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DEVIATIONS FROM OPTIMAL CHOICE: SKILLED PERFORMANCE, FEEDBACK, AND BAYESIAN DECISION MAKING

The University of North Carolina at Greensboro Ph.D. 1982

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DEVIATIONS FROM OPTIMAL CHOICE: SKILLED PERFORMANCE, FEEDBACK, AND BAYESIAN DECISION MAKING

by

Richard A. Bauman

A Dissertation submitted to
the Faculty of the Graduate School at
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Approved by

Dissertation Adviser

APPROVAL PAGE

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In the present study, reinforcement initiated the probabilistic assignment of food to either the right or the left lever and each assigned food was held available. But, if food were assigned to the right lever, a 5-sec minimum waiting time (a DRL 5 secs schedule) was activated and the temporal availability of food assigned to this lever was limited to 5 secs. If food were assigned to the left lever, a longer (L secs) DRL schedule was activated. Since a press on the left lever could not satisfy the 5-sec DRL requirement, the optimal form of choice for the present procedure was alternation, if and only if the temporal accuracy of a rat were perfect. Only if this were true, would the absence of food following the first leverpress perfectly predict the availability of food for switching. Each of 5 rats was presented with each of the six possible combinations formed from two magnitudes of L (10 and 40 secs) and three magnitudes of its probability (0.50, 0.75, and 0.95).

The results show that the medians for distributions of first and second latencies following reinforcement closely matched the DRL interval associated with a lever. The interquartile ranges of these distributions were ordinally related to the size of the DRL interval. Neither measure of temporal accuracy was affected by the probability that food was assigned to a lever. The spatial sequence of leverpresses following reinforcement revealed two deviations from the optimal choice. One was a pronounced likelihood of perseverative leverpressing and the second was nonexclusive preference for a lever at the first choice following reinforcement.

Two Bayesian rules of decision making were used to show how imperfect temporal accuracy degrades the predictiveness of unreinforced feedback so that a perseverative second press becomes more probable. Non exclusive choice is discussed as a phylogenetic solution to the problem of shifting resources.

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Finally, Robert and Valerie contributed substantially to this project. A computer program written by Robert allowed me to accurately and efficiently plot the many graphs that populate the Appendix. And

Valerie, at rather great personal sacrifice, gave me the opportunity to pursue a goal that at times seemed elusive but always remained important.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The contemporary study of choice is guided by a material form of hedonism that evolved most directly from the empiricist philosophy of Thomas Hobbes. Unlike John Locke, who used pleasure and pain as causes of motion within the mind, Hobbes used pleasure and pain as causes of physical movement (Peters, 1967). He assumed that the sensation of pleasure was generated if the internal(vital) motivation of the body increased, and, conversely, the sensation of pain was generated if vital motion decreased; therefore, an object that increased vital motion caused an animal to move towards it, and an object that decreased vital motion caused an animal to move away from it. The motivation of behavior was for Hobbes a continuous quest by each individual to acquire ever increasing quantities of material goods that belonged to others, and these ever increasing material manifestations of power were accompanied by ever increasing quantities of pleasure. An animal is therefore driven to maximize its pleasure.

Maximizing captures the meaning of the pleasure principle that Hobbes used to develop a philosophy of man as a political animal, and represents a hypothesis that guides the contemporary study of choice. Unlike the philosophical maximizing principle, which served as a logical prerequisite for the thesis that social rules are necessary if the Leviathan of continual movement toward ever greater quantities of individual power and pleasure were to be controlled, a scientific maximizing principle serves as a rule that can be used to identify the value of a choice and to predict the form that behavior will take in an experiment. Delay and frequency are attributes of reinforcement that the value of choice depends on and that can be used to illustrate the prediction of a maximizing rule of choice.

Maximizing can be studied by scheduling discrete opportunities for a hungry animal to choose one of two alternative responses. For example, a hungry rat might be given the opportunity to press either the right lever or the left lever on each trial of an experimental session. A trial begins immediately following the delivery of a food pellet. On each trial, a press on the right lever initiates an x-sec delay and a press on the left lever initiates a y-sec delay. Either delay is terminated by the automatic delivery of a food pellet. In one version of this procedure, a differential-reinforcement-of- other-behavior (DRO) schedule, any leverpress that occurs during a delay resets that delay. Consequently, x and y are minimum delays to food.

We will assume that at asymptote few if any leverpresses occur during a delay interval so that the obtained delays are approximately equal to the scheduled delays. It is well known that the value of an alternative is a function of how immediately a food pellet is delivered following a choice(Shimp, 1969). While there is some dispute about the best way to express the function, a simple reciprocal relation between value and delay seems to describe much of the data(Shimp, 1969). That is, $V(x)=k/x$, where V is the value, x is the delay, and k is a constant of proportionality that transforms the physical units of time into psychological units of value. Therefore, in a choice situation, if x is not equal to y, and if all other relevant factors are equal, our hungry rat will maximize value on each trial by choosing the one lever associated with the shorter delay to food.

In the previous example, delay was the only relevant factor that differed. It is possible, however, to examine the effect on choice of additional variables such as the probability of reinforcement being assigned to one or the other lever. As Brunswick (1955) put it:

> The crucial point is that while God may not gamble, animals and humans do, and they cannot help but to gamble in an ecology that is of essence only partly accessible to their foresight(p. 236).

Consequently, a perhaps more ecologically valid means of scheduling reinforcement would be to deliver food probabilistically following the termination of each delay.

The previous example can be modified to accommodate the probabilistic assignment of food by assuming that immediately following a leverpress, food is randomly assigned to one of the two levers. We may use p to represent the probability that food will be assigned to the left lever and will be delivered at the end of the y-sec delay, and 1-p will be used to represent the probability that food will be assigned to the right lever and will be delivered at the end of the x-sec delay.

In a standard probability learning study, all relevant variables affecting the value of choice are held constant except the probability that reinforcement is assigned to an alternative. Thus, if the delays (x and y) were equal in the above example, the rat could maximize value on each trial by choosing the lever associated with the highest probability of food assignment.

It is also possible to make the delays and the probabilities unequal between levers. In such cases, the value presumably would be some combination of delay and probability. For example, the expected immediacy of reinforcement is the multiplicative combination of the probability of assignment to a lever, the reciprocal of the delay to food following a press on that lever, and k, a constant of proportionality which transforms physical into psychological units. However probability and delay may combine to determine value, one lever will be associated with a higher expected value than the other (ignoring the case of equal value), and so, that lever should be pressed on every choice trial according to a maximizing principle.

Exclusive choice of one alternative would be the form of behavior that maximizes expected value for each of the previously described laboratory choice procedures. There are some conditions, however, in which exclusive choice would not result in maximization (Staddon, 1981). If, for example, the reinforcers were of different types, each meeting a different set of biochemical needs, exclusive choice of one type presumably would not result in maximum value. Exclusive choice would also not result in maximum value if the outcome of a leverpress (either obtaining food or not obtaining food) on one trial were correlated with the outcome of the next choice. For example, if the assignment of food strictly alternated on each reinforced trial, the receipt of reinforcement from one lever would be perfectly correlated with the certain availability of food for pressing the other lever on the next trial. In the original example given, since food was assigned independently after each leverpress, the omission of food following a leverpress was not correlated with the assignment of food for the next leverpress; therefore our hungry rat would maximize by perseveratively pressing one lever.

This kind of independent assignment is unlikely to be typical of most choice situations in nature. Consider the special case in which prey is either in one patch or another, and it remains there until taken. In this case, the consequences of searching in a patch (making a scan) and not detecting prey is potentially correlated with a decreased likelihood of finding prey in the current patch and an increased likelihood of finding prey after switching to the other patch. A critical parameter is the probability that a scan will detect a prey given that the prey is in the patch. If that probability is near 1.0, a scan without detection would be almost perfectly correlated with food being in the other patch. Consequently, in a simplified habitat that contains two patches with prey in only one, the absence of prey following a scan of one patch reduces the expected value of rescanning that patch to zero.

The effect of this kind of feedback on the structure of choice can be evaluated in the laboratory by only assigning food to either the right lever or the left lever immediately following the delivery of a food pellet. A press on the lever to which food was not assigned again initiates a minimum delay; but now the assigned food is not cancelled. Instead, a hold is placed on the availability of an assigned food so that, following an unreinforced leverpress, the rat can correct his choice by switching to the other lever. In the same way that the absence of prey following a scan of one patch was an index that could signal the certain availability of prey for switching to the second patch, the omission of food following a press on one lever will signal the certain availability of food for switching to the second lever. Thus, a rat which maximizes value by minimizing the expected delay between reinforcements will switch to the other lever if the press to the first is not reinforced, and the predator who maximizes the value of foraging by minimizing the expected delay between scans that terminate in kills will alternate patches if, during a scan in the first, prey is not detected. One way to describe this effect is to say that the consequence of the first choice changes the expected values among the alternatives for the second choice. As just described, the consequence of one response might have the potential of signaling the location of reinforcement on the next trial. Whether it actually does so, however, will depend on a variety of factors, including the animal's sensory abilities and its skills in scanning. In the extreme case, for example, the consequences of a scan could not possibly signal subsequent choice if the animal were incapable of distinguishing the possible consequences. In the leverpress case, in contrast, conditions are optimal for such control since the levers are relatively discrete features of the environment, the stimulus changes following an effective leverpress are large, and the presence or absence of a food pellet is discrete and localized in time. Unlike the leverpress situation, the natural situation which involves a scanning of patches requires a more subtle discrimination inasmuch as scanning and its consequences are more varied, complex, and dimensional relative to leverpressing. In natural foraging the production of a stimulus requires a skillful act in which an animal operates on incoming ambient information, by perhaps moving about its habitat or moving its receptors, so that the invariant properties of prey (figure) can be separated from the surrounding spatial and temporal patterns of stimulation (ground) (Gibson, 1966). It is in this sense that production in natural foraging is an active perceptual task, the accuracy of which will affect the probability of finding prey after a perseverative scan or switch. Because value depends on the probability of prey, and the optimal form of choice depends on value, the optimal form of choice will depend on the accuracy of producing stimulation that feeds back into the value of a choice.

As just discussed, the usual two-lever situation makes the issue of accuracy trivial. An inaccurate response such as pressing in midair is unlikely to occur. The leverpress situation can nevertheless be modified so that responding varies along a dimension that determines accuracy, and inaccurate responses are probable. This modification can be made quite easily by first adding a response requirement to the basic DRO contingency. In each of the preceding examples, food was delivered automatically at the end of a minimum delay. However, if food were delivered only if a leverpress followed the end of a minimum delay, the passage of time during a delay would become part of the stimulus complex correlated with food for responding (leverpressing). Thus, a scan requires the production of a particular waiting duration as well as a press to a particular lever. As a result, the accuracy of the waiting-interval production would determine how well correlated a nonreinforced leverpress would be with reinforcer availability following a switch to the other lever. If all waiting intervals met the time requirement, then an unreinforced leverpress to one lever would be perfectly correlated with food availability on the other lever. If, however, waiting time accuracy were imperfect, an unreinforced leverpress would reduce this correlation, since reinforcement might have been assigned to the lever that was pressed but not obtained due to the waiting time's being inaccurate. In such cases, a switch to the other lever would not provide reinforcement. This situation seems analogous to natural foraging situations, since a scan without detection could mean either (1) that the prey was not in the patch being scanned (here the lever, left versus right) or (2) the scan (here the required wait plus leverpress) was insufficiently accurate to reveal the prey in the patch.[1]

This analysis will be illustrated by application to a specific example, which will include the main features of the present research. The addition of a response requirement following a minimum delay effectively transforms a DRO contingency into a differential-reinforcement-of-low-rate (DRL) contingency. A DRL schedule requires that a minimum waiting time separate reinforced responses. The minimum waiting time of a DRL schedule is a delay. However, it is more than a delay, because no instances of the reinforced response are permitted during the time that an animal waits, if reinforcement is to be delivered at the end of that time. For example, on a DRL 5 sec schedule, a leverpress is reinforced with food if at least 5 secs have elapsed since the last leverpress. Each leverpress will be reinforced if the accuracy of producing the 5 sec delay is perfect, so that each leverpress occurs slightly more than 5 sec following the last press. Temporal accuracy is not invariably perfect, however, so that leverpresses occur before the 5 sec temporal boundary. Each leverpress that terminates a waiting time of less than 5 secs resets the minimum delay and thereby extends the interval between reinforcements. What is most important for the present analysis, though, is that since a food pellet is certain to be delivered if a leverpress terminates a waiting time beyond 5 secs, the absence of food following a leverpress is perfectly correlated with the availability of food for making a longer delay.

In a previous example, a press on either the right lever or the left lever would initiate a minimum delay that was only probabilistically terminated by the automatic delivery of a food pellet. When the food assignment was held until collected, the absence of food at the end of one delay could come to signal the certain availability of food for switching to the other lever. If so, we would expect an animal that operates according to the maximizing principle to simply alternate leverpresses if the first press had not been reinforced. The optimal form of choice might deviate from simple alternation however, if a procedure is used in which the reliability of no-food (feedback) is allowed to intimately depend on the accuracy of producing stimulation that the availability of food depends on. This procedure can be illustrated by considering a study (Logan, 1967) in which one of two DRL schedules was assigned, unpredictably, to a single lever. The delivery of a food pellet initiated a trial by activating one of the two DRL schedules; a hold was used, so that if a DRL schedule was activated, the minimum delay of that schedule had to be satisfied before a new assignment could be made. The duration of the short minimum delay was 5 secs for one group, 10 secs for a second group, 15 secs for a third group, and 20 secs for a fourth group. The duration of the long minimum delay and the probability that either delay would be activated were constant at 30 secs and 0.50 respectively.

Logan argued that if an animal was temporally producing a delay he was in effect choosing that delay; therefore it was not necesssary to assign the two DRL schedules to different levers. Instead, the time that an animal waits before pressing a single lever could be used as a measure of which delay was chosen. The distribution of waiting times between the delivery of food and the first leverpress following food delivery, and the distribution of waiting times between the first leverpress and the second leverpress following food delivery, were used to evaluate the sequence of the first two choices following reinforcement.

