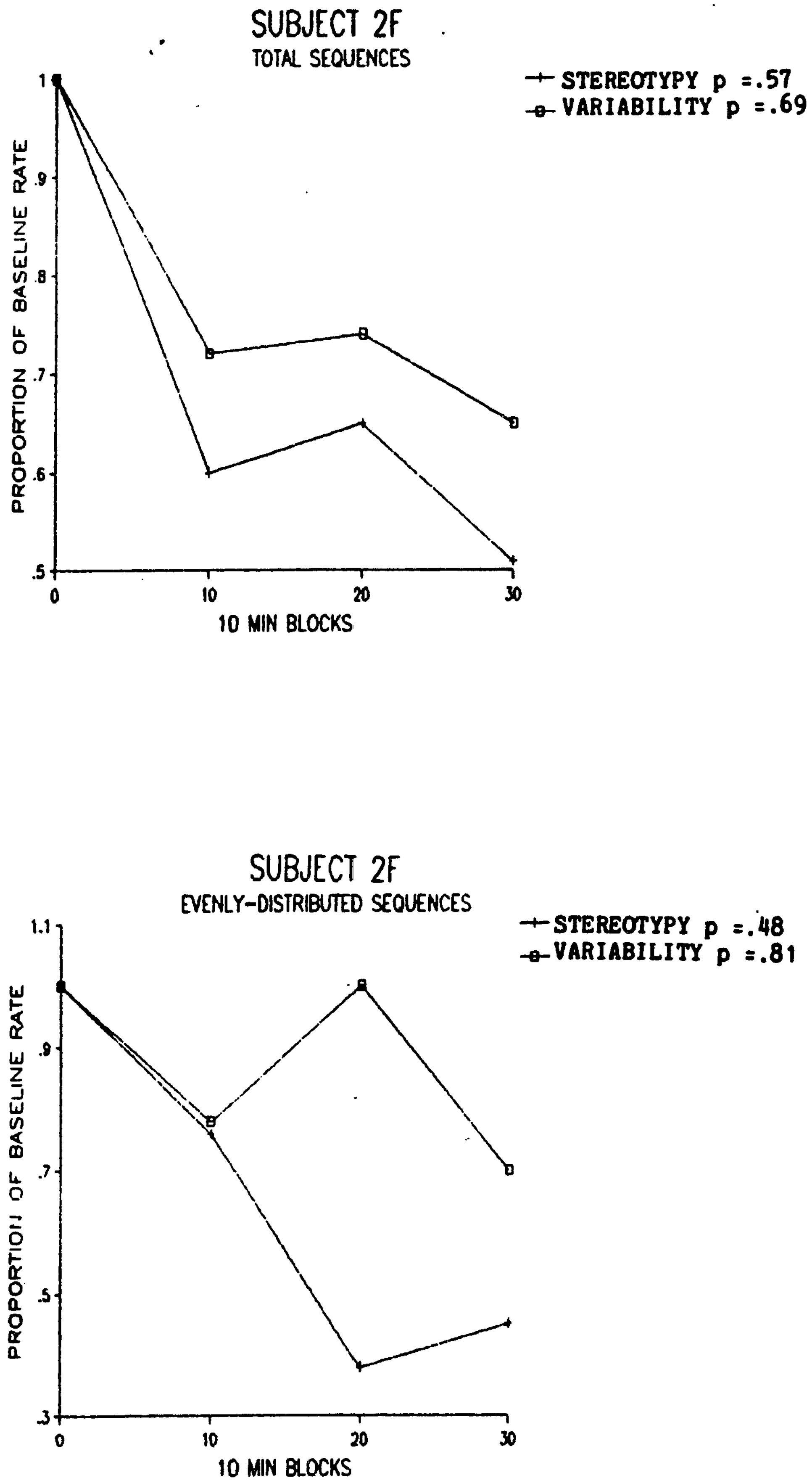
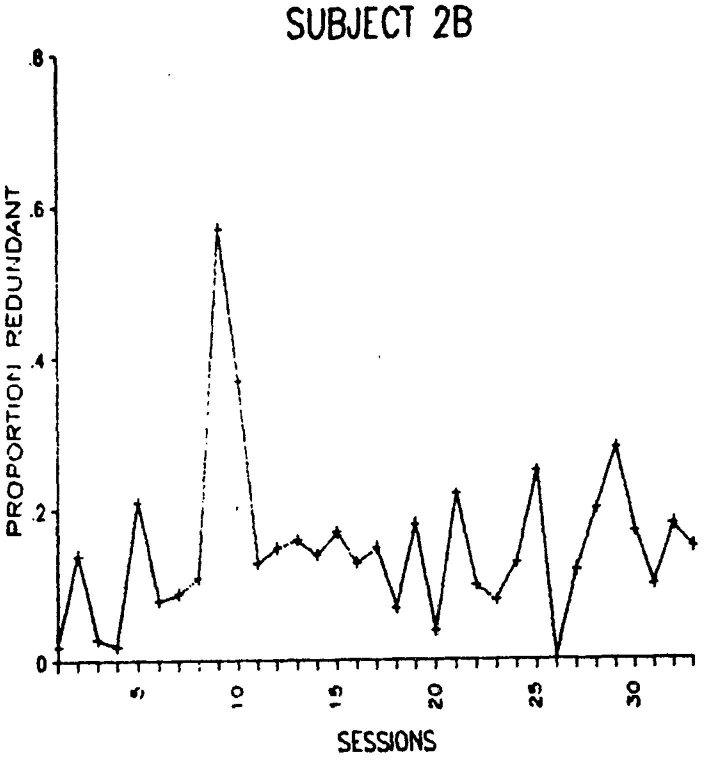

