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## Reinforcement and punishment effects on human operant behavior

Edwin N. Carter  
*University of Massachusetts Amherst*

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REINFORCEMENT AND PUNISHMENT EFFECTS ON HUMAN OPERANT BEHAVIOR

A Thesis Presented

By

Edwin N. Carter

Submitted to the Graduate School of the  
University of Massachusetts in  
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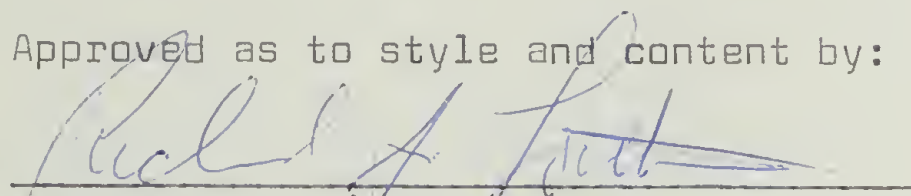
# REINFORCEMENT AND PUNISHMENT EFFECTS ON HUMAN OPERANT BEHAVIOR

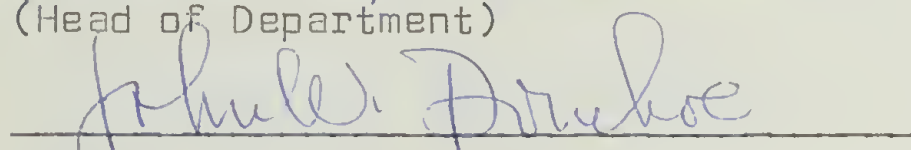
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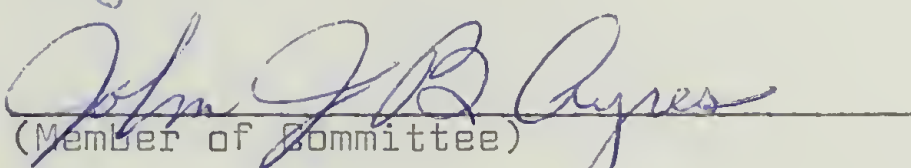
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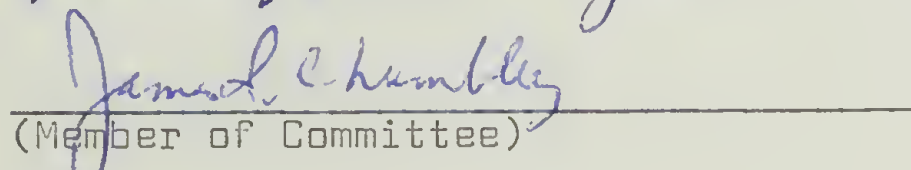
Edwin N. Carter

Approved as to style and content by:

  
(Head of Department)

  
(Chairman of Committee)

  
(Member of Committee)

  
(Member of Committee)



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## INTRODUCTION

In the concurrent operant situation a subject has continuously available two or more response alternatives, each of which is associated with an independent schedule of reinforcement. When no restrictions are placed on when a response may occur, the situation permits an experimental analysis of free operant "choice".

## THE MATCHING LAW

Herrnstein's study: Herrnstein (1961) presented a two key version of the concurrent procedure to pigeons. The schedules of reinforcement in effect were all variable interval (VI) schedules. A VI schedule specifies that the first response after some variable amount of time has elapsed is to be reinforced. Typically a VI schedule is labeled by listing the mean value of the programmed interreinforcement intervals. Herrnstein reinforced pecks on the two keys according to the following pairs of reinforcement schedules: VI 1.5'-extinction (Ext); VI 3' - VI 3'; VI 1.8' - VI 9'; VI 2.25' - VI 4.5'. Thus, when VI 1.8' was in effect on one key, VI 9' was scheduled for the other key. By so arranging the schedules, the overall rate of reinforcement for the combined keys was always the same, although the rate on any particular key could vary. The following equivalency described the results:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \quad (1)$$

where  $R$  = number of responses,  $r$  = number of obtained reinforcements, and the subscripts denote the two different alternatives. The

relative number of responses on either of the two keys always closely approximated the relative number of reinforcements obtained by responding on that key, i.e. relative response rate equalled relative reinforcement frequency.

The equivalency demonstrated by Herrnstein appears to be part of a rather general formulation, frequently labeled the "matching law", relating responding and the attributes of reinforcement in the concurrent paradigm. Neuringer (1967) and Catania (1963 a) have demonstrated matching between key pecks and relative magnitude of reinforcement (seconds access to grain). Chung and Herrnstein (1967) as well as Neuringer (1969) have reported matching between key pecks and relative delays of reinforcement. Shimp (1971) found matching using fixed interval schedules (a constant rather than a variable programmed interreinforcement interval). Herrnstein (1958) has reported matching with ratio schedules (where a fixed or variable number of responses are required for reinforcement) programmed for the alternatives, although it was of a trivial nature since subjects tended to respond exclusively on that alternative with the smaller ratio requirement (Note that if a subject responds only on one alternative, he necessarily receives all his reinforcements on that alternative, and this is not in violation of equation 1). Shull and Pliskoff (1967), using rats as subjects, have reported matching using brain stimulation as the reinforcer.

The matching law as tautologous: Rachlin (1971) has argued that the matching law is tautologous since relative response rate and relative reinforcement rate are not varied

independently. He believes that when no constraints other than <sup>3</sup> the contingencies of reinforcement are placed on the organism and that when choice is between alternatives of an equal operant level, relative response rate must necessarily equal relative reinforcement rate. Any evidence that disconfirms the matching law can be discounted as the result of (a) placing some restraint on the organism (e.g. for a pigeon, requiring different forces to operate the keys), and thus not making the alternatives "equal", or (b) using scheduled rather than obtained schedules of reinforcement in computing the relative reinforcement frequency.

For Rachlin, and those who would agree with his assumptions about the variables operating in the concurrent operant situation, the value of equation 1 lies in the fact that it tells the experimenter about the nature of the constraints he places on the organism, i.e. if matching does not occur, the experimenter can assume he has not adequately set up the experimental situation.

Rachlin's view that relative reinforcement rate is computed on the basis of scheduled rather than obtained reinforcement is certainly justified. The matching law would certainly seem to be more theoretically viable if response rate and reinforcement rate could be varied independently. However, it is unclear why relative response rate necessarily equals relative reinforcement frequency, and does not bear some other, say exponential, relationship to relative reinforcement frequency. It is doubtful if one could ever independently measure the "constraints" placed on an organism in an environment; assuming this ideal could be



achieved, there is no reason to suspect that relative response rate would necessarily equal relative reinforcement frequency.

Findley procedure: Findley (1958) has presented an alternative method for the study of concurrent behavior. A pigeon, for example, is free to respond on either of two keys. Operation of one key, the "changeover" key, causes alternation between two external stimuli, which are superimposed on the other key, the "response" key. Each of the stimuli is associated with an independent, concurrently operative schedule of reinforcement. Responses on the "response" key are reinforced according to the schedule in effect for the particular stimulus showing at that moment. The subject chooses which schedule to respond on by pecking the "changeover" key; he responds on a particular schedule by pecking the "response" key.

Findley was able to demonstrate that the behavior generated by using his "changeover" procedure was equivalent to behavior generated by using two separate response alternatives with independent schedules for each. Use of the Findley procedure results in the matching of relative response rate in the presence of a stimulus to relative reinforcement frequency obtained for responding in the presence of that stimulus.

An advantage to the Findley procedure is that it makes changeovers between schedules explicit, i.e. it allows measurement of the changeover from one schedule to the next independent of responses to either schedule.

Catania (1963 b), using the Findley method, recorded the amount

of time pigeons spent in the presence of a stimulus associated with a particular reinforcement schedule. He found that his subjects matched relative proportion of time spent in the presence of each stimulus to the relative frequency of reinforcement obtained by responding in the presence of that stimulus. In addition he found that relative response rate also matched relative reinforcement frequency.

Using the Findley procedure, Brownstein and Pliskoff (1968) found that even when reinforcement was not response contingent, relative amount of time spent on one schedule matched the relative frequency of reinforcement. Similarly Baum and Rachlin (1969) have demonstrated matching when responses consisted of standing on one or the other side of an experimental chamber.

Concurrent chain procedure: In the concurrent chain procedure two response alternatives, A and B, are programmed with concurrent schedules of "reinforcement". When "reinforcement" is made available on one of the alternatives, say A, the "reinforced" response is followed by the production of a stimulus associated with a new schedule for A, which reinforces with the actual reinforcer. When this new schedule is in effect for A, B is inoperative. There are, then, two components to the concurrent chain schedule: the initial link (or chain) component is the situation during which both A and B are concurrently available, and the terminal link is the situation in which either A or B is available and the other alternative is not available. The use of the concurrent chain procedure permits the study of preference



in situations where the choice response is temporally removed from the reinforcement. Several investigators (e.g. Herrnstein, 1964; Fantino and Herrnstein, 1968) in using the concurrent chain procedure have demonstrated that preference for a terminal link alternative matched the relative rate of reinforcement obtained during the terminal link component for that alternative.

Negative matching: Rachlin and Herrnstein (1969) have presented evidence which hints at the possible extension of equation 1 to "punishment" paradigms. In a series of experiments employing the concurrent chain procedures, they varied several parameters of shock during the terminal links to assess the effect of shock (punishment) on initial link choice. They discovered that given equal positive reinforcement on two alternatives in the terminal links, initial link choice depended on the intensity and frequency of shock during the terminal links and was independent of response rate during the terminal links (the higher the rate or intensity of shock for an alternative, the less frequently it was chosen)--this was true whether the shock was response-contingent or not. Although they were not interested in the implications of their findings for the matching law they did provide an impetus for the use of the concurrent paradigm in the study of punishment, avoidance, etc.

The changeover delay: Generally, concurrent procedures utilize a changeover delay (COD) which specifies a minimum amount of time which must elapse between responses on one alternative and reinforced responses on the other alternative. Catania and Cutts

(1963) found that human subjects, on a concurrent VI 30" - Ext, would respond on the Ext alternative unless a COD was imposed. Without the COD, Catania and Cutts argued, responses on the Ext alternative might have been reinforced by the consequence of a reinforced response on the VI 30" alternative. In this manner a "superstitious chain" of responses might have developed; the effect of the COD would be to discourage such chains, since the COD prohibited the possible reinforcement of a response on the VI 30" alternative within a certain period of time (depending on the COD duration) following a response on the Ext alternative.

Although most investigators (e.g. Herrnstein, 1961) have used a COD, it had not been systematically investigated until the last few years. Allison and Lloyd (1971) using the typical concurrent procedure, found that increasing the COD on a concurrent VI 1' - VI 3' from 5.0" to 7.5" to 12.5" progressively depressed the number of obtained reinforcements, although the relative response rate still equalled the relative reinforcement frequency. At this time it is still unclear what the overall effect of the COD is with regard to the matching law (see Pliskoff, 1971).