Two of the sequences following reinforcement are of interest. One is the perseverative choice of the 30-sec minimum delay. By exclusively terminating each waiting time slightly beyond 30 secs, both the long (the-30 sec) and the short (the-5 sec) minimum delay would be satisfied, and the overall rate of reinforcement would be one pellet per 30 secs. Alternatively, a rat might choose to make the short minimum delay first following reinforcement, and then, if that press is not reinforced, wait the longer interval before the next press. Since the long delay and the probability of assignment were constant in Logan's study, the reinforcement rate generated by this short-long sequence would depend exclusively on the magnitude of the short minimum delay. If, as Logan assumed, the overall rate of reinforcement is being maximized, then it is easy to show that the short-long sequence is optimal for the 5-sec and 10-sec short-delay groups, but the perseverative choice of the 30 sec (long) delay is optimal for the 20-sec short-delay group. When the short delay is 15 secs, both types of response strategies yield the same average rate of reinforcement.

One assumption made implicitly when Logan identified the optimal sequence for each group is that temporal accuracy would be perfect. Perfect accuracy of temporal production would ensure for the 5-sec and 10-sec groups that the probability of reinforcement for choosing the 30 sec delay second following reinforcement would be 1.0, if the leverpress that terminated the first waiting time was not reinforced. Imperfect temporal accuracy, however, would reduce the magnitude of this correlation. If, for example, the 5 sec minimum delay should be chosen, but if the leverpress should occur sooner than 5 secs following reinforcement, the nonreinforcement of that leverpress would not indicate with certainty whether or not the 5-sec DRL schedule had been activated. In such a case, a second consecutive choice of the 5-sec delay could be reinforced. If so, perseverative choices of the short delay interval might tend to occur, causing choice to deviate from its optimal form of strict alternation. In fact, about 30% of the first lever presses were made prematurely by animals in the 5 sec group. Since about 20% of the second leverpresses made by animals in this group were only slightly longer than 5 secs, reinforcement may have strengthened perseveration.

When the smaller DRL was 20 secs, the optimal form of choice was to wait 30 secs before responding; by waiting 30 secs before each leverpress, reinforcement rate would be maximized. The actual times that elapsed between reinforcement and the first leverpress, and between the first and second leverpress, were distributed almost identically, supporting the prediction from maximizing. Inconsistent with maximizing, however, was the fact that the distribution of waiting times peaked between 20 secs and 25 secs. Since there was variability, some of the waiting times were longer than 30 secs and some shorter than 20 secs. A problem of interpretation now arises. Since the region of reinforcement for the 20 secs minimum delay extends beyond 30 secs, the question might legitimately be be asked, "Is a leverpress that ends a waiting time greater than 30 secs an accurate production of the 30-sec delay or an inaccurate but reinforced production of the 20-sec delay?" Likewise, is a leverpress that ends a waiting time that slightly exceeds 20 secs an accurate and perhaps reinforced production of the 20-sec delay, or an inaccurate production of the 30-sec delay? Since Logan′s only measure of choice was the time that an animal waited, and the contingency he used did not define mutually exclusive choices, no answer can be given to either of these questions. Consequently, the sequence of choices following reinforcement can not truly be identified.(This same problem of interpretation could arise with the more extreme differences in DRL, but there the overlap of distributions was less.)

The present study is a laboratory investigation of how the optimal form of choice can be affected by requiring an animal to produce stimulation that could serve as a signal of the availability of food. The DRL was used as a technically simple means of allowing the accuracy of production to affect the value of a choice but, in this study the time that an animal waited before responding was not the only measure of choice, in as much as each of two DRL schedules was assigned to a different lever. Thus, if the long DRL had been assigned, food was delivered only if the animal waited the duration of the long DRL and then pressed the left lever. Likewise, if the short DRL had been assigned, food was delivered only if the rat waited the minimum time required by the short DRL and then pressed the right lever. In addition, an upper limit was imposed on the waiting time for the short DRL so that a press on the right lever could be reinforced only if it occurred between 5 and 10 secs, and a DRL assignment was held until food reinforcement was obtained. Because perseverative choice of the long delay could not satisfy the short delay, and an assigned reinforcement was held until obtained, alternation, if the first press was not reinforced, was the optimal form of choice, assuming the first duration was accurately produced. Furthermore, the responses that earned reinforcements for a choice of either the short or the long minimum delay were temporally and spatially isolated. The sequence of choices following reinforcement could therefore be identified so that the effect of inaccurate production on alternation could be evaluated.

CHAPTER II

METHOD

Subjects

At the start of preliminary training, each of five 90-day-old, male, hooded, rats was reduced to 80% of its free feeding weight by limiting access to food. This deprivation level was maintained for the remainder of the experiment. Each of the 80% weights, except one (265 gms) was between 285 gms and 300 gms.

Apparatus

A standard Grason-Stadler two-lever rat chamber (model E3125B) was housed in a large cabinet that was continuously ventilated and filled with wide band noise. Two levers protruded from the front wall of the chamber such that each lever was equidistant from the side of the chamber nearest to it. Midway between the levers and 1 cm from the grid floor was a 3.8cm x 4.5cm x 1.5cm opening from which the rats collected their pellets.

Above each lever and above the magazine opening was a cuelight. Each leverpress that exceeded 0.28N darkened the cuelight above the lever for about 0.25 sec. The cuelight above the magazine opening remained dark until a leverpress activated the Gerbrands pellet dispenser, at which time the light lit for about 0.25 sec, and the cuelights above each lever darkened. Reinforcers were 45 mg Noyes nutritive pellets.

The first interresponse time (IRT) following the delivery of a food pellet was recorded in one array of eleven counters and the pause that preceded it was recorded in a second array of eleven counters. Because a paüse and a first IRT could be terminated either on the right lever or the left lever, four arrays of counters were used. A separate timer was used to regulate the interval length for the two arrays that recorded pause durations and for the two arrays that recorded first IRT durations. During the first few days of an experimental condition the setting of a timer was adjusted so that a representative summary emerged of those leverpresses that occurred most frequently. This summary was achieved by choosing the timer setting to be not so long that pauses or IRTs were terminated in only a few counters of an array and not so short that many pauses or IRTs were terminated in the last (the eleventh) counter, the upper boundary of which was the length of a session. This rationale allowed shifts of the mode and dispersion of pause and first IRT distributions to be observed.

In addition, individual latencies (pauses and IRTs) were recorded by an event recorder moving at a rate of 1.4 mm per sec. These event records were taken on the last five sessions of each condition; latencies for any response beyond the third after each reinforcement were not recorded.

Procedure

The terminal schedule of reinforcement consisted of a choice procedure in which food reinforcement was assigned probabilistically to one of two levers. The delivery of a food pellet initiated the assignment of food to either the right or the left lever. If it had been assigned to the right lever, it could be obtained only if the rat pressed that lever after waiting at least 5 secs but no more than 10 secs since the last reinforcement or since the last unreinforced leverpress. If the food had been assigned to the left lever, it could be obtained only if the rat waited at least L-secs since the last reinforcement or since the last unreinforced press before pressing the left lever. Thus, the schedule was a choice between two DRL schedules with probabilistic assignment. If the lever to which food had not been assigned was pressed or if a press was made on the lever to which food was assigned but the press failed to meet the associated time requirement, the programmed interval was reset. The resetting of a programmed interval did not cancel food that was assigned. An assigned food was held until it was collected.

The duration of L varied among blocks of sessions as did the probability of assignment. For Rat(R)-1 and R-2, L first equaled 40 secs, and for R-3, R-4, and R-5 L first equaled 10 secs. The relative frequency of L was initially 0.95 for all rats. What follows is a detailed description of the procedure that was used to arrive at these terminal schedules.

During magazine training, neither lever was in the chamber and the white cuelight above the magazine opening accompanied the presentation of each food pellet. This cuelight continued to signal the delivery of food for the remainder of the study.

Once a rat was magazine trained, the right lever was inserted and successive approximations to a press on this lever were followed by a food pellet. One pellet was then delivered for each of 60 presses. Immediately following the sixtieth press, each rat was removed from the chamber.

On the following day, an increasing series of DRL intervals was imposed on right leverpresses. The left lever remained absent from the chamber. For each rat, the DRL intervals and the number of reinforcements at each DRL interval were 0.50 secs, 15 pellets; 1 sec, 30 pellets; 2 secs, 60 pellets; and 5 secs, 120 pellets. Once food was made available, it remained available for only 100 secs. In other words, a 100-sec limited hold (LH) contingency was imposed. After the 120th pellet at DRL 5 secs LH 100 secs, the rat was removed from the chamber.

In the next session, the LH was gradually reduced in the following order: 100, 50, 25, and 10 secs. The 10-sec LH remained in effect for three additional sessions of 120 pellets per session before the LH was reduced to 5 secs where it remained for the the rest of the study.

The DRL 5 secs LH 5 secs schedule was used for 5 sessions of 120 pellets per session. Following the fifth session, the right lever was removed and the left lever was inserted. The DRL interval for left leverpresses was 10 secs and no LH was used. After the third day of DRL 10 secs, R-3, R-4, and R-5 were maintained at their 80% weights, but were not given further training. The DRL interval for left leverpresses was gradually increased to 40 secs over four days for R-1 and R-2. The 40 secs DRL interval was maintained for 5 consecutive days. Following the fifth day of DRL 40 secs for R-1 and R-2, R-3, R-4, and R-5 were again allowed to press the left lever for food that was delivered according to a DRL 10 sec schedule. Both DRL schedules for left lever presses were maintained for an additional nine days before the right lever was reinserted and the DRL 5 secs LH 5 secs contingency was reactivated. The presence of both levers marked the end of preliminary training, and for the remainder of the study a rat could never maximize expected value by exclusively choosing the L sec DRL interval.

The DRL interval for left lever presses, L, and the relative frequency of assignment of L, p(L), were manipulated. The sequence in which each {L,p(L)} pair was used and the number of sessions each pair remained in effect are shown in Table 1 for all rats. All of these {L,p(L)} pairs were imposed for at least 10 days and until the mode of the distribution of postreinforcement pauses showed no systematic variation for five days. All sessions lasted for 100 pellet presentations.

TABLE 1

Number of Sessions

Each cell is a condition that is defined by the intersection of a magnitude of L and a probability of L. In a cell is the number of sessions in which that condition was presented. In parentheses are the numbers of sessions for redeterminations.

R-1

	0.50	0.75	0.95
40	48	47	45(23)
10	29(48)	16	34

R-2

	0.50	0.75	0.95
40	40(24)	46	40(24)
10	14(15)	36	14

R-3

	0.50	0.75	0.95
40	42(29)	48	19
10	23(11)	60	43

R-4

	0.50	0.75	0.95
40	40(29)	52	15
10	31(14)	55	44(7)

R-5

	0.50	0.75	0.95
40	34(21)	18	29
10	28(20)	57	45

CHAPTER III

RESULTS

Introduction

The latency to the first leverpress in each trial is here referred to as Lat-P1 (the postreinforcement pause). If the first leverpress was not reinforced at least one more press had to occur before food could be delivered. The latency to the second leverpress in each trial, measured from the first leverpress following food reinforcement, is referred to as Lat-P2 (the first IRT). The results are divided into two main sections. In the first section, the median and interquartile range of each relative frequency distribution of latencies for P1 and P2 are used to describe the temporal differentiation of leverpressing. In the second section, the probabilities of alternation conditional on the first leverpress following reinforcement not being reinforced are used to describe spatial differentiation of leverpressing.

Temporal Differentiation

Typically, the temporal differentiation of behavior is inferred from a graph of the relation between the central tendency of the distribution of emitted intervals and the required duration. For example, Catania (1970) plotted mean latency from the onset of a stimulus as a function of the required latency. Platt, Kuch, and Bittgood (1973) plotted median leverpress duration as a function of required leverpress duration and Richardson and Loughead (1974) plotted mean IRT as a function of minimum required IRT. The graphic representation of temporal differentiation in the present study was more complex because each of three minimum required delays was imposed at each of three probabilities of reinforcement. Consequently, the traditional graphic format of representing temporal differentiation was expanded so that the differentiation of Lat-P1 and Lat-P2 could be shown for each magnitude of p(L).

The median was chosen as the most representative measure of central tendency for each distribution shown in the Appendix because visual inspection of these distributions revealed that well over three quarters appeared to be positively skewed. This visual impression was evaluated by using the following formula to compute nonparametric coefficients of skewness (Sk) for each Lat-P1 distribution: $Sk=[((P.90+P.10)/2)-P.50]/D$ (Kurtz and Mayo, 1979, p. 165). The symbols P.90, P.50, and P.10 are respectively the 90th, 50th, and 10th percentile points, and D represents the interdecile (P.90-P.10) range. In a negatively skewed distribution, the 90th and 10th percentiles are located relatively close to the origin so that the average of these percentiles, shown in the numerator of Sk, will be less than the median. Consequently Sk will be negative. In a symmetrical distribution, the average of these percentiles will equal the median; hence, Sk will equal zero. In a positively skewed distribution this average will be greater than the median; hence Sk will be positive.

The Sks for each rat and each condition are shown in Figure 1. The scale along the vertical axis of Figure 1 shows the magnitude of Sk above and below zero, opposite which point is a horizontal line. The horizontal axis lists the three magnitudes of probability for the rat's label that appears above this axis. Open points represent Sks for the right lever, closed points represent Sks for the left lever, squares represent Sks obtained when L equaled 10 secs, and circles represent Sks obtained when L equaled 40 secs. Of the 42 observations, 34 coefficients are above zero, one is equal to zero, and only seven are negative. Thus 81% of the distributions were positively skewed.