SUBJECT 2F
TOTAL SEQUENCES
STEREOTYPY p =.57
VARIABILITY p =.69
PROPORTION OF BASELINE RATE
1
.9
.8
.7
.6
.5
0
10
20
30
10 MIN BLOCKS
SUBJECT 2F
EVENLY-DISTRIBUTED SEQUENCES
STEREOTYPY p =.48
VARIABILITY p =.81
PROPORTION OF BASELINE RATE
1.1
.9
.7
.5
.3
0
10
20
30
10 MIN BLOCKS

Figure 5


SUBJECT 2B
PROPORTION REDUNDANT
0
.2
.4
.6
.8
5
10
15
20
25
30
SESSIONS

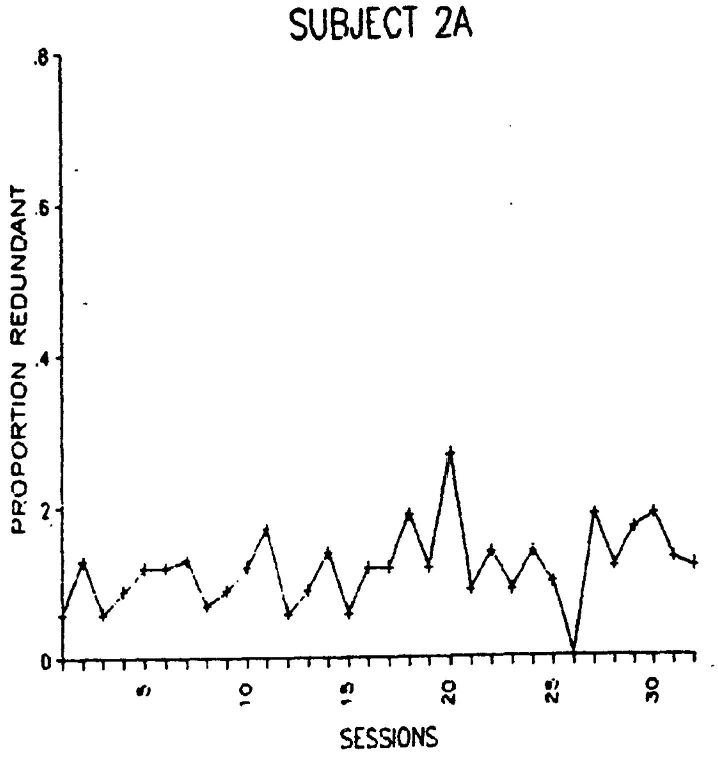
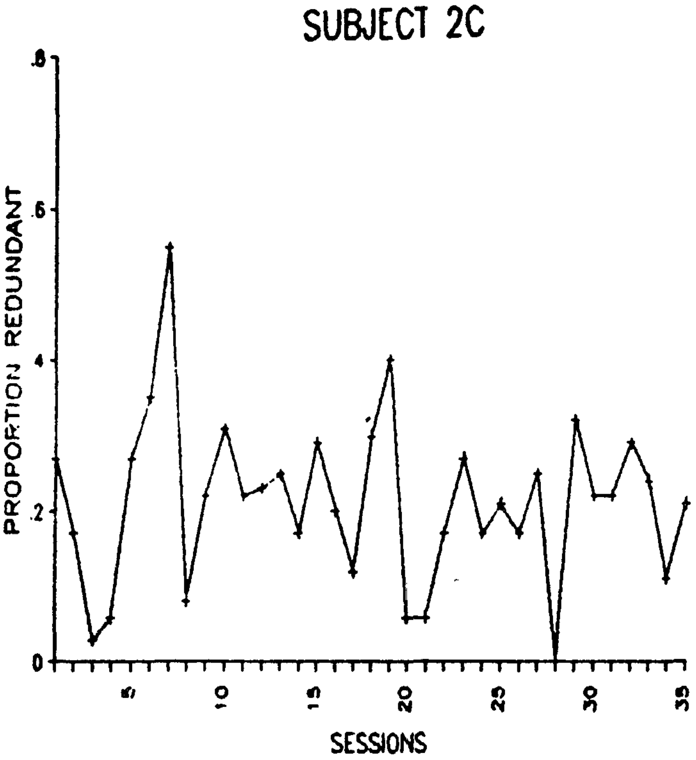