Matching with humans: Schroeder and Holland (1969) presented concurrent VI schedules to humans with macrosaccadic eye movements to two areas of a four dial display used as responses. Reinforcers (signal deflections) were delivered to the two right-hand dials on one VI schedule and to the two left-hand dials on another VI schedule; a COD was imposed between crossover eye movements. For each subject only one pair of reinforcement schedules was

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programmed during the experiment. However, in different sessions one of three different COD's was in effect (0 sec, 1 sec, 2.5 sec).

All subjects matched relative response rate to relative reinforcement frequency when either a COD of 1 or 2.5 seconds was effective; subjects did not match when no COD was programmed. Additionally, those subjects which had a smaller difference in reinforcement schedules arranged by the concurrent schedules had a more rapid changeover rate than subjects which had a larger difference.

Although the Schroeder and Holland study was primarily interested in studying the effect of the COD on human macrosaccadic eye movements, it does indicate that humans can, under certain conditions, match relative response rate to relative reinforcement frequency as predicted by equation 1.

There are numerous other instances of the matching function (see Herrnstein, 1970) and it seems safe to conclude that for pigeons and rats, the relative reinforcement frequency matches the relative response rate in the concurrent situation.

#### PROBABILITY LEARNING

In direct contradistinction to equation 1 are the results of studies that find "probability learning". Probability learning (or probability matching) dictates that choices are distributed in proportion to the relative probabilities of reinforcement and not the relative numbers of reinforcement, i.e. that,

$$\frac{R_1}{R_1 + R_2} = \frac{\frac{r_1}{R_1}}{\frac{r_1}{R_1} + \frac{r_2}{R_2}} \quad (2)$$

where the symbols are identical in meaning to those of equation 1. Note that if organisms match the relative frequency (numbers) of their responses to the relative frequency of reinforcement, then the right side of equation 2 is equivalent to .5 (for two alternative solutions) since if

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2}, \text{ the matching law,}$$

then  $R_1 r_1 + R_1 r_2 = R_1 r_1 + R_2 r_1$ ,

and 
$$\frac{r_2}{R_2} = \frac{r_1}{R_1} \quad (3)$$

i.e. if subjects match relative response rates to relative reinforcement frequencies for an alternative, they are receiving the same probability of reinforcement on all the alternatives.

It is obvious that if organisms match responding to relative frequencies of reinforcement they can not be matching responding to relative probabilities of reinforcement (except where relative frequency of reinforcement for an alternative is:

(a) 1.0 or 0.0, in which case either  $r_2 = R_2 = 0$  or  $r_1 = R_1 = 0$ , and equation 3 is meaningless, or (b) .5, in which case probability



of reinforcement for the alternative is equal).

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A further implication is that when absolute response rates on the alternatives are equal (i.e.  $R_1 = R_2$ ) equation 2 simplifies to equation 1:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1 / R_1}{\frac{r_1}{R_1} + \frac{r_2}{R_2}}, \quad (2)$$

since  $R_1 = R_2$  by assumption, then

$$\frac{R_1}{R_1 + R_2} = \frac{r_1 / R_1}{\frac{r_1 + r_2}{R_1}} = \frac{r_1}{r_1 + r_2} \quad (1)$$

Species differences: Most investigations of probability learning have used human subjects. Typically employing a discrete-trial procedure, each alternative available to the subject has some independent probability of being reinforced on each trial. It is unclear, at this point, exactly what evidence exists to support the notion of probability learning. Some investigators have reported probability learning (e.g. Gardner, 1957; Rubinstein, 1959; Estes, 1964) but it is unclear how general the effect is. For instance, Edwards (1961) in summarizing the probability learning literature through 1960 concluded that probability learning is "at best dubiously supported by experimental data...." and seems to have achieved a widespread acceptance because of:



(1) the probabilities of reinforcement selected for the alternatives (they were almost always either 0, 0.5, or 1.0), and (2) the number of trials each subject was run (typically a small number, under 300). Edwards concludes that with larger number of trials and with differing probabilities of reinforcement, there is no real evidence for probability matching. During the 1960's the trend in research has moved towards the analysis of sequential responding. The findings have generally not supported a simple probability learning explanation of human choice behavior (see Jones, 1971 for a review).

In many probability learning studies there is a tendency for the subject to respond on the alternative with the highest programmed probability of reinforcement with a frequency greater than that predicted by equation 2, (Gardner, 1958; Beach and Schoenberger, 1965; Erickson, 1966; Murray, 1971). This tendency is called "overshooting" and when it becomes so pronounced that the subject responds exclusively on the alternative with the highest probability of reinforcement it is called "maximizing". Note that maximizing results in the greatest expected gain of reinforcement for any particular session.

Within an operant framework, probability learning designs may be viewed as programming ratio reinforcement schedules (more specifically, random ratio schedules) for each of the alternatives, since each response has some probability of being reinforced, reinforcement is dependent upon completion of some variable number of responses. Interestingly, overshooting, and in particular

maximizing, found in human probability learning experiments, accord well with the finding of Herrnstein (1958) that his pigeons exclusively selected that alternative with the lowest ratio requirement. As indicated previously, the phenomenon of maximizing is in accord, though trivially so, with equation 1.

Some comparative theorists (e.g. Bitterman, 1965; Williams, 1971) have argued that certain species behave differently in similar choice situations, i.e. what constitutes a choice response for one species might not do so for another species. More specifically, Bitterman (1965) has forwarded the notion that "higher" organisms tend to maximize, while "lower" organisms probability match in probability learning experiments. Unfortunately data collected in support of such theories are of a doubtful nature because of procedural artifact. For example, Bitterman's studies often employed a correction procedure to regulate exposure to response alternatives; correction procedures violate the defining criteria of concurrent schedules, since the subject is not "free" to respond on any of the alternatives, (see Herrnstein, 1970 for a more detailed critique).

Molecular analyses: Recently Shimp (1969) has presented data which indicate that evidence supporting the matching law may be an artifact of more molecular interactions; specifically he holds that a subject emits that particular sequence of responses which has the highest probability of being reinforced. In Shimp's analysis, emphasis is placed on the "chains" of successive choices emitted by the subject. By analyzing sequences of responses,

Shimp has demonstrated that usually his pigeons emit that particular chain of responses which has the highest probability of being reinforced and not some other chain of responses which has a lesser probability of being reinforced. For Shimp, then, the functional unit of analysis is a sequence of choices and not merely discrete choices taken separately.

When Shimp averages his data over an entire session, by just counting the number of responses on each of the alternatives, the overall result confirms equation 1. Shimp contends that any evidence for equation 1, which holds that responding is sensitive to numbers of reinforcement, may really be a result of averaging sequences of responses, which are maximally sensitive to probabilities of reinforcement.

It is not clear, however, what effect Shimp's particular procedure bears on the generality of his findings. In one of Shimp's discrete-trial procedures, for example, his subjects initially pecked a center key, which illuminated two side keys. These side ("choice") keys were illuminated red one-half of the time and green one-half of the time. When the program scheduled reinforcement and the choice keys were red, the probability of reinforcement for pecking left was .75 and for pecking right it was .25; when the keys were green the probabilities were reversed. Without detailing this particular procedure further, it can be seen that even though Shimp's procedure may have some features in common with concurrent VI schedules, it is a highly complex discrimination procedure and is not the typical concurrent



Nevin (1969) attempted a fine grain analysis of the sequential choice behavior of pigeons in a discrete-trial situation. He reinforced one alternative according to a VI 3' schedule and the other key according to a VI 1' schedule. He analyzed chains of responses and found that the relative frequency of the sequences matched the obtained relative frequency of reinforcement and not the relative probability of reinforcement.

### SUCCESSIVE CHOICE

In the studies presented above, all the alternatives were simultaneously present. In successive, or multiple, situations only one response alternative is ever present; however, in the presence of a particular stimulus, responding is reinforced according to one schedule, while in the presence of other stimuli, responding is reinforced according to other schedules. Typically, the stimuli and therefore the schedules are changed after some fixed or variable amount of time has elapsed.

The typical finding with multiple schedules is that subjects do not match their relative response rates within components to the relative reinforcement frequencies associated with the components. With VI schedules effective in stimulus components, there does appear to be a tendency for relative response rates to be positively correlated with relative reinforcement frequencies, i.e. higher frequencies of reinforcement are associated with higher relative rates of responding (Reynolds, 1963).

Herrnstein (1970) has reasoned that the multiple situation may be profitably viewed as containing numerous "other responses" which are not being measured by the experimenter. These "other responses" tend to interact with the measured response in any stimulus component. In essence, Herrnstein is arguing that the multiple situation is really a concurrent situation, and that just because the experimenter designates and measures only one response, it does not mean that other response alternatives are not available to the subject. Without detailing Herrnstein's analysis, his theory states that when using multiple schedules, the aggregate of the "other responses" is a parameter to be determined post hoc from the data, and fitted into equation 1.

#### EXPERIMENTAL PURPOSE

The present study was concerned with further investigation of the nature of the matching relation. One important function of this study was to try to extend the generality of equation 1 by making a detailed analysis of human concurrent performance.

In the first two experiments Herrnstein's (1961) original study was, in effect, replicated with human subjects to assess whether human concurrent performance was in accord with the dictates of the matching law. It was discovered that human choice behavior conformed to the predictions of equation 1. Detailed sequential analyses of responding were performed to permit a finer grain scrutiny of human **choice** behavior and to determine in what manner selected chains of responses were affected by reinforcement.



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It was found that sequences of responses were maximally sensitive to changes in relative reinforcement frequency and not relative reinforcement probability.

In a third experiment human performance during multiple schedules was investigated. The same reinforcement schedules used in the first two experiments were used in the third experiment, except that in the third experiment different schedules were effective during alternating stimulus components (i.e. successively) rather than being effective for different, though simultaneously available, alternatives. Relative response rate did not vary systematically with variations in reinforcement schedules. The first three experiments together then, permitted a contrast between human successive and simultaneous choice behavior.

A final experiment studied the effects of punishment of human concurrent behavior. Equal positive reinforcement was scheduled for each of two alternatives, and differing frequencies of punishment were scheduled for the alternatives, and the data demonstrated that subjects matched relative response rate to the complement of the relative punishment frequency.

## METHOD

Subjects: Five college student served as subjects (Ss). They received credit towards their grade in their child psychology course as compensation for their participation.