Median latencies for P1 and median latencies for P2 are shown in Figures 2 and 3 . The format of Figures 2 and 3 is identical to that of Figure 1 except that now the scale along the vertical axis represents time. A horizontal line is drawn opposite each number along the y-axis that represented a minimum required delay. The medians in Figures 2 and 3 are coded in the same way that the Sks were coded: namely, closed points represent medians for the left lever, open points represent points for the right lever, squares represent medians for L equal to 10 secs, and circles represent medians for L equal to 40 secs. The medians in Figure 2 were plotted separately from the medians in Figure 3 because the distributions that were used to obtain the medians shown in Figure 3 contained fewer than 50%, and as little as 5 %, of the median latencies for P1 and the median latencies for P2, and it seemed possible that smaller sample sizes might introduce variability that might obscure the relation between median Lat-P1 or median Lat-P2 and the required minimum delay.

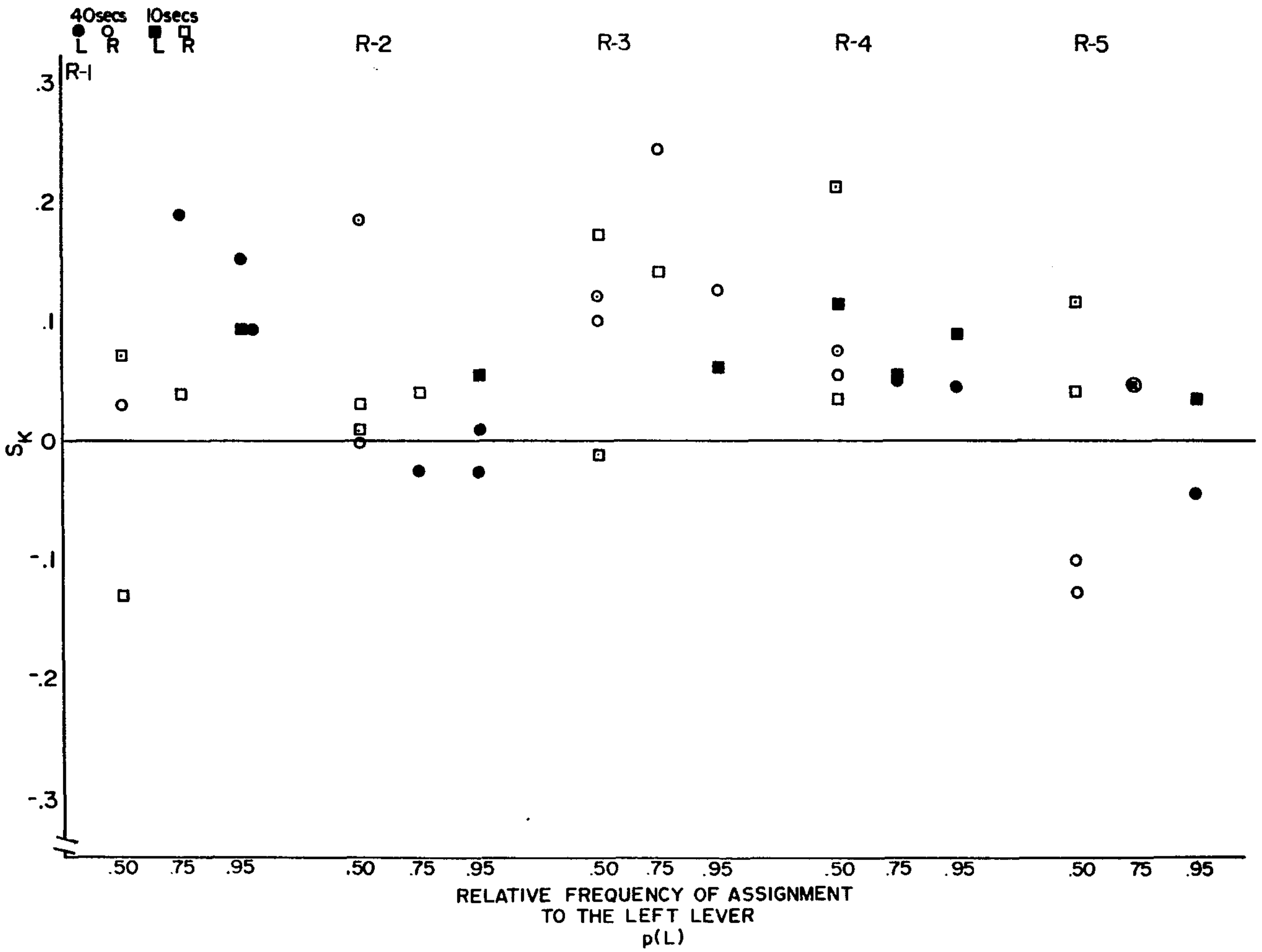


Figure 1. Nonparametric coefficients of skewness (Sk) are plotted above the magnitudes of p(L) for each rat.

The median latencies for the right lever clustered closely about the horizontal line opposite 5 secs in both the top and bottom row of Figures 2 and 3 , although there was perhaps somewhat more scatter in the data from the smaller samples (Figure 3). This matching of median Lat-P1 and median Lat-P2 to the 5-sec required delay suggests that these medians depended on the required delay for the right lever, but not on the required delay for the left lever, nor on the probability of reinforcement assignment, nor on the steady state frequency with which the first or second latencies following reinforcement were terminated by a press on the right lever.

Like median latencies for the right lever, median latencies for the left lever surrounded the horizontal line opposite each time that represented a minimum delay for the left lever. In Figure 2, the median latencies for P1 and the median latencies for P2 cluster about the horizontal line opposite 10 secs, although the medians for Lat-P2 seem somewhat elevated for R-1. Likewise, the median latencies for P1 and the median latencies for P2 cluster about the horizontal line opposite 40 secs, although these medians appear somewhat more dispersed about this line than was the case with the shorter required intervals. In Figure 3, the approximate equality between median Lat-P1 and median Lat-P2 is clearly evident when L was equal to 10 secs but not when L was 40 secs (i.e., one median Lat-P1 for R-1, and four medians for Lat-P2, one for R-1, one for R-5, and two for R-4, were considerably less than the required delay of 40 secs). With the exception of these points, the approximate matching of median Lat-P1 and L, and median Lat-P2 and L, suggest that median Lat-P1 and median Lat-P2 depended on the duration of

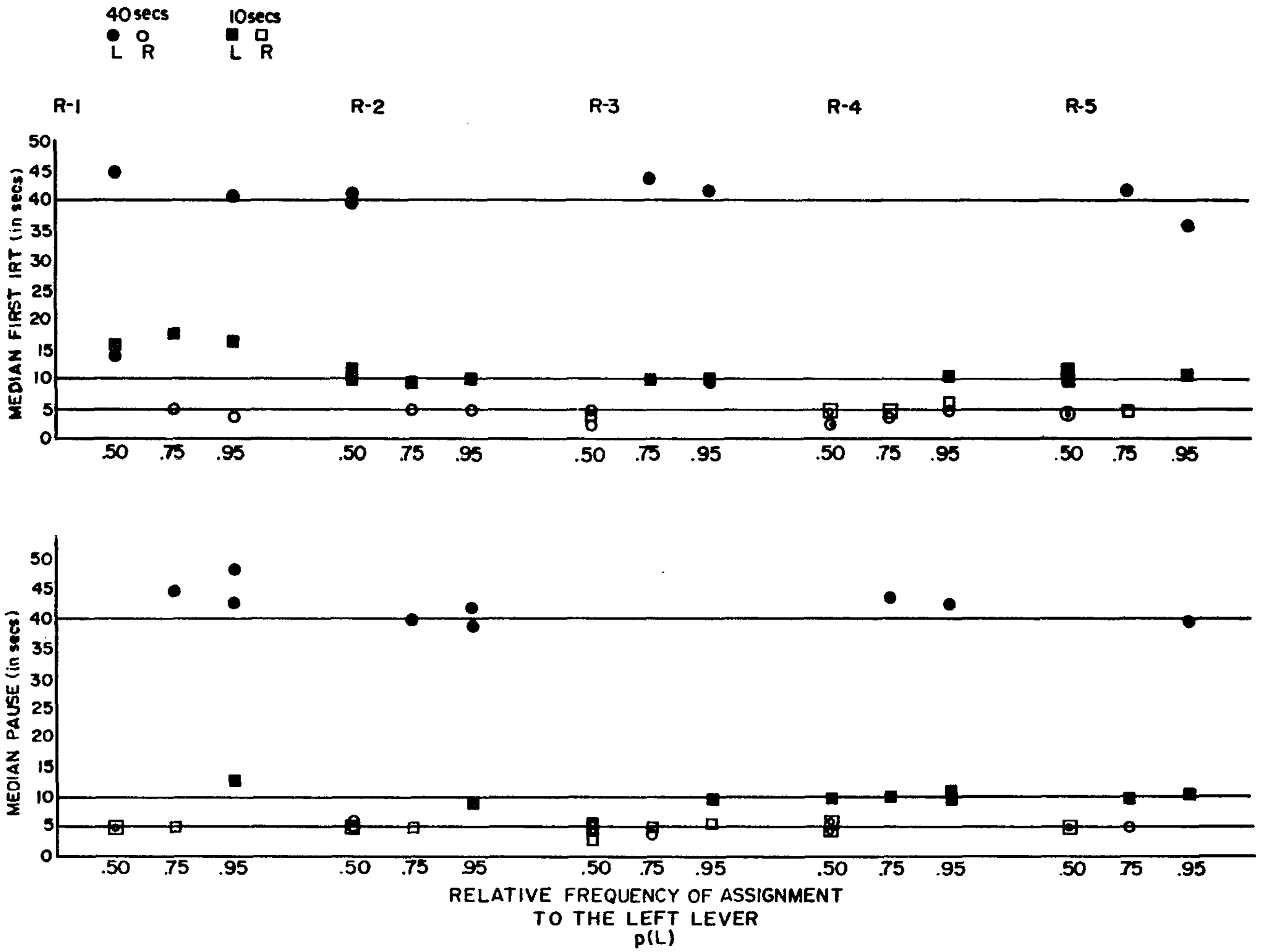


Figure 2. The median time between reinforcement and the first leverpress (bottom row) and the median time between the first and second leverpress (top row) are plotted above the magnitudes of p(L) for each rat. Only those latencies ended on the lever that was most frequently pressed were used to obtain these medians.

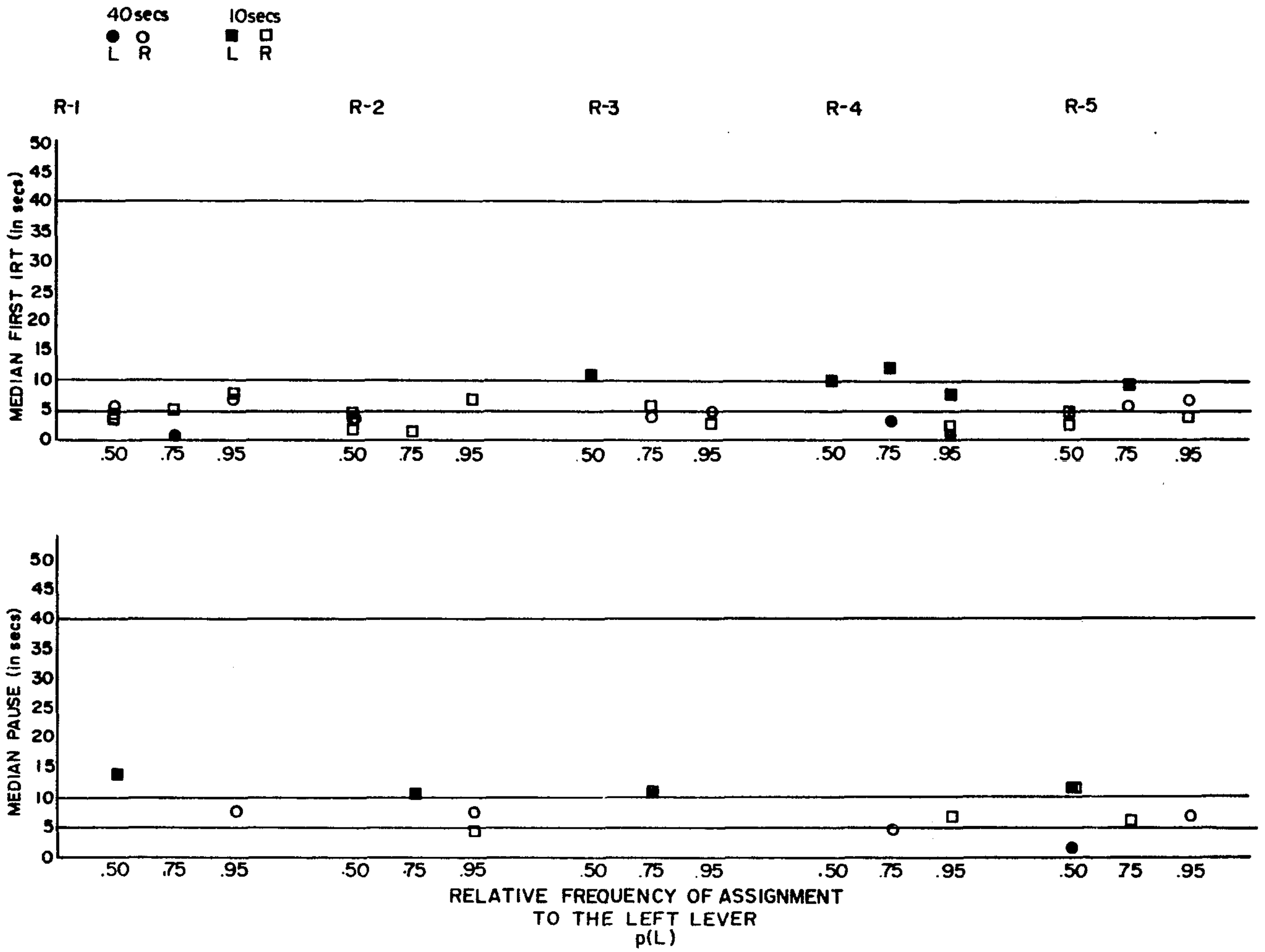


Figure 3. The median time between reinforcement and the first leverpress, and the median time between the first leverpress and the second leverpress are plotted for the lever that was pressed least frequently.

L, but not on its relative frequency of reinforcement (p(L)) nor on the steady state frequency with which presses were made on the left lever.