SUBJECT 2A
PROPORTION REDUNDANT
0
.2
.4
.6
.8
5
10
15
20
25
30
SESSIONS

Figure 5


SUBJECT 2C
PROPORTION REDUNDANT
.8
.6
.4
.2
0
5
10
15
20
25
30
35
SESSIONS

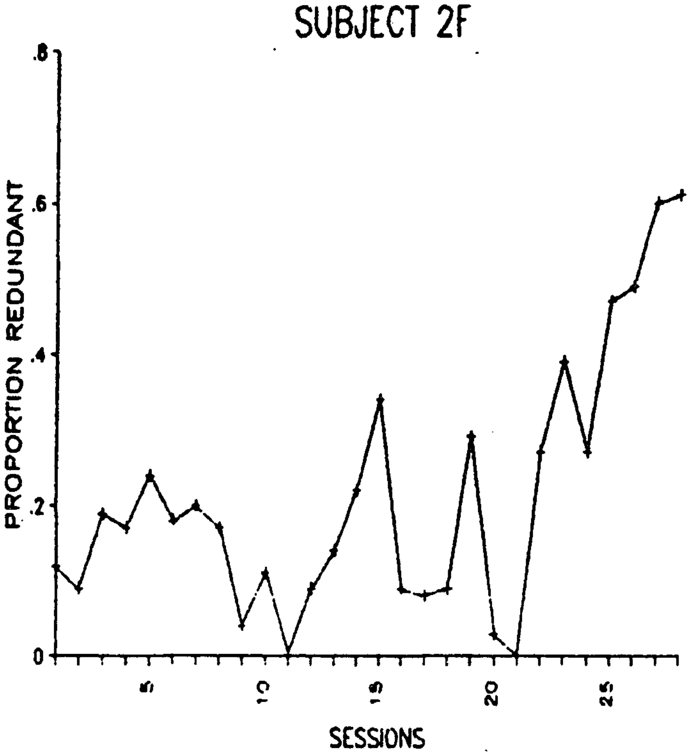

SUBJECT 2F
PROPORTION REDUNDANT