Apparatus: The apparatus consisted of a masonite paneled relay rack containing five buttons,  $\frac{1}{2}$  inch by  $\frac{1}{2}$  inch, spaced  $\frac{1}{2}$  inch apart, placed at chest level to the S. The two leftmost buttons were transilluminated with white light and were the only buttons operative during the experiment. A six-digit add-subtract counter was centered eight inches above the buttons, with two standard jewel lights spaced two inches on either side of the counter; the light on the left was green when operated, and the light on the right was red when operated.

The Ss wore headphones which provided tape-recorded music as masking noise. Additional masking was insured by the operation of an air-conditioner which created a 70 decibel noise. The room was darkened during the experiment.

All equipment was activated by standard electromechanical relay equipment.

Procedure: Each S was brought into the experimental room and seated in front of the relay rack. In each of four different sessions (approximately 20 minutes long) one of the following pairs of VI schedules programmed reinforcements for button presses (responses), each schedule of the pair being assigned to one of the two buttons for the entire session duration:

The length of each interreinforcement interval comprising each VI schedule was obtained from the Fleshler and Hoffman (1962) series.

Table 1 describes the order of presentation of the schedules, detailing for each of the four sessions, for each S, the particular schedule assigned to the left button and the schedule assigned to the right button. Note that the overall reinforcement density programmed by these schedules for responses on both alternatives is a constant for each session (four reinforcements per minute), although the programmed reinforcement density scheduled for any one response alternative is variable.

For expository purposes, whichever button in a session resulted in a higher obtained reinforcement frequency was labeled "A", the other button was called "B". As table 1 indicates, for all Ss, save S18, A was the left button in at least one session and the right button in at least one other session.

Reinforcement consisted of five point additions to the counter and the duration of the reinforcement ( $\frac{1}{2}$  sec), as well as the auditory feedback from the counter, made it an easily discriminable event. Ss lost points on each alternative according to a random ratio (RR) 10 schedule; i.e. on the average, every tenth response was punished. Punishment consisted of one point

TABLE 1  
Conditions for Experiment I

Subject Number	Session Number	Schedule (left button-right button)
S18	1	VI 22.5" - VI 45 "
	2	VI 30 " - VI 30 "
	3	VI 18 " - VI 90 "
	4	VI 15 " - EXT
S19	1	EXT - VI 15 "
	2	VI 30 " - VI 30 "
	3	VI 18 " - VI 90 "
	4	VI 45 " - VI 22.5 "
S20	1	VI 30 " - VI 30 "
	2	EXT - VI 15 "
	3	VI 18 " - VI 90 "
	4	VI 22.5 " - VI 45 "
S22	1	VI 22.5 " - VI 45 "
	2	VI 30 " - VI 30 "
	3	VI 90 " - VI 18 "
	4	VI 15 " - EXT
S23	1	VI 45 " - VI 22.5 "
	2	VI 15 " - EXT
	3	VI 18 " - VI 90 "
	4	VI 30 " - VI 30 "



deductions from the counter. The green light (on the left of the counter) flashed while the point was deducted as an additional signal for the subject. Pilot data had indicated that verbal reports of some consistent "strategy" used by Ss while responding were less frequent with the addition of the punishment contingency and thus provided the rationale for its inclusion.

In order to insure that response rates not become too low, a limited hold (LH) of ten seconds duration was in effect during each session. The LH 10" specified that if a reinforcement was programmed for an alternative the S had ten seconds in which to make the response that would be reinforced. If the reinforcement were not collected within the allotted ten seconds, then it was cancelled; whenever a reinforcement was cancelled the red light (on the right of the counter) flashed briefly as a signal to the S.

The following instructions given to the Ss summarize the experimental procedure:

Your task in this experiment is to determine in what manner to press the two lighted buttons in front of you. The following restrictions govern the manner in which you should press the buttons: (1) Use only one finger for your presses, (2) Press only one button at a time, (3) Press each button briefly.

By appropriately pressing the buttons you will have points added to the counter in front of you. Sometimes, but not all of the time, you will find that you lose a



point because you are pressing incorrectly. When this happens the green light on the left will flash as you lose the point. It is very difficult to entirely avoid losing some points. Frequently you will find that your presses have no effect at all. Whenever the red light on the right flashes it means that you missed an opportunity in which you could have gained points. Your goal is simply to gain as many points as possible on the counter, both by choosing those ways of pressing that add points and avoiding those ways of pressing that cost you points.

You are to wear these headphones while you are pressing. They contain music which is used to prevent you from hearing any distractions. They have nothing to do with the experiment except to serve as a masking noise.

Each session started with the counter reading zero. The punishment contingency was not effective during the initial minute of each session to insure that point totals did not go below zero. No COD was used in this experiment.

## RESULTS

The data collected exclude choices during the first four minutes of each session, since previous data had indicated that possible transfer effects from prior sessions contaminated the data. The limited hold contingency rarely (only twice for all Ss) was encountered, and thus had no substantial effect on the data.

Table 2 indicates the relative frequency of occurrence for B (column a), the relative frequency of reinforcement for B (column b), and the relative probability of reinforcement for B (column c). The close correspondence between relative occurrence and relative reinforcement frequency corroborate equation 1; the overall average deviation from matching for the pooled data (the average across all conditions of the absolute difference between column a and column b for the pooled data) being .072. The obvious close equivalency between relative response rate and relative reinforcement frequency is apparent in both the individual and pooled data. The largest deviation from matching is in the data from the VI 15"-Ext condition, where the response measure exceeds the reinforcement measure by an average of .145. For the other conditions the deviation is much smaller and opposite in direction.

The probability of reinforcement for an alternative was obtained by dividing the number of obtained reinforcements by the number of responses for that particular button. From this data, the relative probability of reinforcement for B was obtained by dividing the probability of reinforcement for B by the sum of the probability of reinforcement for A and the probability of reinforcement for B. Table 2 indicates that the relative probability of reinforcement for B (column c) was approximately constant at 0.5 across all conditions except VI 15" - Ext. It is evident for the VI 22.5" - VI 45" and VI 18" - VI 90" conditions that the probability of a choice matched the relative frequency of reinforcement for that choice and did not

TABLE 2

Relative Occurrence, Relative Frequency of Reinforcement,  
and Relative Probability of Reinforcement for B

Condition	S18			S19			S20			S22			S23			POOLED		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
VI 30"-	494	477	484	472	480	518	391	401	514	472	472	539	469	470	501	459	460	511
VI 30"																		
VI 22.5"-	326	341	517	321	333	515	225	295	431	319	419	526	318	327	510	302	343	500
VI 45"																		
VI 18"-	210	209	478	197	209	519	191	152	500	144	281	478	179	212	557	184	213	505
VI 90"																		
VI 15"-	099	000	000	216	000	000	152	000	000	050	000	000	212	000	000	145	000	000
EXT																		

a Relative occurrence of B ( $\times 10^{-3}$ )

b Relative frequency of reinforcement of B ( $\times 10^{-3}$ )

c Relative probability of reinforcement of B ( $\times 10^{-3}$ )

correspond to the relative probability of reinforcement for that choice. 24

Detailed sequential analyses were then performed on three of the Ss (S18, S19, S22), who were randomly selected from the original five Ss.

Although relative response rate was approximately the same for all Ss in each of the conditions, the absolute response rates (responses per minute) within each session varied considerably. For S18, S19 and S22, Table 3 reveals that there is no systematic trend in absolute response rate for the A alternative within subjects across conditions, e.g. for S19 the highest rate was in the VI 18" - VI 90" condition and the lowest rate in the VI 15" - Ext condition, while for S18 the highest rate was in the VI 15" - Ext condition and the lowest rate in the VI 30" - VI 30" condition. (Note that if there is no relationship between absolute responding on A and the type of condition among the three Ss, then there is no relationship between condition and responding on B, since all subjects had about the same relative rate in each condition.) However, within each condition, S22 always had the lowest absolute response rate on A of the three Ss. Further examination of Table 3 indicates that absolute response rate did not vary with the order in which the conditions were presented to each S.

Table 4 lists the probability of B occurring as the first choice after reinforcement (and since the probability of A is the complement of B, it indirectly specifies the probability of A occurring on the first choice after reinforcement) as a function



TABLE 3  
Absolute Response Rate on A

Condition	S18 (a)	S19 (a)	S22 (a)	POOLED (a)
VI 30"- VI 30"	38.4 (2)*	39.3 (2)	19.9 (2)	32.5
VI 22.5"- VI 45	67.4 (1)	55.2 (4)	20.2 (1)	65.8
VI 18"- VI 90"	48.0 (3)	74.9 (3)	24.2 (3)	49.0
VI 15"- EXT	71.4 (4)	38.4 (1)	17.9 (4)	42.6

(a) Absolute response rate on A (responses per minute)

\* Numbers in parentheses indicate in which session the condition was received

Probability of B given Reinforcement  
Had Occurred on A or B

Subject Number	P(B/rein. on A)	P(B/rein. on B)
S 18		
VI 30 - VI 30	.521	.571
VI 22.5 - VI 45	.310	.333
VI 18 - VI 90	.190	.222
VI 15 - EXT	.052	----
S 19		
VI 30 - VI 30	.538	.498
VI 22.5 - VI 45	.361	.352
VI 18 - VI 90	.146	.200
VI 15 - EXT	.163	----
S 22		
VI 30 - VI 30	.450	.500
VI 22.5 - VI 45	.384	.357
VI 18 - VI 90	.220	.196
VI 15 - EXT	.032	----
Pooled Data		
VI 30 - VI 30	.503	.523
VI 22.5 - VI 45	.352	.347
VI 18 - VI 90	.186	.206
VI 15 - EXT	.083	----

of whether reinforcement had been obtained for an A or B response. In other words, it specifies the probability of B occurring given a reinforced response on A had just occurred or given a reinforced response on B had just occurred. The data from Table 4 indicate that the probability of B (or A) occurring as the first response after reinforcement was independent of what type of choice had just been reinforced, i.e.  $P(B/\text{reinforcement on A})$  approximated  $P(B/\text{reinforcement on B})$  for all conditions.

Data were then analyzed in the following way. A computer marked every time a reinforcement occurred. It then listed what type of choice (A or B) had occurred as the first choice after reinforcement, then what type of choice occurred as the second response, etc. In this manner it was possible to ascertain the probability of A or B occurring as any particular response after a reinforcement, and, in general, to look at particular sequences of responses and determine their sensitivity to reinforcement parameters (see Appendix A for computer program). Note that the number of data points become less and less with each successive choice since the probability that reinforcement had occurred increased with successive numbers of non-reinforced responses and thus limited the length of response chains. For this reason, only response chains of response length five or less were analyzed since longer chain lengths did not occur often enough to yield reliable data. Data were pooled without regard to where reinforcement had just occurred, since Table 4 demonstrated that this variable was unimportant.