Another measure of the temporal dimension of leverpressing that could be used to evaluate the differentiating effect of reinforcement is the interquartile range (IQR) of the Lat-P1 distributions and the Lat-P2 distributions. The IQRs shown in Figure 4 and the medians shown in Figure 2 summarize the same distributions in the Appendix . Likewise, the IQRs shown in Figure 5 and the medians shown in Figure 3 summarize the same distributions in the Appendix . The IQRs are coded in the same way that the medians were coded.

The IQRs for the right and for the left lever were not systematically related to p(L), although they were directly related to the length of the minimum delay. This was true for P1 latencies (top rows) as well as for P2 latencies (bottom rows) suggesting that the IQRs like the medians depend on the length of the minimum delay, but not on p(L). (The absence of a clear relation between IQR and minimum delay in Figure 3b and the lack of a clear separation between the IQRs for the 5-sec and 10-sec requirements might mean that the generality of this relation could be limited by the frequency with which leverpresses end the first latency following reinforcement.)

Conclusion and Discussion of Results for Temporal Differentiation

In conclusion, the medians for Lat-P1 and the medians for Lat-P2 approximately matched the minimum required interval independently of the concurrent reinforcement and time requirement. This matching can be

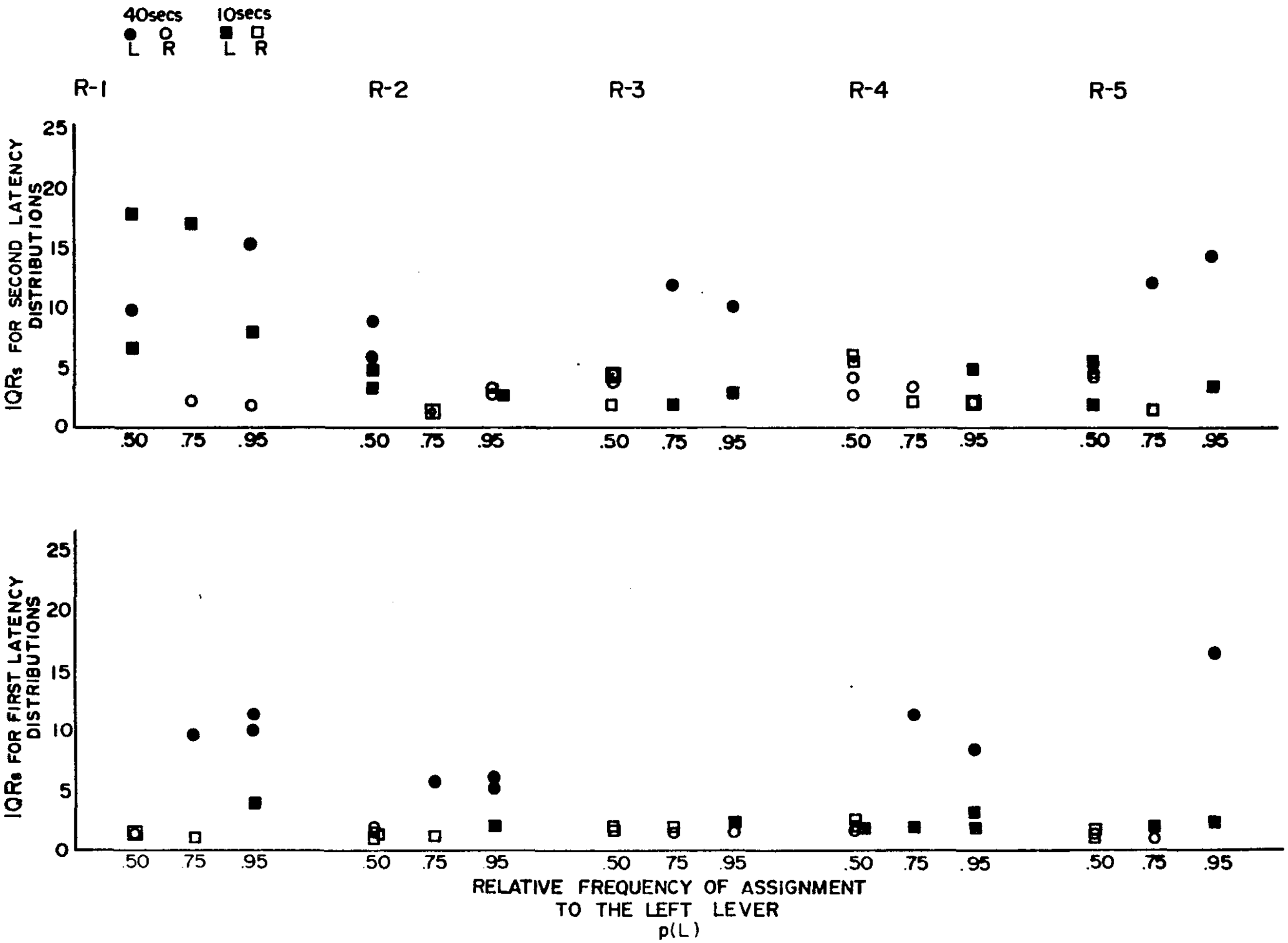


Figure 4. Interquartile ranges for distributions of first latencies are shown in the bottom row and interquartiles ranges for distributions of second latencies are shown in the top row for each rat. Only those latencies ended on the lever that was most frequently pressed were used to obtain these interquartile ranges.

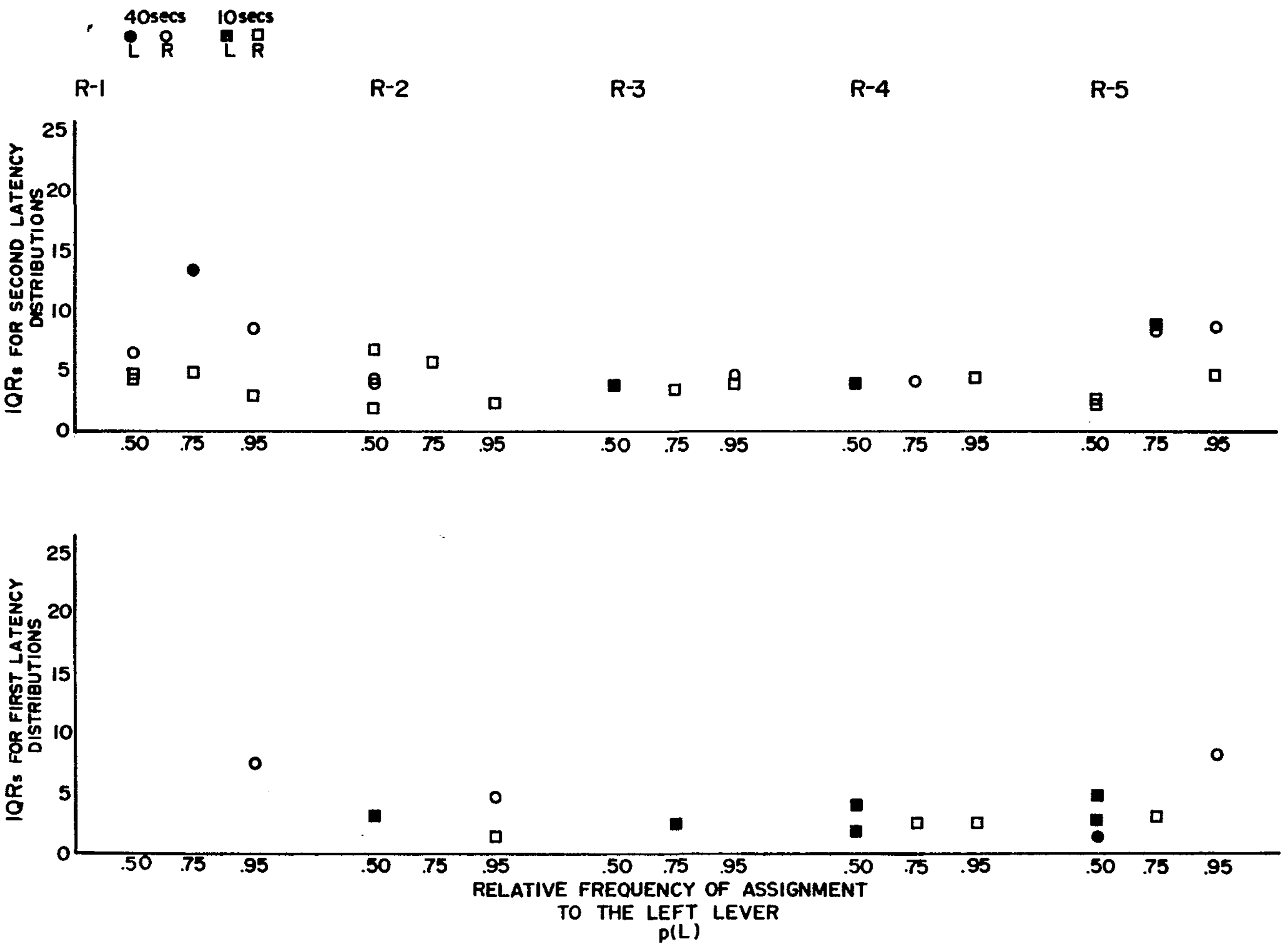


Figure 5. The interquartile ranges for first latency and second latency distributions are plotted for the lever that was pressed least frequently.

explained by assuming that minimum required delay for a lever differentiated a distribution of latencies about a median time that approximately equaled the required delay for that lever. Despite the apparent simplicity of this explanation it fails to give a satisfactory account. Consequently, Platt (1979) proposed a somewhat different explanation. His explanation is based, in part, on the observation reported by Gibbon (1977) that mean obtained duration is proportionally related to mean reinforced duration. Mean reinforced duration is assumed to strengthen leverpresses that terminate latencies beyond the minimum required duration. But this strengthening effect of mean reinforced duration can not alone account for the relation between obtained and required duration because the mean obtained duration is invariably less than mean reinforced duration, and a reduction in the minimum required duration is rapidly followed by a reduction in the mean obtained duration even though many of the latencies that were reinforced before the reduction continue to be reinforced following that reduction. Consequently, Platt added an assumption that mean obtained duration is minimized, perhaps by the cost of increased interreinforcement delays that are generated by latencies that exceed the minimum reinforced duration. This minimax rule of temporal differentiation (minimize the cost of responding by terminating latencies that are no longer than necessary, and maximize the gain by terminating as many latencies as possible that are long enough) determines the relation between the mean obtained latency and the required delay. If the control by the minimizing process is rather strong, the mean might actually become shorter than the minimum required duration.

The minimizing process might be used to explain the frequently reported finding that mean (or median) duration is a fractional-exponent power function of required duration. Thus, median duration invariably does not match required duration. Median duration (Lat-P1 or Lat-P2) did match required duration in the present study. This matching can be explained by considering three factors that could have acted to increase the correspondence between the required duration and median reinforced duration. One factor is the limited hold. At the very least, the limited hold separated the distribution of reinforced durations for the short and long DRL intervals. Mutually exclusive sets of reinforced durations may have acted to reduce the variability of the distribution of durations for each DRL interval in a way that caused the required delay to more closely approximate the median reinforced duration. Likewise, the presence of such temporally separated distributions of reinforcements might also have encouraged a reinforcement interaction that caused the distribution of durations for each lever to appear more contrasting than if the DRL interval for each lever had been presented alone. Such a reinforcement interaction might reduce the variability of each duration distribution so that once again the required delay might be more approximately equal to the median reinforced duration.

Finally, the preliminary training and the extended number of sessions that a long required duration was maintained (see Table 1) could also have acted to reduce the dispersion of the long and short duration distributions so that the required duration and median reinforced duration were more equal.

The point to be made here is that there are candidates which might contribute to reduced variability of the long and short duration distributions. In fact, the small absolute size of many of the nonparametric coefficients of variation for both the short and long duration distributions (see Table 2) is compelling evidence that variability, as measured by the IQR, was astonishingly low, or (conversely) temporal accuracy was very high. Such generally high temporal accuracy could have increased the equality between the minimum required duration and median reinforced duration so that if median reinforced duration differentiates median duration, as Platt (1979) and Gibbon (1977) contend, median duration should approximately equal minimum required duration, which is the relation shown in Figures 2 and 3. In effect, the limited hold, the potential for reinforcement interaction, and specialized and extensive training, may have acted to constrain the minimizing process so that median reinforced duration was a more exact temporal replica of the minimum required duration.

The matching of median duration to minimum required duration was shown in Figures 2 and 3 to be independent of the frequency with which presses on a lever were reinforced. One implication of this finding is that a conditioned response in the present study was not only a press on either the right or the left lever but also importantly included the duration that preceded a leverpress (Fetterman and Stubbs, 1982). In other words, each operant was a spatiotemporal unit. This outcome is not unprecedented in view of Reynolds' (1964) finding that following extinction of keypecking that was reinforced on a DRL 20-sec schedule, as few as two reinforcements completely reinstated the preextinction

TABLE 2

Nonparametric Coefficients of Variation

Each cell is a condition that is defined by the intersection of a magnitude of L and a probability of L. In a cell is the nonparametric coefficient of variation for the lever that was most frequently pressed first during that condition. Coefficients for the left lever are underlined and those coefficients in parentheses are for redetermined conditions.

R-1

	0.50	0.75	0.95
40	.25	.23	.21(.26)
10	.25(.23)	.19	.57

R-2

	0.50	0.75	0.95
40	.26(.29)	.15	.13(.15)
10	.25(.21)	.24	.23

R-3

	0.50	0.75	0.95
40	.40(.36)	.36	.37
10	.66(.34)	.55	.24

R-4

	0.50	0.75	0.95
40	.36(.37)	.26	.20
10	.28(.39)	.18	.19

R-5

	0.50	0.75	0.95
40	.30(.28)	.23	.41
10	.34(.27)	.19	.21

temporal form of behavior. Reynolds concluded:

> The rapidity and accuracy of reconditioning suggest that the process is in this instance related to performance rather than to relearning. From the two reinforcements, the bird does not relearn the temporal spacing of successive pecks that prevailed before extinction any more than it relearns to peck. The performance has not been lost during extinction, rather it lacks one of its conditions of occurrence, the reinforcer.(pp. 273-274)

The finding that in the present study the temporal form of behavior for either lever remains intact across a wide range of reinforcement rates, one of which approached but did not equal extinction (0.05 conditions), is an extension of Reynolds' finding insofar as it shows that the presence and accuracy of temporal performance remains intact despite radical changes of reinforcement frequency. This result might not be a mere laboratory artifact, produced by unnatural conditions; it takes little thought to realize that the Darwinian fitness of those predators who can accurately forage for prey, despite radical changes in prey density, is increased because they are most likely to make efficient use of limited resources, survive, and thereby reproduce.