.8
.6
.4
.2
0
5
10
15
20
25
SESSIONS

Figure 5

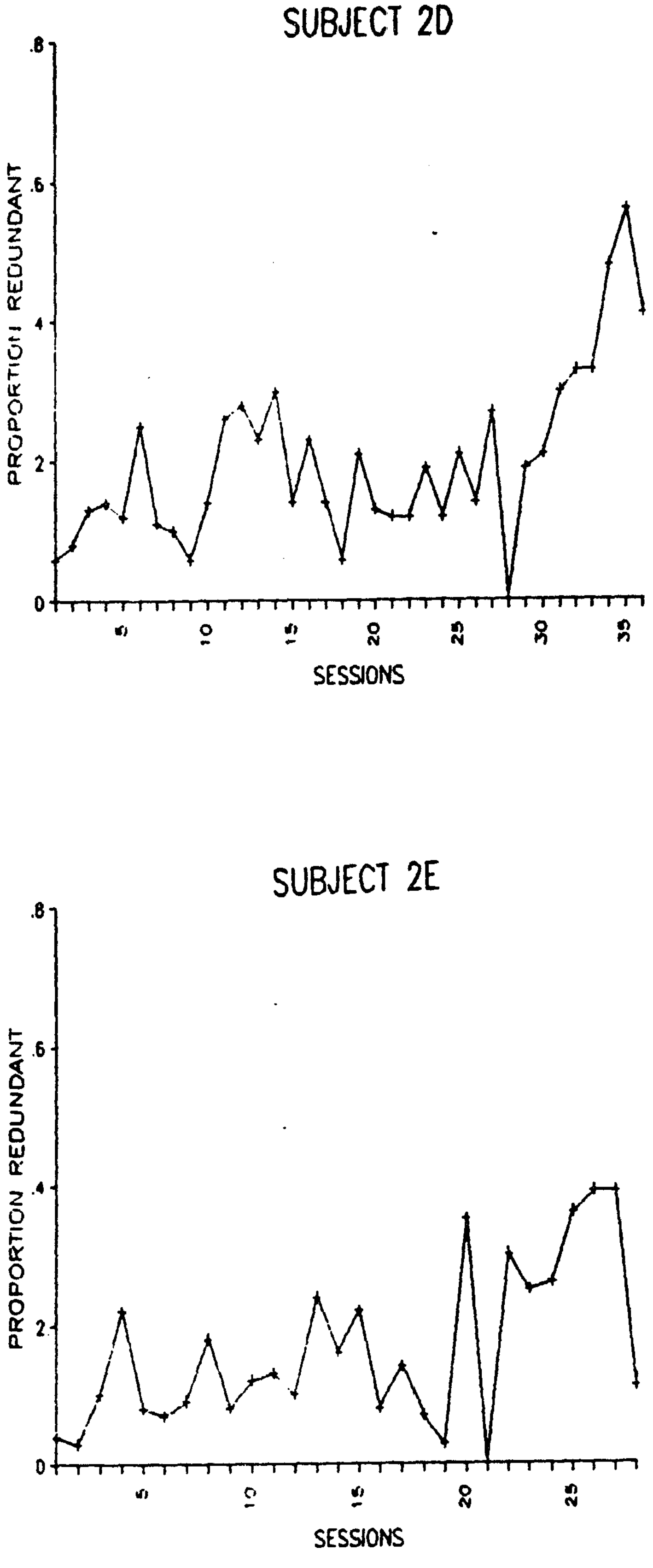

SUBJECT 2D
PROPORTION REDUNDANT
.8
.6
.4
.2
0
5
10
15
20
25
30
35
SESSIONS
SUBJECT 2E
PROPORTION REDUNDANT
.8
.6
.4
.2
0
5
10
15
20
25
SESSIONS