Figure 1 shows for each of the conditions the probability of B occurring (relative response rate for B), the relative reinforcement frequency for B, and the relative probability of reinforcement for B as a function of whether B occurred as the first, second, third, fourth, or fifth choice after reinforcement. The VI 15" - Ext condition is excluded since B hardly ever occurred in that condition. A gradual, though small, decrease in the probability of B occurring is in evidence with successive choices, i.e. the probability of B occurring (filled circle plot) decreased as the number of responses since the previous reinforcement increased. This is to be expected since the reinforcement schedule for A programmed a higher reinforcement density than the schedule for B, and therefore with an increase in the number of successive non-reinforced responses, the probability that a reinforcement for A will occur increases more rapidly relative to the probability that a reinforcement for B will occur.

Another striking feature of Fig.1 is the close correspondence between the relative occurrence of B function and the relative frequency of reinforcement for B function (open square plot). For all three Ss, this correspondence indicates that even when B responses were divided into subsets (i.e., grouped according to whether they occurred as the first through fifth response after reinforcement), the relative response rate of B still matched the relative reinforcement frequency for B function. The relative probability of reinforcement was a constant .5 for all choices in all conditions (filled diamond plot). In total Fig.1 indicates that



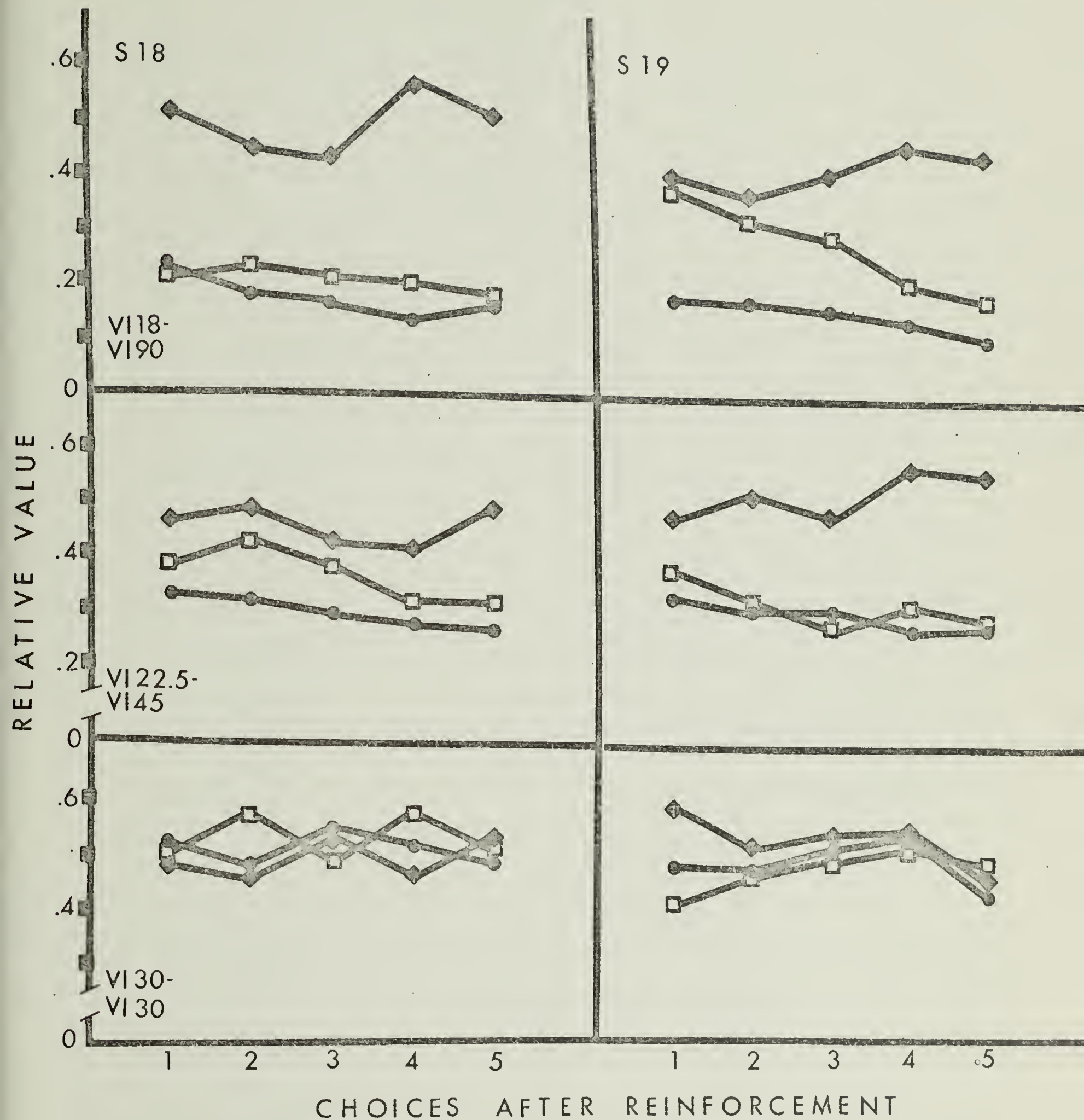


Fig. 1 (a). Relative probability of reinforcement, relative frequency of reinforcement, and relative rate of occurrence for B as a function of whether B occurred as the first through fifth choice after a reinforcement, for S18 and S19.

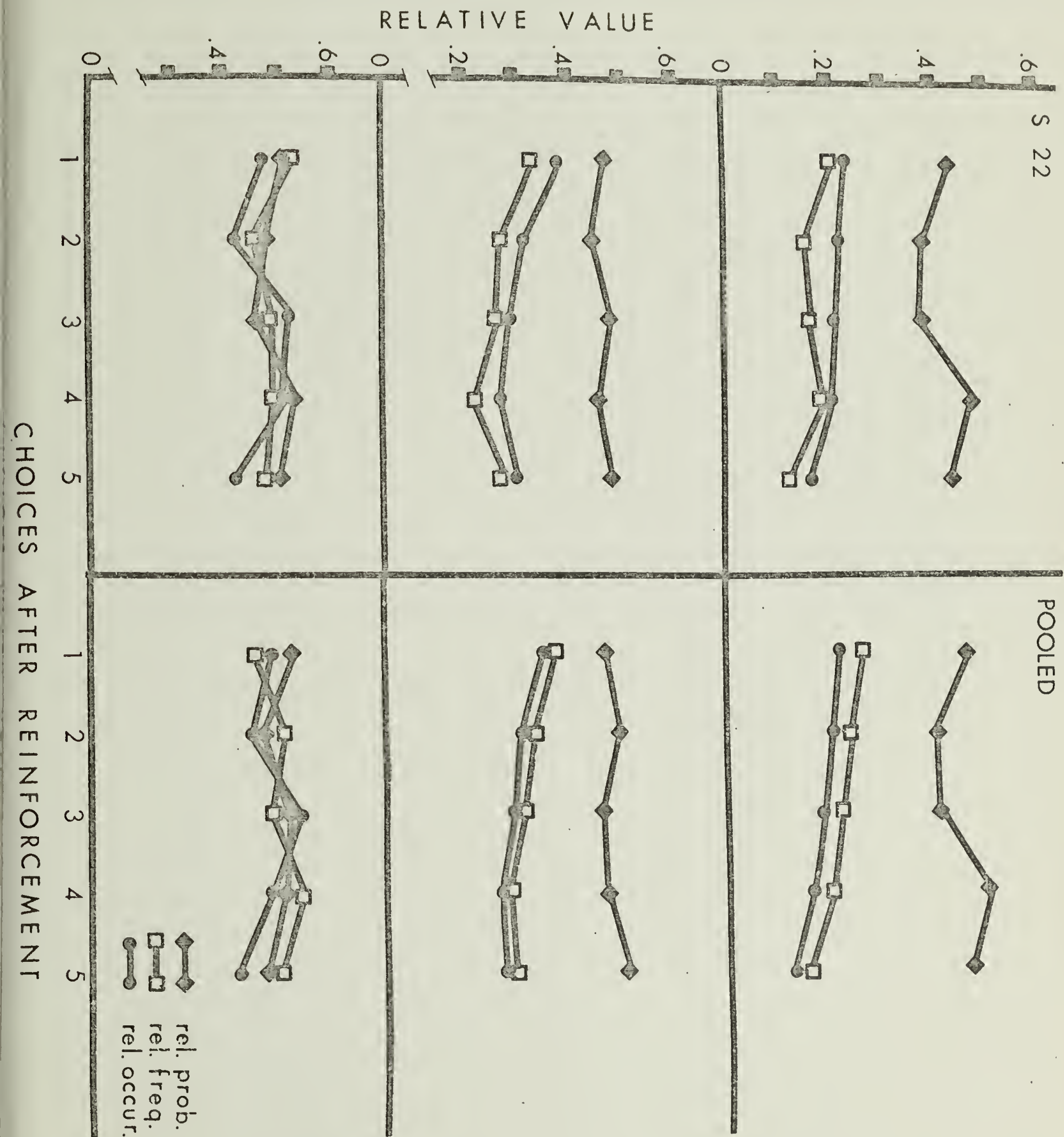


Fig. 1 (b). Relative probability of reinforcement, relative frequency of reinforcement, and relative rate of occurrence for B as a function of whether B occurred as the first through fifth choice after a reinforcement, for S22 and for all three Ss pooled together.



the Ss matched relative choices to relative reinforcement frequencies and not reinforcement probabilities.

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An even more fine grain analysis of the data in Fig. 1 was then initiated. Because of the nature of concurrent VI schedules, the probability of reinforcement for a response on one alternative increases as a function of the number of successive choices of the second alternative. A subset of the data was collected to see how "changeovers" from A to B were influenced by the number of successive choices of A. As the number of successive A choices increases, the probability of B being reinforced (i.e. of a changeover from A to B being reinforced) increases. Figure 2 is a plot of the relative response frequency of B, relative frequency of reinforcement for B, probability of reinforcement for B, and relative probability of reinforcement for B as a function of successive choices of A. The effect is again emphatic. For the VI 18" - VI 90" and VI 22.5" - VI 45" conditions, the probability of B occurring matches the relative frequency of reinforcement for B, and the relative probability of reinforcement for B again is a constant 0.5. This is so despite the fact that the probability of reinforcement for B increases with successive A choices. Figure 2 supports Fig. 1 in demonstrating that selected subsets of responses indicate a sensitivity to relative reinforcement measures and not to relative probability measures.