Results and Discussion for Spatial Differentiation I: Perseveration and Temporal Accuracy

The contingency of reinforcement that was used in the present study localized behavior in space as well as time. The differentiated spatial form of leverpressing was examined by using the four possible sequences: LL, LR, RL, and RR that are formed from the left and right locations for the first two leverpresses following reinforcement.

The principle importance of these sequences is that they can be used to show the effect of temporal accuracy on the differentiation of any sequence of leverpresses following reinforcement, including the optimal one. One way to illustrate this effect is to imagine an ideal rat who only presses a lever following a latency that slightly exceeds the delay for that lever. If a rat were capable of perfect temporal accuracy, then the absence of a pellet following the first leverpress is perfectly correlated with reinforcement for waiting the required time before pressing the other lever. The absence of a pellet following the first press could accordingly come to function as a discriminative event which controls a switch to the alternate lever. However, such certain alternation on the second press might not be expected if temporal accuracy were imperfect. This expectation can be understood by considering what would happen if the pause before the first response (i.e. the Lat-P1) were too short. In such cases, an unreinforced response on a given lever could be followed by a reinforced response on the same lever (if the reinforcer were assigned to the lever first pressed and if the waiting time before the first press were too short). Then the second press on that same lever would be reinforced if the waiting time since the last press had been long enough. In other words, inaccurate temporal production allows for the reinforcement of perseverative responses. A mechanism that supplies reinforcement with opportunities to strengthen perseveration can be found in a study reported by Eckerman and Lanson (1969).

Eckerman and Lanson scheduled reinforcement for pecking at one location along a rectangular strip that was subdivided into smaller rectangles. Their results revealed that the spatial range of pecks about the reinforced location was greater when reinforcement was scheduled intermittently than when it was scheduled continuously. The implication of this finding is that intermittent reinforcement increases variability within a spatially defined response class.

In the present study, reinforcement was scheduled continuously for each spatial sequence of the response class {RL,LR} if, and only if temporal accuracy were perfect. Because temporal accuracy was invariably not perfect food was delivered only intermittently for either RL or LR. This temporal inaccuracy might therefore generate variability within the spatial response class {RL,LR} which could take the form of an increased frequency of perseverative leverpressing.

According to the present analysis, if temporal accuracy is perfect, the absence of food following the first press predicts the certain availability of food for switching. Due to these contingencies we should expect most if not all of the second presses to be made on the other lever. The probability of alternation should therefore approximately equal 1.0. If temporal inaccuracy increases so that food is more likely to be delivered for a second press on the lever that was pressed first, however, perseverative responses are more likely to be reinforced. As a result, the probability of alternation should decrease. This categorical prediction was evaluated by first computing the probability of alternation for each rat in each condition.

Alternation could occur in the present study only if the first leverpress following reinforcement had not been immediately reinforced. Also, alternation could occur in either of two directions. Thus, the probability of alternation, P(A), was obtained for each rat by multiplying the relative frequency of first presses which were not reinforced, P(-R) or P(-L), and the corresponding conditional probability that the second press would be made on the alternate lever, P(L|-R) or P(R|-L). By adding each multiplicative combination:

$$P(A)= P(-R)P(L|-R) + P(-L)P(R|-L)$$

Three features of P(A) are important. One is that if the location of the first leverpress is either exclusively right or exclusively left, then P(A) equals either P(L|-R) or P(R|-L) because P(-R)+P-L)= 1.0. A second feature is that P(A)= 1.0 if temporal accuracy is perfect. This is easily seen once it is recognized that P(L|-R)=P(R|-L)= 1.0 when temporal accuracy is perfect. The third feature is that P(A)= 0.50 when a rat alternates on half the ocassions. This can happen if the first leverpress occurs exclusively on one lever but the location of the next press is equiprobable, or if the first press is occasionally made at either location but the conditionals equalize the probability of an unreinforced press on each lever so that the sum equals 0.50. The most perfect form of this effect occurs when all probabilities equal 0.50.

Figure 6 shows the individual probabilities of alternation for each condition. L equaled 10 secs for each P(A) along the bottom row and L equaled 40 secs for each P(A) along the top row. Within a column, p(L) is constant. Note that the dotted bars in the right column represent estimates derived from the Lat-P1 and Lat-P2 distributions. Unlike the other probabilities of alternation which were obtained from the sequential records of the last five days of a condition, the sequential records for the initial determination of the first condition were rendered uninterpretable by a printout counter malfunction.[2]

In general, although many P(A)s shown in Figure 6 are greater than 0.50, few approach the certainty of alternation that is predicted by the assumption of perfect temporal accuracy. In fact, several probabilities fall well below 0.50. Since the dispersions of the Lat-P1 and Lat-P2 distributions show that temporal accuracy was not perfect, the obtained P(A)s are consistent with the hypothesis that temporal inaccuracy promotes perseverative responding.

Temporal inaccuracy might not only reduce the probability of alternation below 1.0, the limit of certain alternation. Instead, the amount that P(A) is reduced by temporal inaccuracy might be related to the magnitude of temporal inaccuracy. This stronger hypothesis was evaluated by computing the product-moment correlation between P(A) and temporal inaccuracy in both 0.50 conditions. These conditions were chosen because for both magnitudes of L, P(A) varied over a wide range, and the extreme P(A)s were represented by more than one rat.

Before this correlation could be obtained, temporal inaccuracy had to be measured. This was done by using the proportion of first latencies which were too short and which were ended on the lever most frequently pressed first. Because the minimum delay was included within one of the class intervals, this proportion had to be estimated by

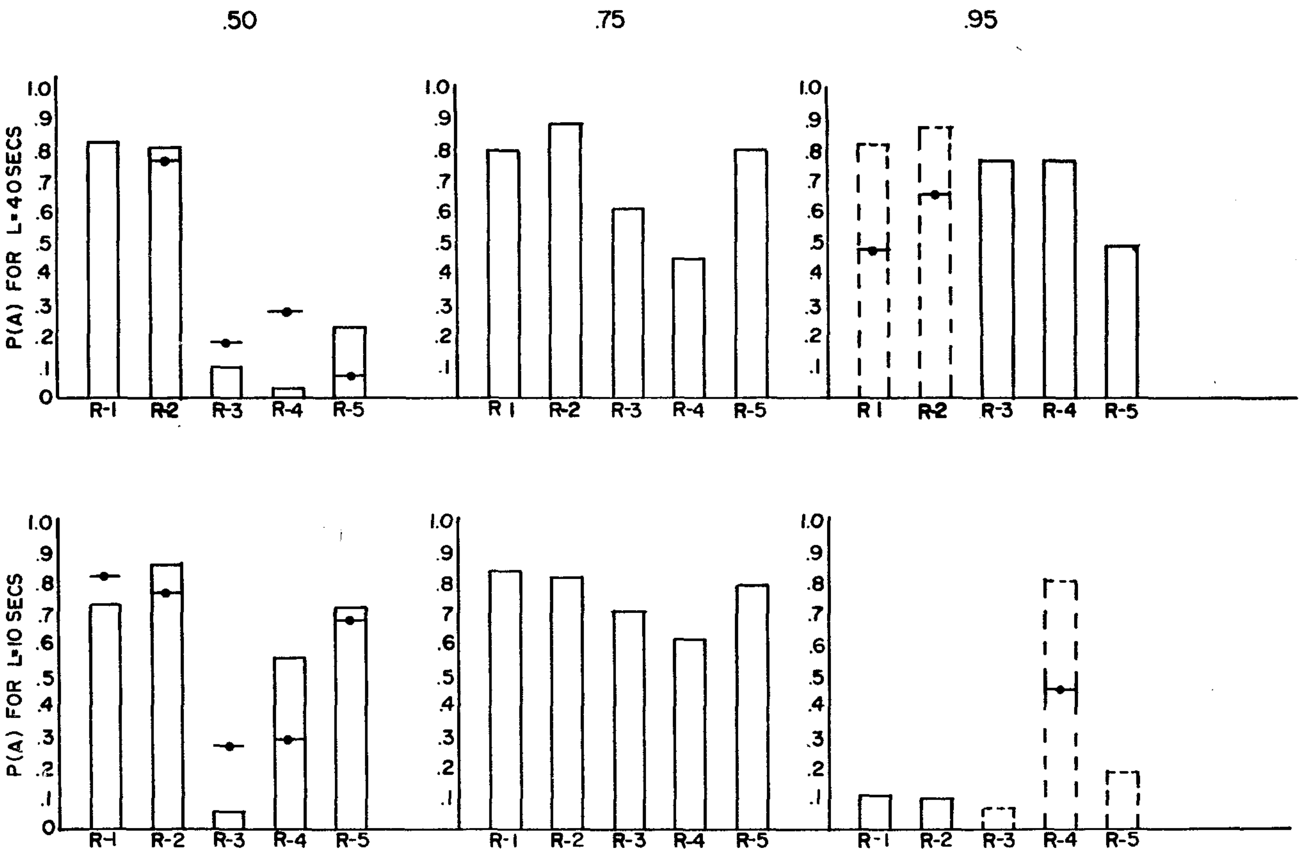


Figure 6. The probabilities of alternation for the 10 secs DRL interval (bottom row) and the probabilities of alternation for the 40 secs DRL interval (top row) are plotted above the magnitudes of ` p(L) for each rat.

multiplying the relative frequency of the class interval that contained the minimum delay by the proportion of that class interval between its lower real bound and the delay. This estimate was then added to the sum of the relative frequencies in all shorter class intervals. The entire sum was an estimate of the proportion of first latencies that were ended at or before the minimum delay.

The Pearson r for the relation between this measure of temporal inaccuracy and P(A) was -0.853 for the 10-sec condition and -0.870 for the 40-sec condition. The probability of an r of 0.805 or more is less than 0.05 for a one-tailed test when the df=3. Since the obtained r for each condition is sufficiently improbable if it was an outcome of sampling error, continuous increases in temporal inaccuracy might promote continuous decreases in probability of alternation.

In contrast to the wide variation of P(A) in both 0.50 conditions, P(A) was below 0.20 for each of four rats in the 10 sec, 0.95 condition. Although P(A) was relatively large for R-4 during the initial determination, the redetermination of P(A) shows a dramatic decrease. Thus, perseveration was extremely probable when when L equaled 10 secs and the relative frequency of assignment to the left lever was 0.95. Since temporal inaccuracy and P(A) could be estimated directly from the redetermination data for R-4, the calculation of r for this condition included these data. The obtained magnitude of r was -0.631 for a one-tailed test with 3 df, far less than the -0.805 required for significance, although, in view of the few degrees of freedom, the direction and magnitude of the obtained r are suprisingly congenial to the hypothesis that temporal inaccuracy encourages perseverative responding.

In the format of the present study, perseverative responding can not be reinforced if temporal accuracy on the first response is perfect. An animal can be reinforced for perseverating only if he is temporally inaccurate and he perseverates. The more inaccurate he is and the more he perseverates, the more often he will be reinforced for perseverating. Temporal accuracy was not perfect in the 10 secs, p(L)=0.95 condition and so perseverative responses were reinforced. Thus, we might expect the probability of perseveration to be related to the probability of reinforcement for perseveration. The relative frequency of reinforcement for perseveration was obtained for R-1, R-2, and the redetermination for R-4 by first counting the frequency with which each of the four possible sequences of two leverpresses terminated in a pellet delivery. (Note: This count could not be done for R-3, R-5, and the initial determination for R-4 because of a printout counter malfunction.) The sum of the frequency of reinforcement for LL perseveration and RR perseveration was divided by the total frequency of reinforcement for alternation and perseveration. This probability equaled 0.92 for R-1, 0.94 for R-2, and 0.45 for R-4. These probabilities of reinforcement are in perfect ordinal agreement with the corresponding probabilities of perseveration: 0.89, 0.90, and 0.54. Since no relation between frequency of reinforcement for perseveration and frequency of perseveration is logically forced by the contingency used in the present study, the obtained ordinal agreement between these variables is consistent with the possibility that increased temporal inaccuracy generates increased opportunities for reinforcement of perseveration which shape increasing amounts of perseverative pressing.

At this point an important qualification about the effect of temporal inaccuracy on the probability of alternation must be invoked. The evidence used to support the hypothesis that perseveration occurs because temporal inaccuracy reduces the probability of reinforcement for alternation has been correlational. The reported correlations between temporal inaccuracy and the probability of alternation, and the ordinal agreement between the probability of perseveration and the probability of reinforcement for perseveration could alternatively be attributed to the greater value of pressing the right lever for those animals who were most temporally inaccurate.