Figure 6

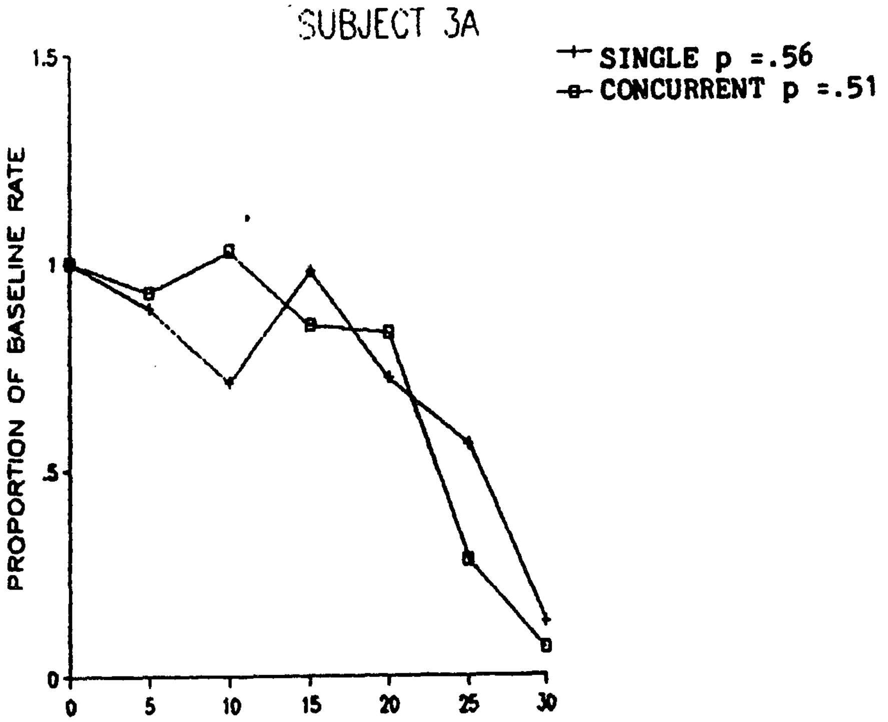

SUBJECT 3A
SINGLE p =.56
CONCURRENT p =.51