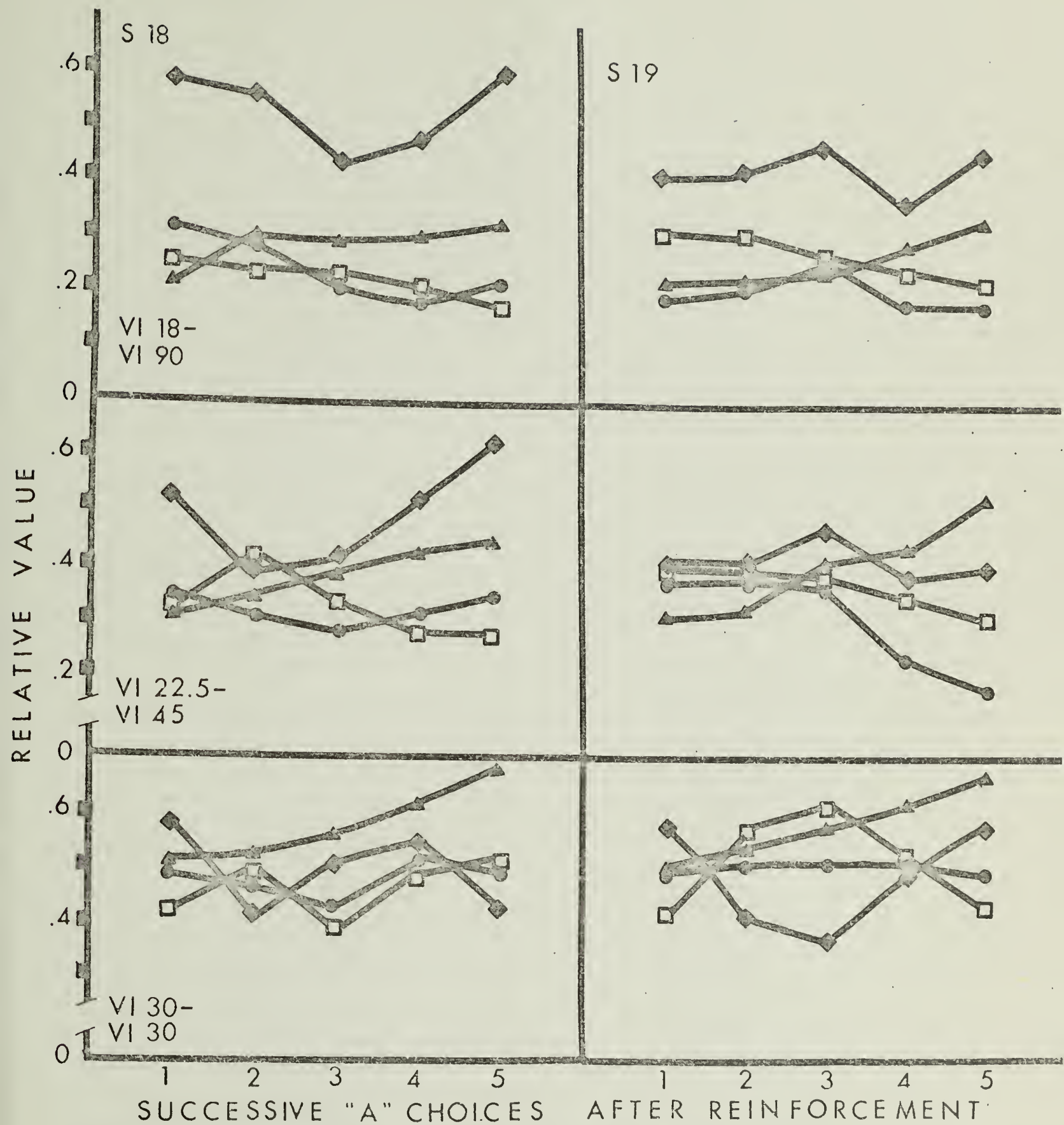


Fig. 2 (a). Relative probability of reinforcement, relative frequency of reinforcement, relative rate of occurrence, and probability of reinforcement for B as a function of successive A choices after reinforcement, for S18 and S19.



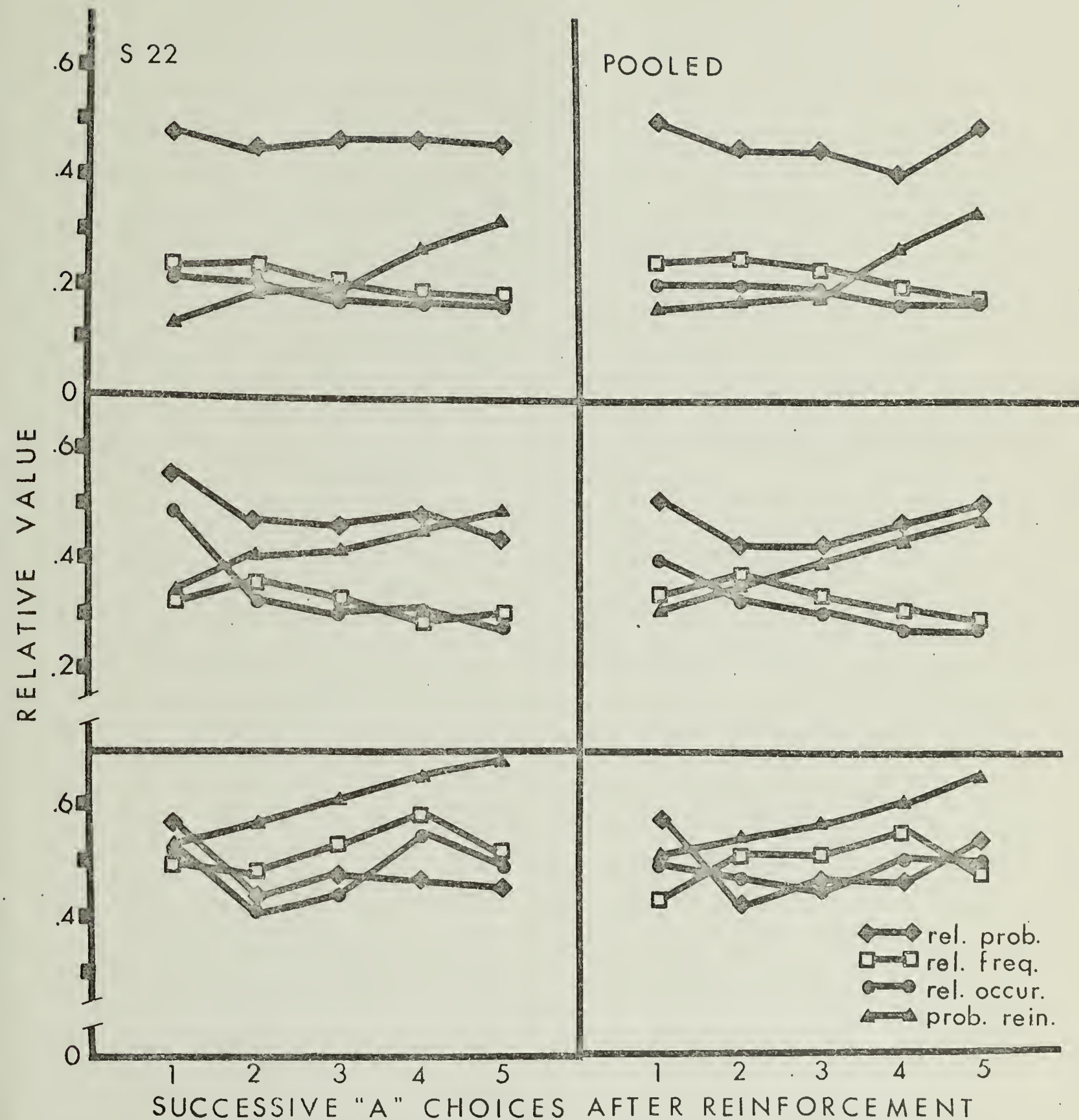


Fig. 2 (b). Relative probability of reinforcement, relative frequency of reinforcement, relative rate of occurrence, and probability of reinforcement for B as a function of successive A choices after reinforcement, for S22 and all three Ss pooled together.

## EXPERIMENT II

In Exp. I, it was possible that the findings may have been affected by the inclusion of the punishment contingency (one point loss on RR 10) and/or the particular reinforcement magnitude that was used (five points). This experiment examined these possibilities by excluding the point-loss contingency and using a different reinforcement magnitude. Additionally, the effects of receiving each condition more than once were investigated.

## METHOD

Subjects: Three new Ss of the same status as of Exp. I were used.

Apparatus: The apparatus was the same as in Exp. I.

Procedure: The procedure was similar to that of Exp. I. Table 5 details the experimental design. S47 received exactly the same instructions as Ss in the first experiment; however, he was run for eight sessions, approximately 20 minutes in duration, receiving each condition twice. S50 and S51 were run just as Ss in Exp. I except no point loss contingency was applied. S50 got a reinforcement magnitude of five points, S51 received a reinforcement magnitude of three points.

## RESULTS

As in Exp. I, data were not collected from the first four minutes of each session. No Ss "missed" any reinforcements,

## Conditions for Experiment II\*

Subject Number	Session Number	Reinforcement Magnitude	Schedule (left button-right button)
S50	1	5pts.	EXT - VI 15"
	2		VI 22.5" - VI 45"
	3		VI 30" - VI 30"
	4		VI 90" - VI 18"
S51	1	3pts.	VI 90" - VI 18"
	2		VI 30" - VI 30"
	3		EXT - VI 15"
	4		VI 22.5" - VI 45"
S47	1	5pts.	EXT - VI 15"
	2		VI 18" - VI 90"
	3		VI 30" - VI 30"
	4		VI 15" - EXT
	5		VI 30" - VI 30"
	6		VI 22.5" - VI 45"
	7		VI 90" - VI 18"
	8		VI 45" - VI 22.5"

\* see text for explanation



The limited hold contingency never became effective.

Table 6 reveals that all three Ss demonstrated matching of relative response rate on B to relative reinforcement frequency of B. The deviation from matching averaged across all conditions was .046 for S50 and .052 for S51, which very closely approximates the average deviation from matching (of the pooled data) for the three Ss in Exp. I (.072). As in Exp. I, the greatest deviations were on the VI 15" - Ext alternative, where Ss overresponded on the Ext alternative.

There was no ostensible difference between the performance of S50 and S51 (.046 and .052 average deviation from matching respectively) indicating that differing reinforcement magnitude did not affect performance.

Data for S47 who received each condition twice is subdivided according to whether each condition occurred as his first or second exposure to a particular condition (see Table 5). Table 6 shows that the average deviation from matching is .018 for "first exposures" and .012 for "second exposures". The average deviation from matching for the combined data from both exposures is .012. The deviation from matching data for S47 is considerably smaller than for any of the other Ss analyzed in Exp. I and Exp. II. It is apparent that the finding of matching in Exp. I is not substantially altered by repeated exposure to the conditions.