Results and Discussion for Spatial Differentiation II: The First Leverpress and Maximizing

In a standard probability learning procedure, each trial is initiated by reinforcement if an assigned reinforcer is held available until the correct choice is made. An animal can maximize expected value on the first trial of this procedure by exclusively choosing first, following reinforcement, the alternative that reinforcement was most probably assigned to. Since reinforcement was probabilistically assigned to one of two levers, and once assigned it was held available, a rat in the present study could likewise maximize expected value by exclusively pressing one lever first following reinforcement. This means that the probability of either the first left or the first right leverpress following reinforcement should equal 1.0 if choice is optimal. Figure 7 shows the relative frequency of pressing the lever

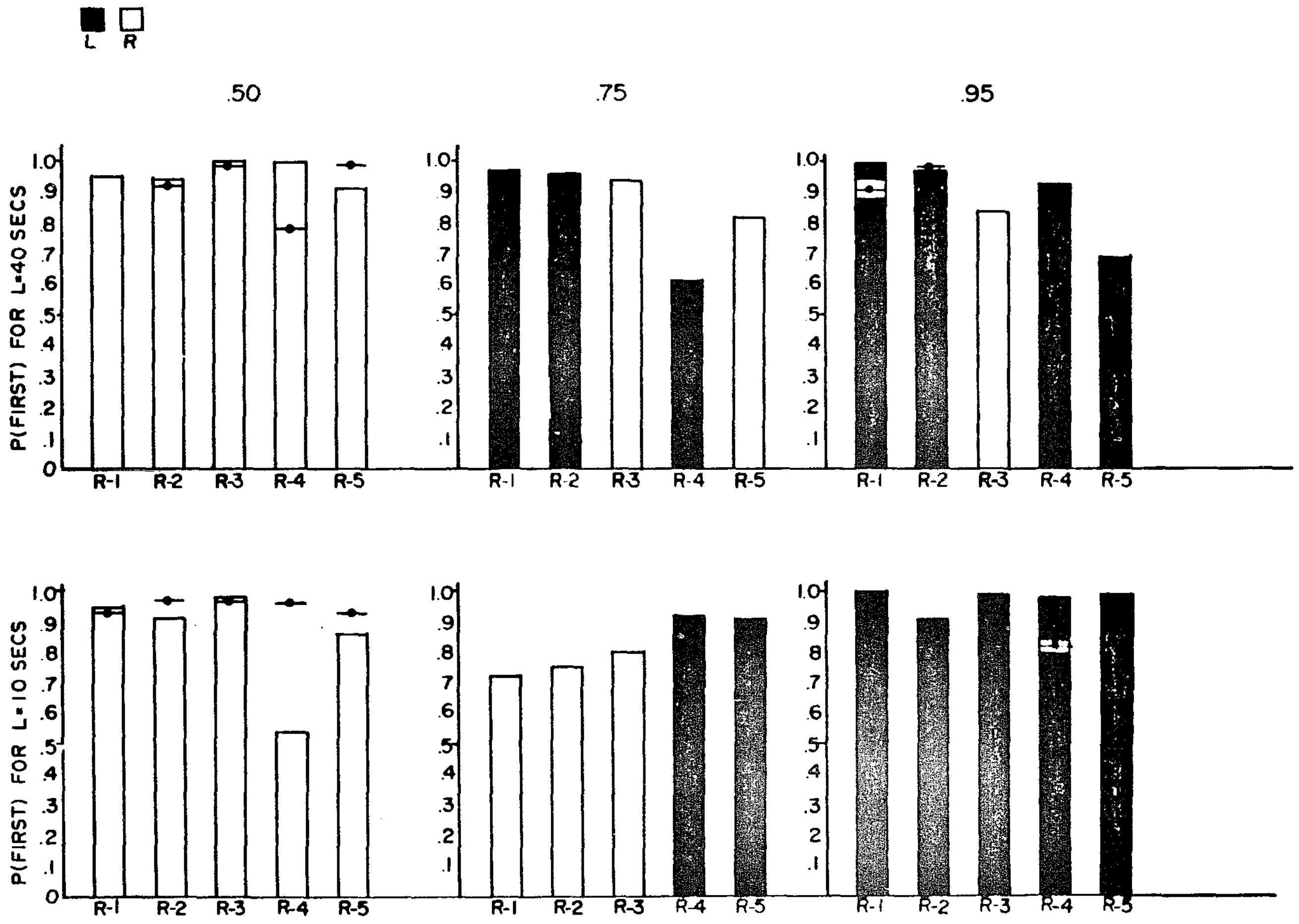


Figure 7. The probabilities of pressing the lever that was most frequently pressed first are shown for the 10 secs DRL interval (bottom row) and the 40 secs DRL interval (top row). Again, the magnitudes of p(L) are shown along the x-axis for each rat.

that was most often pressed first for each rat in each condition. Note that each redetermination point is represented by a line through a closed circle and each bar and associated point refer to the same lever. Although a few of these probabilities approach exclusive choice, none equals 1.0, and several are considerably less than 1.0. Quite obviously, this nonexclusive choice is not congenial to a maximizing assumption. The choices are clear: Is nonexclusive choice to be treated as a deviation from maximizing, or is it to be the focus of an analysis that does not assume an all-or-none effect of value on choice? Although no one answer can be given to this question, the alternative paths are clearly marked and they will be described in the following section.

CHAPTER III

DISCUSSION

Introduction

In a recent theoretical article, Staddon (1981) used the formal properties of various two-alternative choice procedures to identify the choice that at each moment would maximize reinforcement probability. He thereby generated a sequence of choices for each procedure that would occur if the subject chose the alternative that at the moment was associated with the highest probability. These sequences were not necessarily the sequences that maximized the global or overall rate of reinforcement. The formal properties of the present two-alternative choice procedure can likewise be used to generate the momentary maximizing sequence of choices. More important, it will also be shown that deviations from this optimal sequence can be explained by showing how imperfect temporal accuracy introduces an additional source of uncertainty that affects the scheduled availability of reinforcement.

Optimal Choice in the Laboratory

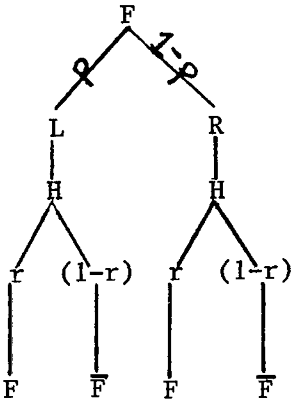
Standard probability learning with correction is a discrete trial choice procedure that is formally similar to, yet less complex than the procedure that was used in the present study. Each trial begins with the assignment of a reinforcer to one of two alternatives, either alternative A or alternative B. If the first choice is not reinforced, the assigned reinforcer remains available until the animal corrects his choice by switching to the alternative that reinforcement was assigned to. Thus, the obtained relative frequency of reinforcement for choosing an alternative will equal the programmed probability of assignment to that alternative. 'Assignment probability' refers to the relative frequency with which reinforcement is scheduled for a choice of a particular alternative. In the usual procedure, a response to the alternative to which reinforcement is assigned is invariably reinforced, but it is possible also to reinforce such responses intermittently. 'Availability probability' refers to the likelihood that a response to the correct alternative will actually produce the reinforcer.

The common properties of probability learning with correction and the present procedure can be used to show that the general form of the momentary maximizing sequence of choices for each procedure is the same. In a standard probability learning study that includes a correction contingency, the relative frequency of assignment to one alternative is p, and the relative frequency of assignment to the other alternative is 1-p. If p represents the relative frequency of assignment to alternative A and p is greater than 1-p, then an animal will momentarily maximize reinforcement probability by exclusively choosing A at the first opportunity following reinforcement. If that response is not reinforced, the momentary probability is 1.0 for a choice of B. Therefore, simple alternation following a nonreinforced response is the general form of the sequence that would result from momentarily maximizing reinforcement probability.

Unlike the situation in a standard probability learning study, the momentary value of a choice in the present study does not depend exclusively on reinforcement probability. In the p(L)=0.75 and the p(L)=0.95 conditions, the larger probability of reinforcement for a first press on the left lever is offset by the longer delay that precedes a reinforced press on that lever. What this means is that value is a combination of reinforcement probability and delay. The most simple combination of probability and delay which has received empirical confirmation (Shimp,1969) is the product of reinforcement probability, the inverse of delay, and a constant that transforms the physical units used to measure delay into the psychological units of value. In the present study, the product of the probability of assignment to a lever and the reciprocal of the DRL interval for that lever defines the minimum expected delay between reinforcement and the first leverpress. Thus, the first choice will momentarily maximize value if a rat exclusively chooses one lever so that he minimizes the expected delay to the first reinforced press. Since each assigned reinforcer is held, an unreinforced press on the lever of maximum value effectively reduces the probability of assignment to that lever to zero, thereby reducing the value of a press on that lever to zero. This effect of an unreinforced first press on the probability of assignment presupposes, however, that temporal accuracy is perfect. If temporal accuracy is not perfect, then availability of reinforcement for alternating will not be certain. Suppose for example, that a reinforcer is assigned to the right lever and that the first press is on the right lever; but suppose also that the press terminates a pause of less than 5 secs. A reinforcer, then, will not be made available for that press even though it was assigned to the right lever. When this happens, reinforcement will not occur following a switch to the other lever but rather only following a pause of at least 5 secs and a second press to the lever first pressed. In other words, if the first press occasionally ends a pause that is too short, responding to the same lever again can be reinforced. The effect of temporal inaccuracy, then, is analagous to reducing the availability of reinforcement for a particular lever since perseverative responses can be intermittently reinforced.[3]

We may consider, then, how explicitly reducing availability of reinforcement for a single lever affects the optimal sequence of choices. By analyzing the explicit procedure we may gain insight into how temporal inaccuracy might affect the optimal sequence in the present procedure.

The following diagram can be used to represent the addition of uncertain availability to a probability learning procedure that holds an assigned reinforcer.



(modified from Staddon, Hinson, and Kram, 1981)

Food (F) is the event that initiates the assignment of a reinforcer in such a way that the relative frequency of assignment to the left alternative is p and the relative frequency of assignment to the right alternative is 1-p. An assigned reinforcer is held (H) and made available with probability r for choosing the alternative that reinforcer was assigned to.

Alternation is the optimal form of choice when the availability of reinforcement is certain. If r equals 1.0 and the first press is not reinforced, then the availability of reinforcement for a switch to the lever that was not pressed first is certain. In effect, the certain availability of reinforcement does not require a rat to make a decision about which lever reinforcement was assigned to following an unreinforced press. When the availability of reinforcement is uncertain, on the other hand, a first press that goes unreinforced does call upon the animal to make a decision. If r is less than 1.0 and the first press is not reinforced, then reinforcement is perhaps (but not necessarily) assigned to the other lever. Instead, reinforcement might have been assigned to the alternative that was chosen first, but it just might not have been available for the first choice of that alternative. Thus, the second choice becomes a decision that requires an animal to infer, given nonreinforcement of the first choice, which alternative reinforcement was most probably assigned to. In this form, the problem of inference is distinctively Bayesian, because past information (nonreinforcement) is being used to update a probability of reinforcement that will direct future choice. In what follows, Bayes′ rule will be used to show how uncertain availability ($r<1.0$) affects this updated probability so that perseverative choices can become members of the optimal sequence.

The asymptotic probability of reinforcement for a first choice of either the left or right alternative is not affected by unreinforced choices. On the first trial, the reinforcement probability of each alternative is simply the product of the probability that reinforcement was assigned to an alternative and the probability that reinforcement was available for choosing that alternative. By using the assignment probabilities and r, the availability probability, the probability of reinforcement for the left alternative is $(p)(r)$, and the probability of reinforcement for the right alternative is $(1-p)(r)$. Thus, the first choice depends exclusively on the probability of assignment. If $p=0.75$ and the first choice momentarily maximizes reinforcement probability, the left alternative should be chosen exclusively on the first trial.

An unreinforced choice on the first trial is information that can be used to update the probability of assignment to the alternative that was chosen first. For example, if the left choice is not reinforced, then the probability of food given a left choice on trial 2, $P(F|L_2)$, equals the product of the probability that food was assigned to the left alternative but the first left choice was not reinforced, $P(L|\overline{F})$, and the probability, r, that food is made available for a choice of the left alternative on trial 2: $P(F|L_2)= P(L|\overline{F})(r)$. $P(L|\overline{F})$ updates the probability of assignment to the left lever by taking into consideration that a press on the left lever was not reinforced. The effect of nonreinforcement on the probability of assignment to the left lever can be evaluated by using Bayes' rule in the following way:

$$P(L|\overline{F})= \frac{P(\overline{F}|L)\ P(L)}{(\overline{F})}$$

$P(\overline{F}|L)$ represents the probability of no food for a choice of the left alternative given that reinforcement was assigned to the left alternative. Since a reinforcer assigned to the left alternative will not be delivered only if it is not available, $P(\overline{F}|L)= 1-r$. $P(L)$ is equivalent to p, the probability of assignment to the left alternative, and $P(\overline{F})$ represents the probability of no food. Since we are assuming that a choice of the left alternative was not reinforced, $P(\overline{F})$ consists of the probability that a reinforcer was assigned to the left but was unavailable or that the reinforcer was assigned to the right. Thus, $P(\overline{F})$ equals $[p(1-r)+(1-p)]$. $P(L|\overline{F})$ therefore equals:

$$P(L|\overline{F})=\frac{(1-r)\ (p)}{[p(1-r)+(1-p)]}$$

The probability of a second choice of the left lever being reinforced, $P(F|L_2)$, and the Bayesian probability that food is assigned to the left lever given a nonreinforced choice of left, $P(L|\overline{F})$, can now be used to show the effect of availability on the optimal sequence. In the numerator of the last expression for $P(L|\overline{F})$, the magnitude of uncertainty about the availability of food is represented by $1-r$. Hence, if food is certain to be available ($r=1.0$), the probability is zero that food was assigned to the left lever on the first trial, $P(L|\overline{F})= 0.0$. Thus, the probability that second choice of the left lever will be reinforced, $P(F|L_2)$, will also equal zero since $P(F|L_2)$ equals $P(L|\overline{F})r$. An r less than 1.0, however, does not allow $P(L|\overline{F})$ to be reduced to zero by an unreinforced choice of the left lever. This means that $P(L|\overline{F})$, and therefore the probability of food for choosing left again, $P(F|L_2)$, will be greater than zero. An r considerably less than 1.0 might sufficiently prevent $P(L|\overline{F})$ from being reduced by an unreinforced choice of the left lever so that $P(F|L_2)$ exceeds the probability of reinforcement for switching to the right, $P(F|R_2)$. Thus, a maximizing animal might again choose the left alternative. Such a perseverative choice is a deviation from simple alternation that is caused by a decrease of the certain availability of reinforcement. In the present study, the certain availability of reinforcement was reduced by temporal inaccuracy; therefore, uncertain availability could have contributed to those perseverative deviations that were most prominently represented by the postreinforcement sequences of both 0.50 conditions and the L=10 secs, p(L)= 0.95 condition.