PROPORTION OF BASELINE RATE
1.5
1
.5
0
0
5
10
15
20
25
30

Figure 6

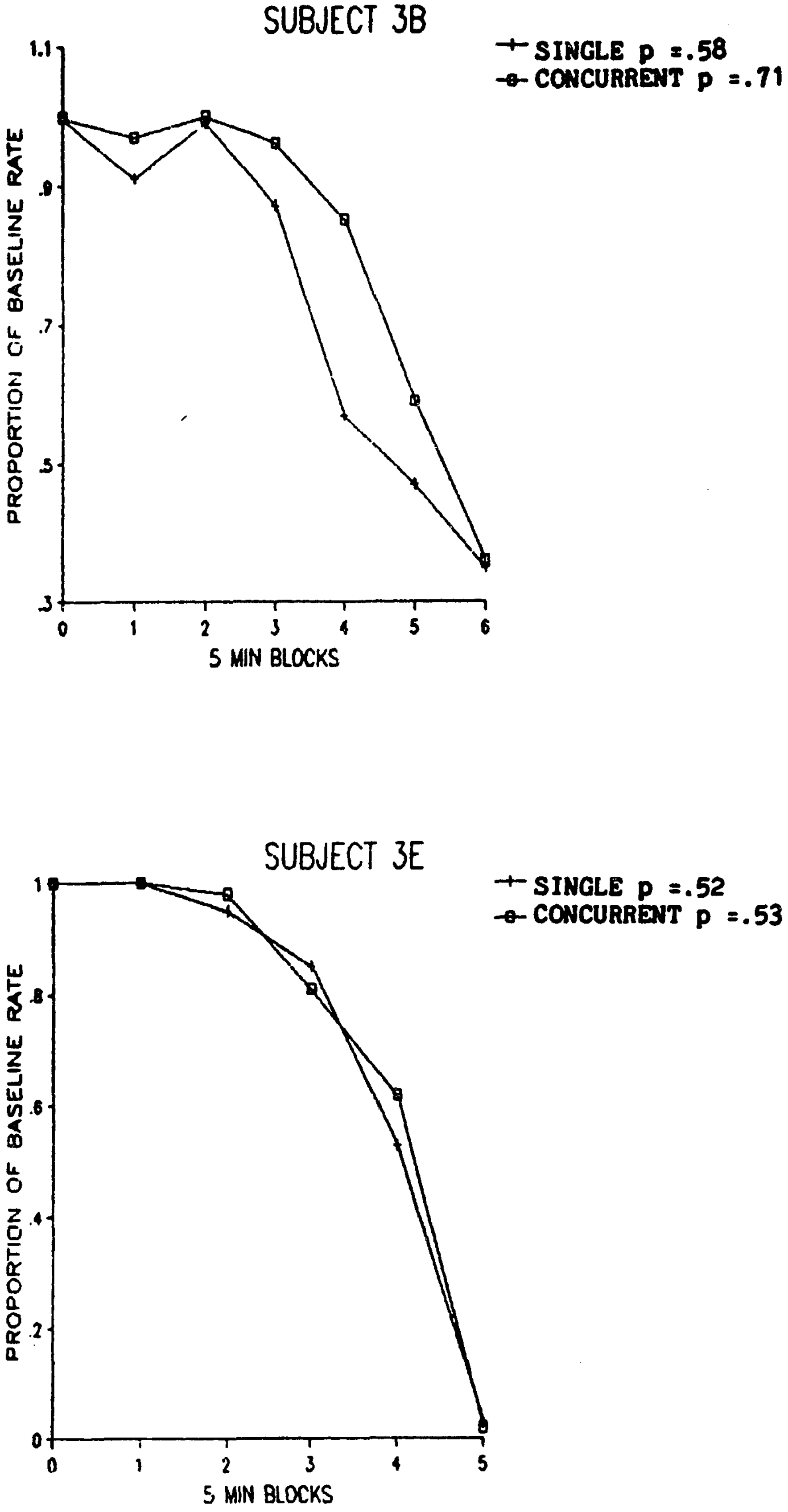