TABLE 6

Relative Occurrence and Relative  
Frequency of Reinforcement for B  
for Subjects 47, 50, 51

Subject Number		VI 30"- VI 30"	VI 22.5"- VI 45"	VI 18"- VI 90"	VI 15"- EXT
S 50	a	.496	.312	.112	.142
	b	.500	.311	.149	.000
S 51	a	.494	.359	.156	.102
	b	.456	.340	.205	.000
S 47	a	.487	.312	.190	.021
	b	.492	.314	.169	.000
First sessions	a	.427	.302	.176	.032
	b	.445	.298	.155	.000
Second sessions	a	.547	.322	.204	.010
	b	.539	.330	.183	.000

\* see text for explanation

a relative occurrence of B

b relative frequency of reinforcement for B

## EXPERIMENT III

The first two experiments demonstrated that equation 1 effectively predicted human simultaneous choice behavior. The purpose of the present experiment was to test the applicability of equation 1 to a successive choice situation. In the present experiment, the same pairs of reinforcement schedules used in the first two experiments were given to each S; however rather than each schedule of a pair being assigned to a different alternative, the schedules alternated every minute, assigning reinforcements successively for responses on one alternative rather than simultaneously for responses on two different alternatives.

## METHOD

Subjects: Three new students, identical in status to those of previous experiments served as Ss.

Apparatus: The apparatus was identical to that of Exp. I.

Procedure: The procedure was similar to Exp. I. Here, however, only one button was lit and operative (the one farthest to the S's left). The schedules within each pair alternated with each other at one minute intervals. Either the red or green stimulus (jewel light) was correlated with a particular schedule during the session. Following the convention of previous experiments, responses during that stimulus associated with the schedule producing the higher density of reinforcement

were labeled "A", responses during the other stimulus, "B". The red stimulus light was associated with A in at least one session, and with B in at least one session for all Ss. The punishment contingency was again effective (RR 10), and consisted of one point deductions from the counter; reinforcement magnitude was five points. Table 7 illustrates the experimental conditions for each S.

Instructions to the Ss reflected the procedural variations; they were instructed that the lights might help them to gain more points, but not told in what way. Sessions were approximately 40 minutes in duration. The punishment contingency was not effected for the first two minutes of each session.

## RESULTS

As in previous experiments, data were excluded from the first four minutes of each session. Table 8 demonstrates the lack of matching between the relative response rate of B and relative reinforcement frequency for B. The most striking feature of the data is that the relative rate of B is a constant, about .45, value in all experimental conditions for all Ss, except for the VI 15" - Ext condition where it is a bit lower (.302). Note that when  $R_1 = R_2$ , as in the present experiment, the relative probability of reinforcement equals the relative reinforcement frequency (see previous discussions).

The absolute rate of A is also presented in Table 8. It is evident that there is a tendency for the rate of A to increase

TABLE 7

## Conditions for Experiment III

Subject Number	Session Number	Schedule (red - green)
S33	1	VI 30" - VI 30"
	2	VI 90" - VI 18"
	3	EXT - VI 15"
	4	VI 22.5" - VI 45"
S35	1	VI 22.5" - VI 45"
	2	VI 30" - VI 30"
	3	VI 18" - VI 90"
	4	EXT - VI 15"
S36	1	EXT - VI 15"
	2	VI 90" - VI 18"
	3	VI 22.5" - VI 45"
	4	VI 30" - VI 30"



Relative Occurrence and Relative  
Frequency of Reinforcement for the B  
Component for a Multiple Schedule

Subject Number		VI 30"- VI 30"	VI 22.5"- VI 45"	VI 18"- VI 90"	VI 15"- EXT
S33	a	.428	.448	.491	.333
	b	.483	.285	.200	---
	R rate in A	27/min.	31/min	38/min.	44/min.
S35	a	.483	.487	.396	.396
	b	.492	.343	.150	---
	R rate in A	35/min.	45/min.	52/min.	50/min.
S36	a	.455	.411	.458	.351
	b	.489	.326	.100	---
	R rate in A	24/min.	31/min.	39/min	40/min.
Pooled Data	a	.452	.449	.448	.362
	b	.487	.318	.150	---
	R rate in A	25/min.	36/min.	43/min.	45/min.

a relative occurrence of B

b relative frequency of reinforcement for B

R response

(and necessarily for the absolute rate of B to increase since the two rates are about the same in all conditions) as the density of reinforcement for A increases (or as it **decreases** for B).<sup>1</sup>

Comparing the results of this experiment with Exp. I two facts are apparent. First, Ss do not match relative rates in successive components to the relative reinforcement frequency obtained in those components; second, they do match relative rates on simultaneous alternatives to the relative reinforcement frequency obtained in those components.

1 See Appendix B for a more complete presentation of absolute response rate data from Exp. I and Exp. III.

## EXPERIMENT IV

The first two experiments demonstrated that human Ss matched relative response rates to relative reinforcement frequencies in a simultaneous choice task. The present experiment was concerned with whether or not Ss would match relative rates to relative punishment frequencies in a similar situation.

## METHOD

Subjects: Three new Ss of the same status as previous Ss served in the present experiment.

Apparatus: The apparatus was identical to that of Exp. I.

Procedure: The only difference between this experiment and Exp. I was that each session here contained equal reinforcement schedules for both alternatives (VI 30" - VI 30") and scheduled one of the following pairs of punishment schedules for each condition.

- (1) Ext - RR 1.66
- (2) RR 2.22 - RR 6.66
- (3) RR 3.33 - RR 3.33
- (4) RR 2.50 - RR 5.00

For this experiment that alternative which resulted in a higher obtained punishment frequency was labeled B. Matching would then refer to any possible equality between the relative rate of B and the complement of the relative punishment frequency for B, i.e. higher punishment frequencies should reduce choice of

a particular alternative. All other aspects of this experiment were identical to Exp. I. Table 9 lists the conditions for each S.

## RESULTS

As in previous sessions, data was ignored from the first four minutes of each session; additionally it was noted that no Ss came into contact with the limited hold procedure.

Table 10 indicates that the relative choice of B approximates the complement of its relative frequency of punishment. For the pooled data, the average deviation from matching was .036 which is somewhat less than the average deviation from the pooled data of the Ss in Exp. I (.073).

Unlike the trend of the first experiments Ss do not overshoot the RR 1.66 alternative, i.e. they do not respond on the RR 1.66 alternative more often than predicted by equation 1 (which is 0). They rarely respond to it at all. This differs somewhat from the results of Exp. I and Exp. II where there was a tendency to respond more often than predicted on the Ext alternative of the VI 15" - Ext condition.

Comparing Exp. I with Exp. IV, it is apparent that equation 1 is symmetrical in describing human simultaneous choice behavior for both reinforcement and punishment paradigms.



## Conditions for Experiment IV

Subject Number	Session Number	Schedule (left button-right button)
S 9	1	RR 6.66 - RR 2.22
	2	RR 2.50 - RR 5.00
	3	RR 3.33 - RR 3.33
	4	----- - RR 1.66
S 10	1	RR 3.33 - RR 3.33
	2	RR 5.00 - RR 2.50
	3	RR 2.22 - RR 6.66
	4	RR 1.66 - -----
S 15	1	RR 1.66 - -----
	2	RR 3.33 - RR 3.33
	3	RR 2.50 - RR 5.00
	4	RR 6.66 - RR 2.22

Relative Occurrence and Relative  
Frequency of Punishment for B

Subject Number		RR 3.33 - RR 3.33	RR 5.00 - RR 2.50	RR 6.66 - RR 2.22	EXT - RR 1.66
S 9	a	.425	.363	.235	.063
	b	.500	.333	.250	.000
S10	a	.459	.369	.234	.035
	b	.500	.333	.250	.000
S15	a	.433	.349	.239	.026
	b	.500	.333	.250	.000
Pooled Data	a	.439	.360	.236	.041
	b	.500	.333	.250	.000

a relative occurrence of B

b complement of relative frequency of punishment for B

## DISCUSSION

The major purpose of this study was to determine whether the matching law (equation 1) provided an adequate means of analyzing human concurrent operant (simultaneous choice) performance.

Experiment I provided a straightforward test of the matching law. In Table 2 it is clear that for a series of different pairs of reinforcement schedules, Ss matched the relative rate of their responses on each of two alternatives to the relative number of reinforcements obtained by responding on each of the alternatives. The demonstration of matching with humans in a concurrent operant situation thus parallels the findings of others (see Herrnstein, 1970 for a review) with other species (mostly pigeons). The detailed sequential analyses performed on the same data (Fig.1 and Fig.2) indicated that the overall matching equivalency was not ostensibly due to the averaging of more molecular, qualitatively different, local effects. It appears as though at least in the present situation that human concurrent behavior is sensitive to frequency of reinforcement and not relative probability of reinforcement.

The largest deviation from matching was observed in the VI 15" - Ext condition (average deviation from matching being .145). It is possible that responses on the Ext alternative might be reinforced by the consequence of a reinforced response on the VI 15" alternative -- such an effect in concurrent schedules

has been postulated elsewhere (e.g. Catania and Cutts, 1963).

It would appear as though this study is at odds with studies that have demonstrated probability learning with humans (see Jones, 1971 for a review). At this point it is unclear exactly what effect procedural differences may play. Most human probability learning experiments employ ratio schedules, i.e. there is some probability of any particular choice being reinforced; the more behavior emitted, the higher the obtained number of reinforcements. In Exp. I of the present study, reinforcements were delivered by VI schedules, not ratio schedules. Typically human probability learning studies use discrete-trial procedures, where Exp. I used a free-operant procedure. It is unclear exactly what effect discrete-trial procedures as compared to free-operant procedures have on the applicability of the matching law in describing human behavior. However, several investigators (e.g. Nevin, 1969) have found that equation 1 described their results in discrete-trial procedures with pigeons.

In a similar vein, the data of Exp. I argue against comparative theories (in particular Bitterman, 1965) which hold that "higher" organisms tend to maximize in simultaneous choice experiments, while "lower" organisms probability match.

Finally, the sequential data from Exp. I do not support theories holding that matching results from the averaging of local effects (e.g. Shimp, 1969). Shimp's notion is that his pigeons tend to choose exclusively, the alternative that, at the time the choice occurs, has the highest probability of being



reinforced, i.e. they are in reality maximizing. By averaging over many responses, the net effect is matching (i.e. equation 1), which masks the fact that the choices are really sensitive to the probabilities of reinforcement. Although it can be argued that Shimp's results may be peculiar to his procedure and/or his species used, one aspect of his procedure is noteworthy.

No amount of evidence, nor any other theories, can ever dispel maximizing notions as long as maximizing theorists continue seeking explanations via reductionistic arguments --there always must be some other, more molecular, unit of analysis, e.g. analyses of interresponse times. Clearly the data of Exp. I can not convincingly argue against possible maximizing, at some other, as yet unspecified, level of analysis.

The other three experiments in this study were concerned with further investigating the nature and extent of the matching law with humans.