Given that the availability of reinforcement is uncertain, the probability of assignment, p, can act to promote the likelihood of perseveration. The size of the Bayesian probability that food was assigned to the left lever given an unreinforced press on this lever varies directly with the magnitude of p. This statement is easily understood when it is recognized that p is in the numerator of $P(L|\overline{F})$ and (pr) is subtracted from 1.0 in the denominator of $P(L|\overline{F})$. Because the probability of food for a second press on the left lever is an increasing function of $P(L|\overline{F})$, the probability of a perseverative press on the left lever will increase as p increases. p was very large in the L=10 secs, p(L)= 0.95 condition; therefore, the highly probable and pervasive LL perseveration might represent the combined effect of uncertain availability and a large probability of assignment to the left lever.

In summary, the perseveration that was such a salient feature of performance in both 0.50 conditions and in the L=10 secs, p(L)= 0.95 condition, was explained not as an empirical obstacle to a maximizing account of choice, but instead as an optimal deviation that was caused by the uncertain availability of reinforcement and intensified by a large probability of assignment.

Optimal Choice in the Natural Habitat

In natural habitats, successful foraging depends on fine discriminations and skilled (differentiated) responding. In contrast, the usual probability learning situation requires minimal skill and discrimination. The animal must press one of two discretely localized levers with some minimum force, and so there is differentiation along spatial and force dimensions; however, these differentiations are essentially bivalued and fairly gross. The present procedure more closely approximated the kind of skilled, continuous differentiated repertoire likely to prevail in natural foraging by adding temporal differentiation to the usual spatial differentiation. To "detect" whether food was available or not for a given spatial response, the animal was required to discriminate the duration of time since the last response. Thus, imperfect temporal discrimination in effect determined availability and therefore choice, as was just shown above. Treisman (1975) has shown how imperfect discrimination will affect optimal foraging in the wild. Given the similarity of the approach, it is worthwhile to consider his analysis.

A predator might be confronted with the following choice: rescan habitat A for potential prey or switch to habitat B. The value of each alternative is a gain-effort ratio (GER). The GER for switching, GER(switch), is positively related to the probability that prey is present in a habitat, Pr_0 , the value of captured prey, V_c , and the probability than an animal will detect prey given that it is present, $P(\mathrm{det}|\mathrm{prey})$. GER(switch) is inversely related to the effort required to switch, E_h, plus the one unit of effort required to scan the new habitat once. Thus,

$$\mathrm{GER(switch)} = \frac{\mathrm{Pr}_0 \; V_c \; P(\mathrm{det}|\mathrm{prey})}{E_h + 1.0}$$

Rescanning a habitat can only occur if at least one scan did not reveal the presence of prey. Thus, the probability of detecting prey on the first rescan of a habitat equals $P(\mathrm{det}|\mathrm{prey})$ times the probability that prey was present on the first scan but was not detected, $P(\mathrm{prey}|\overline{\mathrm{det}})$. Bayes′ rule can be used to evaluate $P(\mathrm{prey}|\overline{\mathrm{det}})$, and by assuming that each rescan is the equivalent of one unit of effort, the GER after n negative scans is:

$$\mathrm{GER}(n^{th}\ \mathrm{rescan}) = \frac{\mathrm{Pr}_0 \; V_c \; [P(\overline{\mathrm{det}}|\mathrm{prey})]^n \; P(\mathrm{det}|\mathrm{prey})}{[P(\mathrm{det}|\mathrm{prey}]^n \; \mathrm{Pr}_0 + (1-\mathrm{Pr}_0)}$$

$P(\overline{\mathrm{det}}|\mathrm{prey})$ represents the probability of not detecting prey that is present in a habitat, and $(1-\mathrm{Pr}_0)$ represents the probability that prey is not present in the habitat that is being rescanned.

The optimal form of choice for a predator who maximizes GER will depend exclusively on the prior probability (Pr_0) of prey in a habitat, the effort (E_h) required to switch, and the probability [$P(\overline{det}|prey)$] that available prey is not detected, if the value (V_c) of a capture is equal for both habitats.[4] The effect of E_h, $P(\overline{det}|prey)$, and Pr_0 on the optimal form of choice will be shown by holding two of these three variables constant and manipulating the third. For example, if the effort required to switch habitats is near zero, $E_h \simeq 0.0$, and Pr_0 and $P(\overline{det}|prey)$ are constant and above zero, the GER(switch) will invariably exceed GER(rescan); therefore, a maximizing predator would simply alternate habitats. As the effort of a switch increases, however, the GER for a switch decreases so that at some threshold value of effort, the GER for a rescan will exceed the GER for a switch. Beyond this threshold a maximizing predator will begin to perseveratively scan a habitat. A similar analysis can be used to explain the perseveration found in the present study. Each choice of a lever required a rat to wait a minimum time, which in Treisman's terms is equivalent to scanning the temporal horizon of either the left habitat (lever) or the right habitat (lever). Although the physical effort required to switch habitats (levers) was not large, the psychological effort of waiting a minimum delay following a switch was costly. If the effort in terms of cost covaried with the required duration of a scan, the the GER for a switch to the left habitat when the minimum duration of a scan was 40 secs (L=40 secs) should have been smaller than the GER for a switch to the left habitat when the minimum duration of a scan was 10 secs (L= 10 secs); therefore, a rat should be more likely to rescan when L equalled 40 secs than when L equalled 10 secs. Consistent with this expectation, in 7 of 9 possible comparisons afforded by the present investigation, the probability of perseveration was greater when L equaled 40 secs than when L equaled 10 secs. The binomial probability of obtaining this or a more extreme outcome is 0.07 if an increase and a decrease were equally likely.

The probability of not detecting available prey, $P(\overline{\text{det}}|\text{prey})$, can also be used to explain alternation and perseveration as optimal forms of choice. $P(\overline{\text{det}}|\text{prey})$ will equal zero for the ideal predator who perfectly detects the presence or absence of available prey. Consequently, the GER for a rescan will equal zero and the GER for a switch will exceed zero for any finite amount of effort required to switch. Simple alternation is therefore the optimal form of choice for the ideal predator who perfectly detects the presence of available prey and for the ideal laboratory predator who, as in the present study, perfectly detects the duration that signals the availability of food. Perfect detectability of prey should reduce the GER for a rescan to zero in the same way that perfect temporal accuracy should have eliminated uncertainty (1-r) about the availability of food, so that the probability of reinforcement for a perseverative choice would have been reduced to zero. In fact, since any undetected prey is effectively unavailable, $P(\overline{\text{det}}|\text{prey})$ represents the unavailability of prey, as (1-r) represents the scheduled unavailability of food. (1-r) and $P(\overline{\text{det}}|\text{prey})$ are not, however, conceptually identical. Unlike (1-r), which can be increased without decreasing the detectability of an assigned reinforcer, $P(\overline{det}|prey)$ depends on those stimulus features, such as shape, size, and color, and the background, that uniquely determine the imperfect detectability of prey. Therefore, the unavailability of prey is an outcome of imperfect detectability, in the same way that the unavailability of food in the present study was an outcome of imperfect temporal accuracy. Consistent with this comparison is the finding that measures of temporal accuracy vary with the size of the DRL (Platt, 1979). For example, in the present study, the IQRs and the median latencies depended on the length of the minimum delay, not on overall density of reinforcement or on probability of assignment. The general conclusion is that the predator's perseverative scan can not be independent of the imperfect detection of prey, nor in the present study, can the rat's perseverative leverpress be independent of the imperfect detection of the stimulation that signaled the availability of reinforcement.

The optimal form of choice can include perseverative scans of a habitat only if the accuracy of detecting available prey is not perfect. That is, if $P(\overline{det}|prey)$ is above zero. Likewise, only if (1-r) is above zero can the optimal form of choice for probability learning with correction include perseverative choices of an alternative. When $P(\overline{det}|prey)$ and (1-r) are above zero, a negative scan of the most valued habitat does not reduce the GER of a rescan to zero, and an unreinforced choice of the most valued alternative does not reduce the probability of food for a perseverative choice to zero. In fact, a large $P(\overline{det}|prey)$ greatly lessens the reduction of GER(rescan) by a negative scan in the same way that a large (1-r) greatly lessens the reduction of either

$P(F|A)$ or $P(F|B)$, whichever alternative was chosen first, so that the predator will be likely to rescan and the laboratory animal will be likely to perseveratively choose, as rats did in both 0.50 conditions.

The last variable that can affect the optimal form of choice is Pr_0 , the a priori probability that prey is available in a habitat. If $P(\overline{det}|prey)$ and E_h are constant and above zero, then at a threshold magnitude of Pr_0 the GER for a rescan will exceed the GER for a switch. Above this threshold, perseverative scans become increasingly more likely and as Pr_0 approaches 1.0 the number of rescans necessary to reduce the GER for a rescan below the GER for a switch approaches infinity. In the present study, the probability of assignment, which is similar to the a priori probability of prey, was near 1.0 in the L=10 secs, p(L)=0.95 condition. Therefore, the ubiquitous and extremely probable LL perseveration in this condition might represent the combined effect of a large a priori probability of food in the left-lever habitat and the imperfect detection of stimulation that signaled the availability of food.

Concluding Discussion

The assignment of a reinforcer to one of two levers, the holding of an assigned reinforcer, and the scheduled certain availability of an assigned reinforcer are formal properties of both the present procedure and a standard probability learning procedure that includes a correction contingency. Unlike the usual laboratory choice behavior, imperfect temporal production reduced the certain availability of an assigned reinforcer in the same way that imperfect detectability reduces the availability of an assigned prey; therefore, the present procedure may be viewed as a methodological bridge between the study of choice in the laboratory and the decision making of an animal who must forage for prey. In this sense, the present procedure is akin to the laboratory choice procedure that Lea (1979) used to study foraging. Lea's simulation of foraging allowed him to examine parametrically the choices of a laboratory animal who was confronted with choices that resembled those that a predator might be confronted with. By using this procedure, Lea was able to evaluate whether the choices of laboratory animals which deviated from the axioms of optimal foraging were true deviations or perhaps were a product of the standard procedures that are used to study choice in the laboratory. His results showed two primary deviations that were also reported in the literature of optimal foraging. One was "...the occurrence of stochastic rather than exclusive preference..."(Lea, 1979, p. 884). In other words, animals do not exclusively prefer the most valued alternative source of food. Instead, the probability of choosing an alternative increases monotonically as the value of that alternative increases. The first-order conditional probabilities in Figure 6 show that no rat in the present study exclusively pressed one lever first following reinforcement(Shimp, 1973). The first choices of R-1 and the first choices of R-2 in the L=10 secs, p(L)= 0.75 condition illustrate nonoptimal performance in another way. By choosing the right lever first, the expected delay to reinforcement was longer than it would have been had the left lever been chosen first. Since food was delivered more immediately for a right leverpress than for a left leverpress, and more frequent deliveries of food mean larger amounts of food, this nonoptimal choice might be an instance of a preference for a small immediate reward over a longer delayed, much larger reward, despite a reduction in the overall intake of food (eg. Lea, 1979; Rachlin and Green, 1972).

In the present study, the perseverative deviations from the optimal sequence of simple alternation could be reconciled with a Bayesian account of optimal foraging or optimal choice by showing that temporal inaccuracy can affect the value of a perseverative choice. Nonexclusive choice and preference for immediacy will require a more basic reformulation of the axioms of optimal choice. Nonexclusive choice might indicate that the effect of reinforcement on a choice is not all-or-none. A complementary explanation of nonexclusive choice is that a predator who does not choose exclusively can perhaps more effectively monitor alternative food sources (Baum, 1981, p.77). Although this predator would not optimize, nonexclusive choice would allow a predator to monitor alternative sources of prey so that behavior could quickly be readjusted if the density of prey should change. One reason why the density might change is the very act of predation. That is, the available prey could be reduced by repeated kills. Nonexclusive choice might therefore convey a selective advantage to predators who do not choose the most valued habitat exclusively. Nonexclusive choice in the laboratory might therefore represent a phylogenetic type of variability that is adaptive in the natural habitat but not in a laboratory study of choice.

Preference for immediacy might also convey a selective advantage on predators. If the availability of long-delayed, large prey is not certain, then those predators who choose the certain availability of the small, immediate prey are effectively avoiding the risk that the large prey may not be available at a later time.

FOOTNOTES

[1] The number of kills might be maximized if a predator rapidly scans a patch so that an available prey will be detected most immediately, but not so rapidly that available prey will be missed. A predator who misses available prey might detect prey while rescanning or after returning from another patch where prey was not available. In either case, the delay between kills is extended beyond the minimum time between kills because a rapid scan caused a predator to miss available prey. Likewise, the minimum time between kills might be prolonged if a predator scans a patch too slowly even though prey might be detected and killed. Therefore, the excessively rapid and excessively slow scanning of a patch might act to titrate the duration of a predator's scan about an optimal duration which minimizes the time between kills. The DRL analog is a laboratory tool that might be used to study the shaping of an optimal duration of scan.

[2] It should be recognized that the estimated P(A) will be equivalent to the P(A) that the corresponding sequential record would yield only if the first choice following reinforcement was exclusive. Since choice was not exclusive, these probabilities are only estimates. But, the Lat-Pl distributions for all first conditions show that choice was so nearly exclusive that any deviation between the actual and estimated P(A) is probably very small.

[3] Although the major emphasis here is that temporal inaccuracy can affect availability, it should be recognized that since availability depends on temporal inaccuracy, and temporal inaccuracy depends on the length of the minimum delay, availability depends on the length of this delay. The availability of reinforcement for right leverpresses will therefore not equal the availability of reinforcement for left leverpresses.

[4] If n represents the number of negative rescans before a switch then by setting GER(switch) equal to GER(rescan) n is shown to equal:

$$\frac{[\ \log(1-Pr_o\ ) - \log[E_h + (1-Pr_o\ )]\ ]}{\log[P(det|prey)]}$$

Thus, the critical number of rescans does not depend on V_c, if V_c is the same for both habitats. If V_c is not equal for both habitats then n also depends on the ratio of values that reverses itself following each switch.