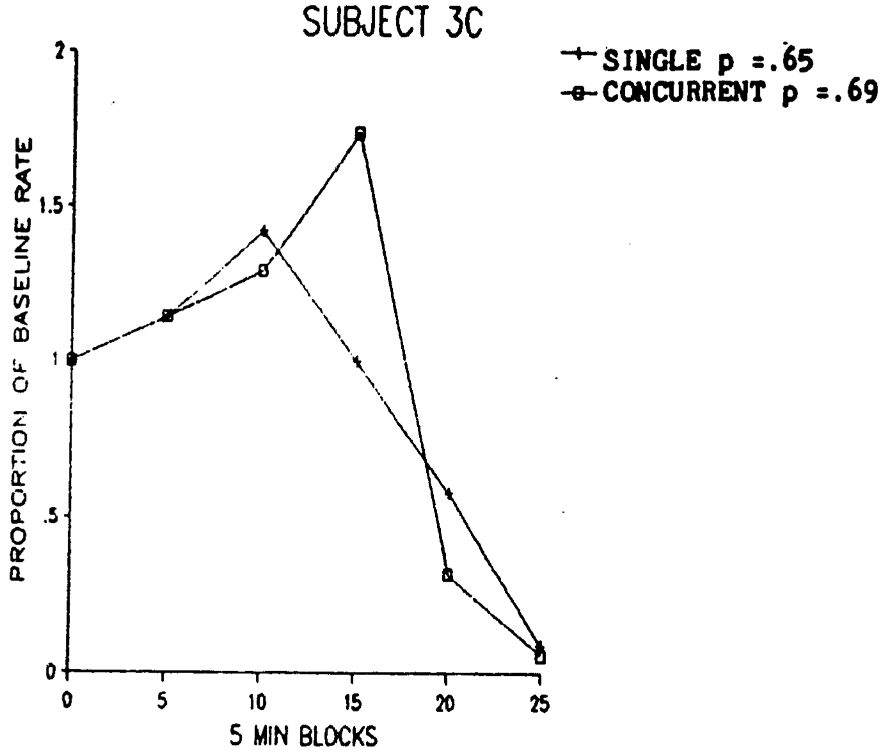
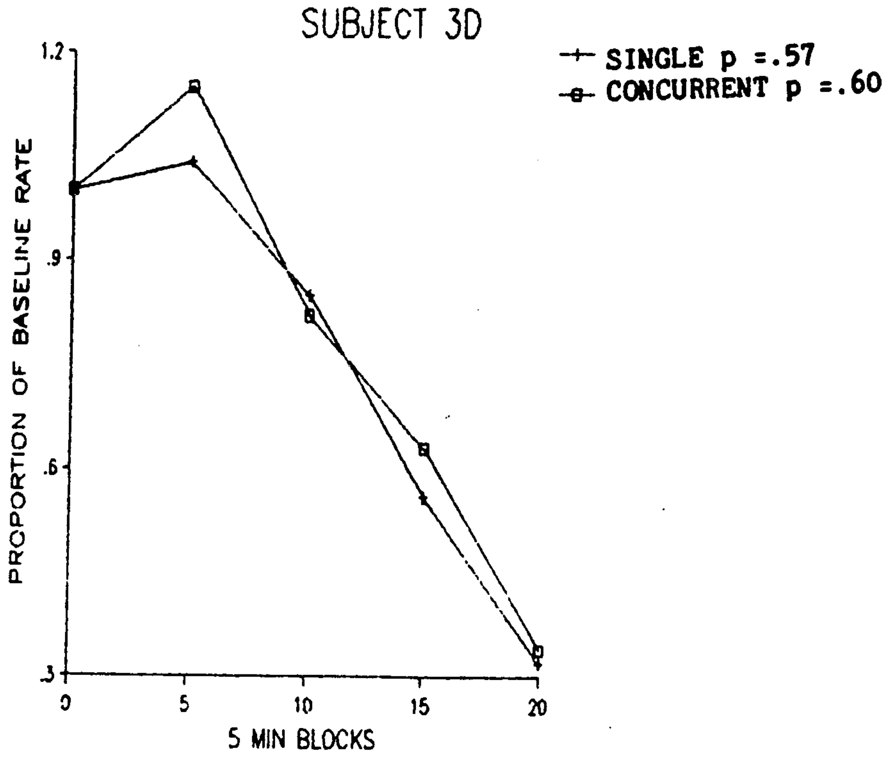