Experiment II (Table 6) demonstrated that the exclusion of the point-loss contingency had no effect on the matching tendency of human subjects. In fact, there was less total average deviation from matching for Ss without the point-loss contingency (average deviation of .046 and .052 for S50 and S51 respectively vs. .072 combined average deviation for the five subjects in Exp. I). Due to the smaller number of Ss used in Exp. I, it is unclear from the data whether or not the point-loss contingency results in a larger deviation from matching or whether the superior performance of S50 and S51 (compared to Exp. I) was

an individual difference variable.

Experiment II also demonstrated that there were no differences between Ss who received different magnitudes of reinforcement (five points for S50 and three points for S51). Both Ss closely matched relative response rate to relative reinforcement frequency.

S47 received each condition twice. For S47, the average deviation for all eight sessions was .012 which is considerably less than the .072 combined average deviation for the Ss in Exp. I. It appears as though his superior overall performance is not due to receiving each condition twice since when data were analyzed to show his performance on just the first exposure to the conditions, his average overall deviation from matching was still only .018. At any rate, the data of S47 indicate that equation 1 still holds even when conditions are repeated for a single subject.

The data from the first two experiments in conjunction with the findings of Schroeder and Holland (1969) provide strong evidence for matching (equation 1) with human Ss. The present data demonstrated matching using four different pairs of reinforcement schedules for each S and a button pressing response, the Schroeder and Holland study used only one pair of reinforcement schedules for each S and eye movements as responses.

One difference between these two human studies involves the use of the COD procedure. Schroeder and Holland did not find matching unless an COD was imposed; the present study found matching without a COD. It is unclear to what extent the difference

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may be due to the difference in the response system used.

Experiment III tested the applicability of the matching law to human multiple (successive choice) procedures. The finding (Table 8) was that relative response rate did not vary across conditions, i.e. the absolute response rate in the presence of a stimulus associated with a particular reinforcement schedule of a pair equalled the rate in the presence of another stimulus associated with the other reinforcement schedule of the pair. The failure to find matching when schedules were alternated rather than presented simultaneously is in accord with studies using pigeons which also fail to find matching (e.g. Catania and Reynolds, 1968) with multiple schedules. In studies using multiple VI schedules with pigeons, however, there usually is a tendency for relative response rates to be positively correlated with relative reinforcement frequency. In Exp. III there was no such correlation. The genesis of the difference between pigeons and humans can not be determined from the present data. Another puzzling aspect of the data was the fact that the absolute response rate increased in the stimulus components as the reinforcement density in the A component increased (and, necessarily, as the reinforcement density in the B component decreased) with differing conditions. This dependence between reinforcement schedules and absolute response rates found in the multiple situation was not found in the concurrent situation. It appears evident that there are fundamental differences between human successive and simultaneous choice behavior, i.e. that the procedural variations manifest themselves as differences both in the

relative and absolute response rates.

One possible resolution of the discrepancy between behavior on multiple and concurrent schedules may be to adopt a view similar to that of Herrnstein (1970). In Herrnstein's analysis, all situations should be viewed as concurrent situations. According to Herrnstein (1970), in multiple situations the aggregate of behavior that does not occur on the designated manipulandum is to be determined in some way, frequently by curve fitting, post hoc from the data. Although the estimation of parameters post hoc has limited predictive power, Herrnstein's analysis does suggest a possible way to reconcile the differences between multiple and concurrent behavior.

The final experiment investigated the feasibility of using the concurrent paradigm to measure the effects of varying punishment frequencies on human choice behavior. The findings (Table 10) revealed that Ss would match relative response rates on an alternative to the complement of the relative punishment frequency for that alternative. It thus appears as though the matching law may be useful in the prediction of punishment effects as well.

All in all, three of the four experiments comprising this study demonstrate emphatically the conformity of human concurrent behavior to the tenets of equation 1, and suggest the feasibility of using the matching law as an instrument for predicting and quantifying human behavior in simultaneous choice situations. As noted previously, experiments arising from a probability



learning schema are not necessarily in contradiction with experiments using the discrete-trial or free-operant concurrent paradigm. It is quite possible, as some authors have suggested (Shimp, 1969), that contrasts in performance between the two paradigms may result from the different schedules of reinforcement typically used (ratio schedules in most probability learning experiments versus interval schedules in most concurrent operant experiments) and not represent some fundamental qualitative difference in the way organisms behave.

Nearly all psychologists regardless of theoretical bent, would agree that psychology should concern itself with principles that are: (1) orderly, and (2) applicable to a wide variety of situations (general). Previous accounts of operant behavior (e.g. Skinner, 1966 a) have maintained that the appropriate datum of psychology should be the probability of occurrence of a specified bit of behavior. Generally, this probability is related to changes in time, as a function of the response reinforcement contingency (i.e. response rate). Voluminous collections of data (e.g. Ferster and Skinner, 1957) have amply demonstrated that orderly relationships exist between response rate and schedules of reinforcement.

Interestingly, operant psychologists have obfuscated the distinction between probability of response and rate of response. Sometimes the two are equated (Skinner, 1966 b), othertimes response probability is inferred from response rate (Skinner, 1966 a). This tendency manifests itself by imparting a spurious quantitative feature to the data -- one that is not in fact there. For most probability theorists, probability of response as an inference from response rate does not have quantitative significance, i.e. specifying a value for the absolute rate of a response does not specify a numerical value for the probability of the response.

(Estes, 1959, suggests one possible way of relating response probability and absolute response rate. The minimum possible interresponse time for a subject is estimated --  $1/h$ . This estimate

of  $\frac{1}{h}$  must be based on pilot work, etc. with the subject. The 55  
number of responses per minute a subject actually makes in the  
experiment is then measured. The probability of  
response,  $p$ , is the product of  $r$ , the response rate, and  $h$ , the  
maximum number of responses per unit time which could occur, i.e.  
 $p = rh$ . The cogency of Estes' analysis is contingent upon the  
accuracy and reliability in the "estimation" of  $h$ . If  $h$  can not  
be accurately determined, then the analysis can not be quantified.).  
If the notion of probability of response is to be of general  
importance, then a more specific statement of it seems required.  
Any conceptual schema which permits such analyses should, a priori,  
be preferable to one that does not.

The present data indicate that the matching law provides a  
powerful predictive and quantitative measure of human concurrent  
behavior. As such, it would seem that relative response rate,  
as measured in simultaneous choice situations, provides an  
excellent measure of response probability in humans, both in  
situations using positive reinforcement (Exp. I and Exp. II)  
and punishment (Exp. IV).

Unfortunately, the adoption of relative response rate as a  
general response unit for the study of human behavior appears  
premature in light of the data from Exp. III, which revealed  
that relative response rate in the multiple situation was  
insensitive to changes in reinforcement densities. Herrnstein,  
(1970) has suggested that in the multiple situation, there are  
numerous "other responses", i.e. the multiple situation is really

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a concurrent situation, except that the experimenter is only measuring responses on one alternative. Just because the experimenter has determined that there is only one response alternative does not mean that there are not other "alternatives" in the multiple situation. In fact these "other behaviors", traditionally not measured in the multiple situation, may be reinforced in the same way as Ext responses in the VI 15" - Ext condition of Exp. I were reinforced, i.e. an occurrence of one of the "other behaviors" may be "reinforced" by the consequence of a reinforced response on the manipulandum for which the experimenter has programmed reinforcement. For Herrnstein, these other behaviors should be determined as a post hoc parameter for each S.

An extension of Herrnstein's approach supports the use of the relative response measure. It proposes that relative response rate, at least with human Ss, is the only appropriate measure for determining the influences of environmental manipulations on behavior, i.e. the dependent variable of a science of behavior should be relative choice and the paradigm should be the concurrent procedure. In effect, such an emphasis obviates the use of procedures employing only one manipulandum and using absolute response rate as the index of response probability.

A sufficient appeal for the use of the relative response measure can be made on the basis of its orderliness, generality, and quantitative specificity. There is, however, a growing corpus of data which comes into sharper focus when viewed in the context of the relative choice paradigm, and argues even more for its adoption.



The matching law represents a more formal restatement of other conceptions of behavior (e.g. Schoenfeld and Farner, 1969) which have emphasized the notion that organisms should be viewed as always behaving. According to such analyses, behavior may change from moment to moment but the "amount" of behavior is always constant, i.e. reduction in the absolute frequency of occurrence of one particular response necessarily results in the increase of some other response. Such notions of "behavioral streams" are easily translatable into the language of the relative choice paradigm since this schema in theory views all situations as composed of an infinite number of response alternatives.

In a similar vein, relative response measures incorporate many of the notions of Adaptation-Level Theory (Helson, 1964). Without going into the basic tenets of the Adeptation-Level Theory, suffice it to say it emphasizes the influence of "contextual factors" on behavior. It is obvious from the nature of the relative response rate measure that it emphasizes the notion of "context" by computing the absolute response rate on an alternative as a fraction of the sum of absolute response rates on all alternatives. Relative rate, then, is determined by considering the rate on an alternative in the "context" of all other response rates.

A concurrent analysis assumes an interesting posture with respect to disputes over whether reinforcement strengthens a particular response (Thorndike, 1911) or weakens competing responses (Studden and Simmelhag, 1971) since it claims they are

really different sides of the same coin. The absolute rates on the individual alternatives in Exp. I did not bear any systematic relationship to the schedule of reinforcement maintaining them, and yet the relative rates did, thus indicating that both "weakening" and "strengthening" notions do not appropriately describe human concurrent behavior.

Additionally, a matching analysis views distinctions between negative reinforcement and punishment as being unnecessary, since reductions in the relative frequency of a response (incurred by typical "punishment" paradigms) must cause an increase in the relative frequency of another response (typically interpreted as a "negative reinforcement" paradigm).

The application of the concurrent schema could be extended further at this point; it is sufficient to note that it does provide a novel and more quantitative account of seemingly diverse data.

In the final analysis, it appears that any behavioral paradigm which avails itself to empirical quantification is one that is more precise and scientifically viable. Current theories of operant behavior, particularly human operant behavior, it can be argued, lack this specificity; the concurrent paradigm appears to offer, at least for the analysis of human behavior, a more promising alternative.

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## APPENDIX A



## COMPUTER PROGRAM FOR ANALYZING DATA

Each of the six possible events ( $R_1, R_2, r_1, r_2, \text{punishment}_1, \text{punishment}_2$ ) is encoded and listed in the order they occurred for each subject in a session. The computer reads a particular "sequence length" (M) and then groups all the events into all possible series of consecutive events of length M. A set of "comparative numbers" (J) is read into the computer and compared against each series of consecutive events generated from the data. Thus a count can be made of the frequency of occurrence of any particular sequence J of length M.

```

        DIMENSION X(6000), SEQ (50), KOUNT (50), DIGIT (2000)
        REAL INUM
        READ 1, M, J.
1   FORMAT (2I5)
        READ 3, N
3   FORMAT (I5)
        READ 2, (SEQ(IJ), IJ=1, J)
2   FORMAT (9F8.0)
        READ 5, (X(I), I+1, N)
5   FORMAT (70F1.0)
        IF (EOF, 60) 999, 10
10  I = 1
11  IA = 1
        IO = 0
15  DIGIT(IA) = X(I+10)
        IA = IA + 1
        IF (10.EQ. M-1) GO TO 20
        IO = IO + 1
        GO TO 15
20  CONTINUE
        KM = M
        K = 0
        INUM = 0.
32  INUM = INUM + DIGIT(KM) * 10. ** K
        IF (K.EQ. M-1) GO TO 40

```

```
      KM = KM-1
      K = K+1
      GO TO 32
40    CONTINUE
      IJ= 1
48    IF(INUM.EQ.SEQ(IJ))50,51
50    KOUNT (IJ) = KOUNT(IJ)+1
      GO TO 55
51    IJ= IJ+1
      IF(IJ.GT.J)55,48
55    CONTINUE
      I = I+1
      IF(X(I).EQ.0.) 60,11
60    CONTINUE
      DO 70 IJ = 1,J
70    PRINT 71, KOUNT(IJ),SEQ(IJ)
71    FORMAT (I6,5X,F15.0)
999  CONTINUE
```

## APPENDIX B

Figure A presents the pooled absolute response rate on the A and B alternatives for S18, S19, and S22 in the concurrent situation of Exp. I for the VI 30"-VI 30" (1), VI 22.5" - VI 45" (2), VI 18"-VI 90" (3), and VI 15"-Ext (4) conditions. There is ostensibly no relationship between condition and absolute response rate on either of the simultaneously available alternatives.

Interestingly, however, Fig B. demonstrates that there is a relationship between condition and pooled absolute response rate for S33, S35, and S36 in the multiple situation of Exp. III. As indicated in the text, this relationship is very nearly monotonic. The only aberrant data point is the B rate during the VI 15"-EXT condition was, however, .362 while for the other three conditions the relative response rate was around .45.

It is clear that there are differential effects on absolute and relative response rates as a function of whether the choice response is simultaneous or successive. The genesis of such an effect is not clear. It would be interesting to note , however, whether the response rate-condition relationship of Exp. III would be maintained if the stimulus intervals were longer, say five minutes each. Such an experiment might test the notion that the relationship between response rate and condition of Exp. III might have been due to the fact that much of the responding during the B component was "superstitiously reinforced" by reinforced responding during the A component.



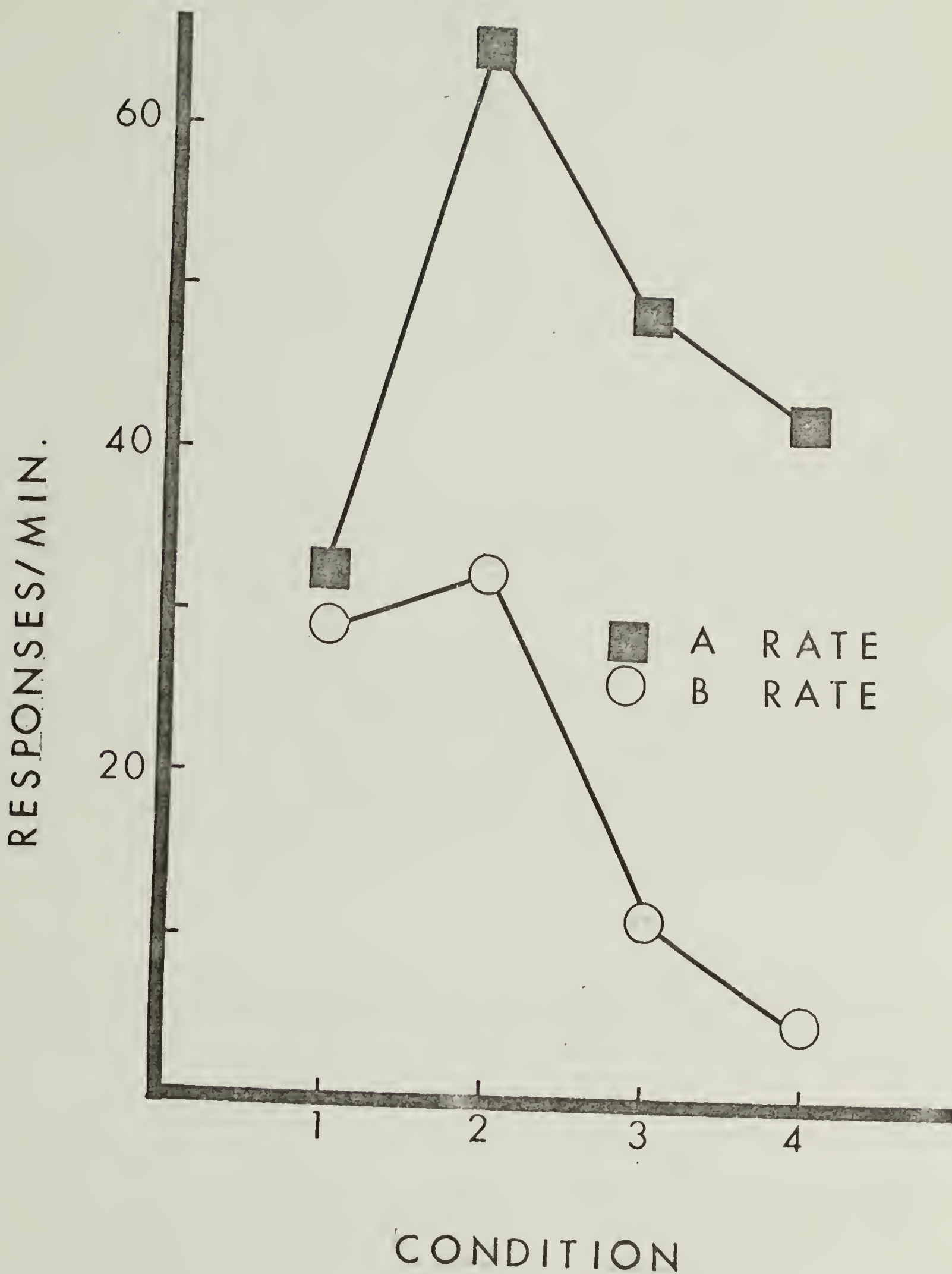


Fig. A Absolute response rates on A and B alternatives for S18, S19, and S22 for the VI 30"-VI 30" (1), VI 22.5"-VI 45" (2), VI 18"-VI 90" (3), and VI 15" -EXT (4) conditions of experiment I.

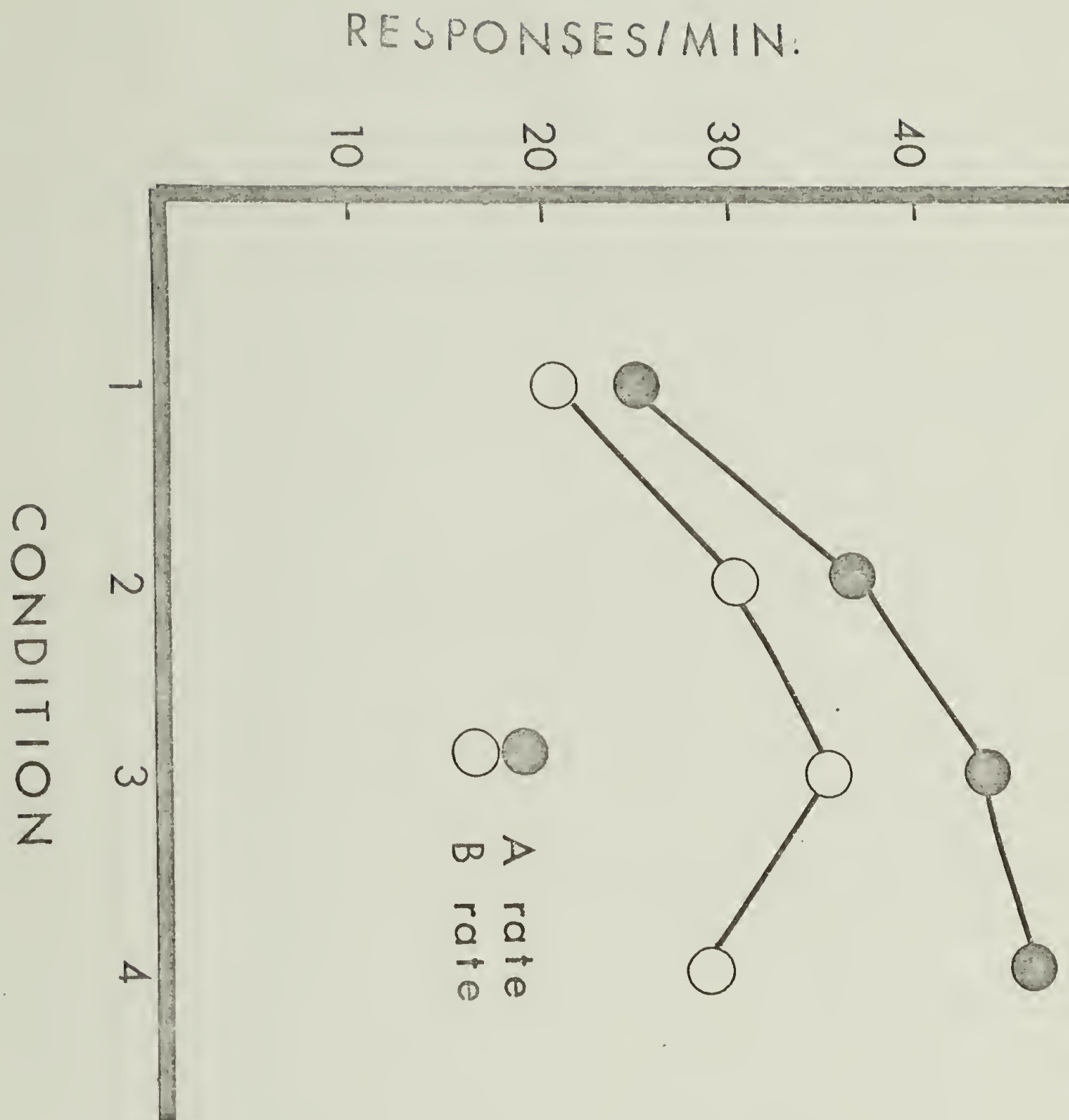


Fig. B. Pooled absolute response rates during stimulus A and stimulus B for S33, S35, and S36 for the VI 30"-VI 30" (1), VI 22.5"-VI 45" (2), VI 18"-VI 90" (3), and VI 15"-Ext (4) conditions of experiment III.