SUBJECT 3B
SINGLE p =.58
CONCURRENT p =.71
PROPORTION OF BASELINE RATE
1.1
.9
.7
.5
.3
0
1
2
3
4
5
6
5 MIN BLOCKS
SUBJECT 3E
SINGLE p =.52
CONCURRENT p =.53
PROPORTION OF BASELINE RATE
1
.8
.6
.4
.2
0
0
1
2
3
4
5
5 MIN BLOCKS

Figure 6


SUBJECT 3C
SINGLE p =.65
CONCURRENT p =.69
PROPORTION OF BASELINE RATE
2
1.5
1
.5
0
0
5
10
15
20
25
5 MIN BLOCKS


SUBJECT 3D
SINGLE p =.57
CONCURRENT p =.60
PROPORTION OF BASELINE RATE
1.2
.9
.6
.3
0
5
10
15
20
5 MIN BLOCKS

BIBLIOGRAPHY

Antonitis, J. J. (1951). Response variability in the white rat during conditioning, extinction and reconditioning. Journal of Experimental Psychology, 42, 273-281.

Amsel, A. (1962). Frustrative non reward in partial reinforcement and discrimination learning: Some recent history and a theoretical extension. Psychological Review, 69, 306-308.

Capaldi, E. J. (1967). A sequential hypothesis of instrumental learning. In K. W. Spence and J. T. Spence (Eds.), The psychology of learning. New York: Academic.

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

D'Amato, M. R., and Siller, J. (1962). Partial reinforcement and response variability. Journal of General Psychology, 66, 25-31.

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

Ferraro, D. P., and Branch, K. H. (1968). Variability in response location during regular and partial reinforcement. Psychological Reports, 23, 1023-1031.

Fleshler, M., and Hoffman, H. S. (1962). A progression for generating variable-interval schedules. Journal of the Experimntal Analysis of Behavior, 5, 529-530.

Guthrie, E. R. (1952). The psychology of learning. New York: Harper.

Guthrie, E. R., and Horton, G. P. (1946). Cats in a puzzle box. New York: Reinhart.

Herrnstein, R. J. (1961). Stereotypy and intermittent reinforcement. Science, 33, 2067-2069.

Keller, F. S., and Schoenfeld, W. N. (1950). Principles of psychology. New York: Appleton-Century-Crofts.

Martin, G. L., and Pear, J. L. (1978). Behavior modification. Englewood Cliffs: Prentice-Hall.

Mellon, R. C., and Shull, R. L. (1986). Resistance to change produced by access to fixed-delay versus variable-delay terminal links. Journal of the Experimental Analysis of Behavior, 46, 79-92.

Miller, G. A., and Frick, F. C. (1949). Statistical behavioristics and sequences of responses. Psychological Review, 56, 311-324.

Nevin, J. A. (1979). Reinforcement schedules and response strength. In M. D. Zeiler and P. Harzem (Eds.), Reinforcement and the organization of behavior. New York: Wiley.

Nevin, J. A. (1987, in press). Behavioral momentum and the partial reinforcement effect. Psychological Review.

Nevin, J. A., Mandell, C., and Yarensky, P. (1981). Response rate and resistance to change in chained schedules. Journal of Experimental Psychology: Animal Behavior Processes, 7, 278-294.

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

Page, S., and Neuringer, A. (1985). Variability is an operant. Journal of Experimental Psychology: Animal Behavior Processes, 11, 311-324.

Schoenfeld, W. N. (1950). On the difference in resistance to extinction following regular and periodic reinforcement. Presented at the Conference on the Experimental Analysis of Behavior (Note 20, February 27, 1950). Reprinted in Journal of the Experimental Analysis of Behavior, 1968, 11, 259-261.

Schoenfeld, W. N., Harris, A. H., and Farmer, J. (1966). Conditioning of response variability. Psychological Reports, 19, 551-557.

Schwartz, B. (1981). Reinforcement creates behavioral units. Behavioural Analysis Letters, 1, 349-357.

Schwartz, B. (1982a). Failure to produce response variability with reinforcement. Journal of the Experimental Analysis of Behavior, 37, 171-181.

Schwartz, B. (1982b). Interval and ratio reinforcement of a complex sequential operant in pigeons. Journal of the Experimental Analysis of Behavior, 37, 349-357.

Schwartz, B. (1986). Allocation of complex, sequential operants on multiple and concurrent schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 45, 283-295.

Skinner, B. F. (1938). The behavior of organisms. New York: Appleton-Century-Crofts.

Vogel, A., and Annau, Z. (1973). An operant discrimination task allowing variability of reinforced response patterning. Journal of the Experimental Analysis of Behavior, 20, 1-6.