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APPENDIX

Two graphs are shown for each rat for each presentation of an experimental condition. The spatial arrangement of each pair preserves the temporal order of latencies following reinforcement so that the left graph of a pair represents the relative frequency of postreinforcement pauses (first latencies), and the right member of a pair represents the relative frequency of first IRTs (second latencies). Each relative frequency for the right lever (a triangle) and each relative frequency for the left lever (a square) is above the upper real limit of a class interval. Where only triangles or squares appear, choice was either exclusive for the right or left lever, or so few presses were made on one lever that the relative frequency for that lever was less than .006.

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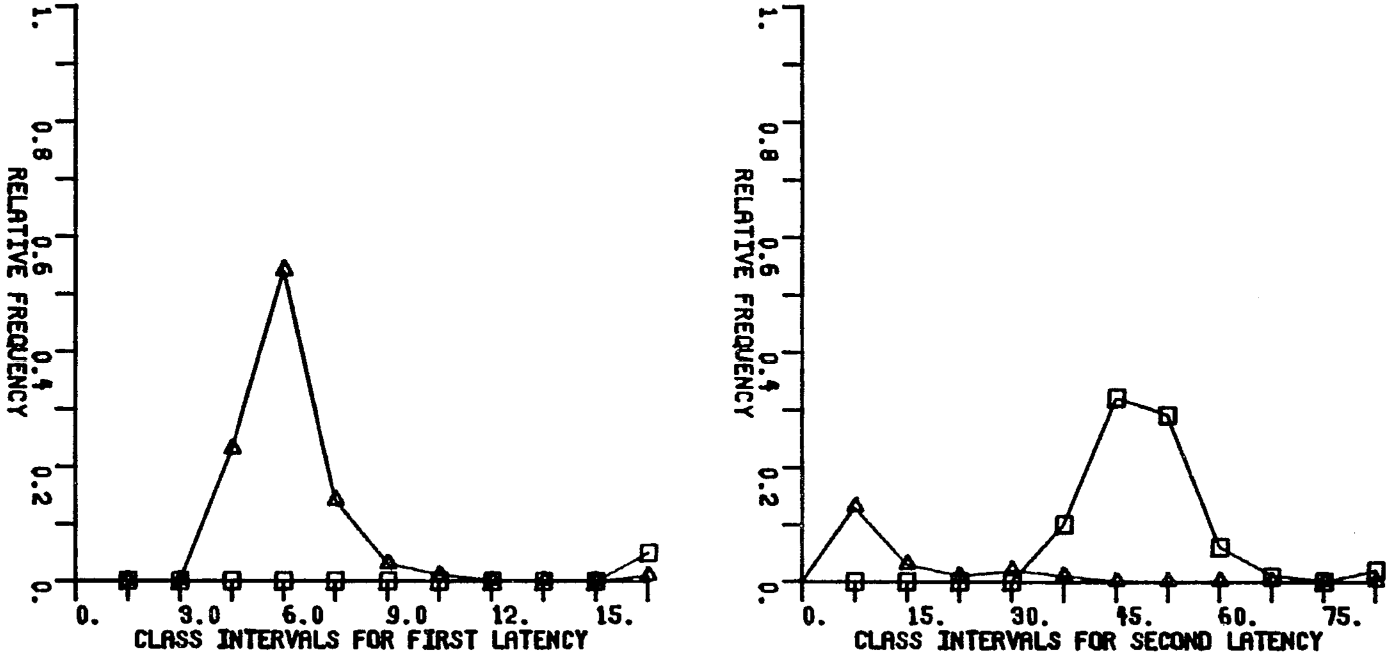
R-1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CLASS INTERVALS FOR FIRST LATENCY
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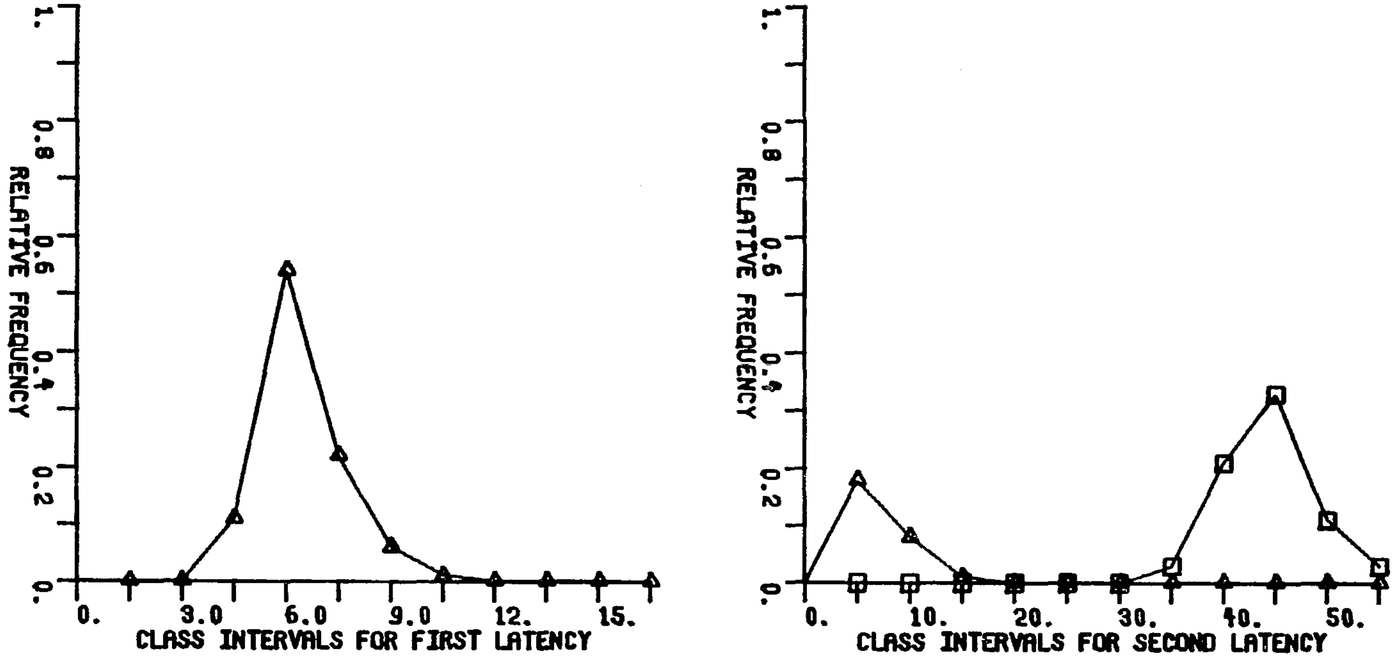
CLASS INTERVALS FOR SECOND LATENCY

R-2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CLASS INTERVALS FOR FIRST LATENCY
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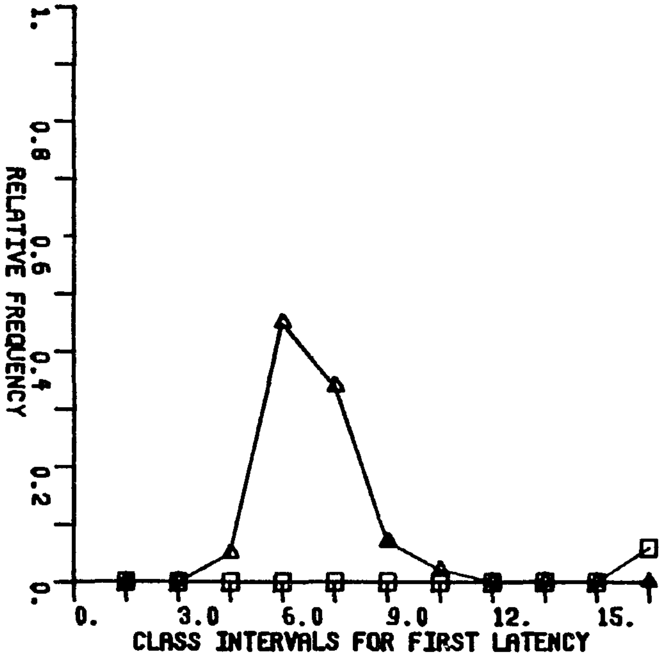
CLASS INTERVALS FOR SECOND LATENCY

R-2(redet)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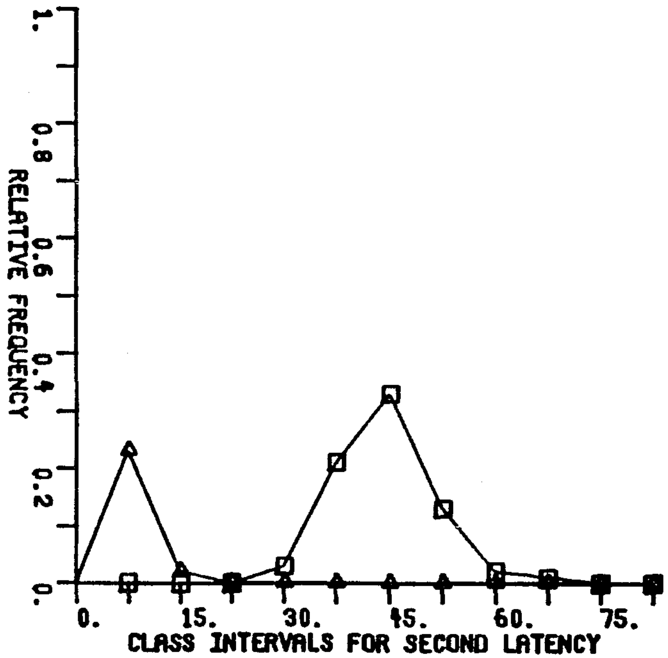
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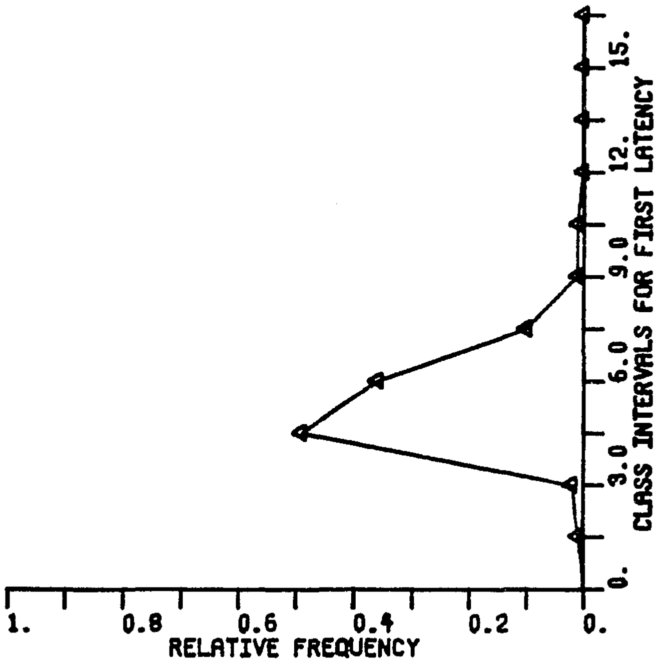
CLASS INTERVALS FOR SECOND LATENCY

R-3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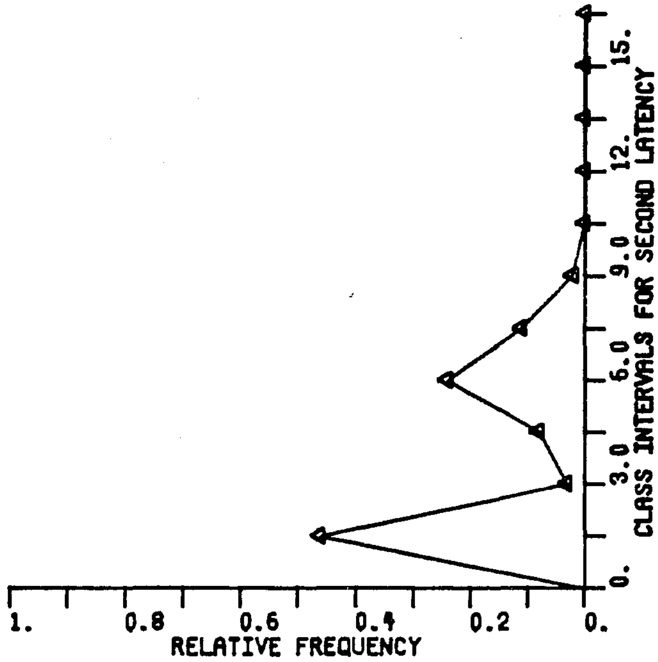
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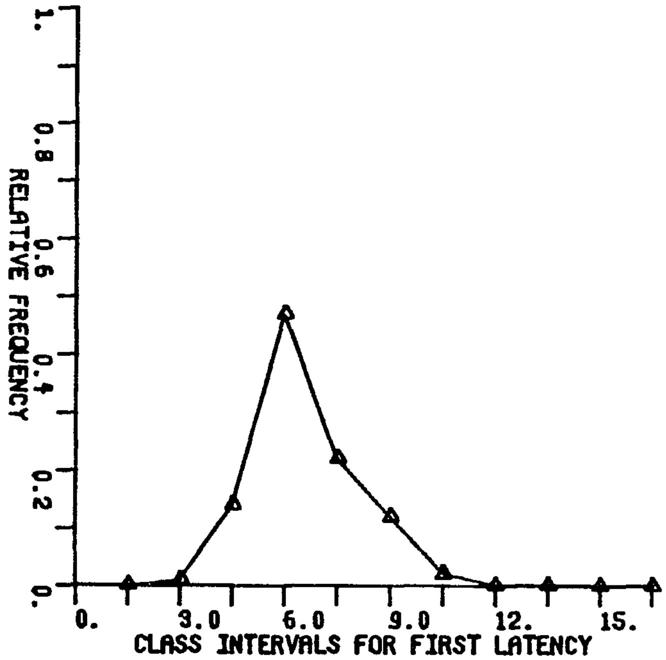
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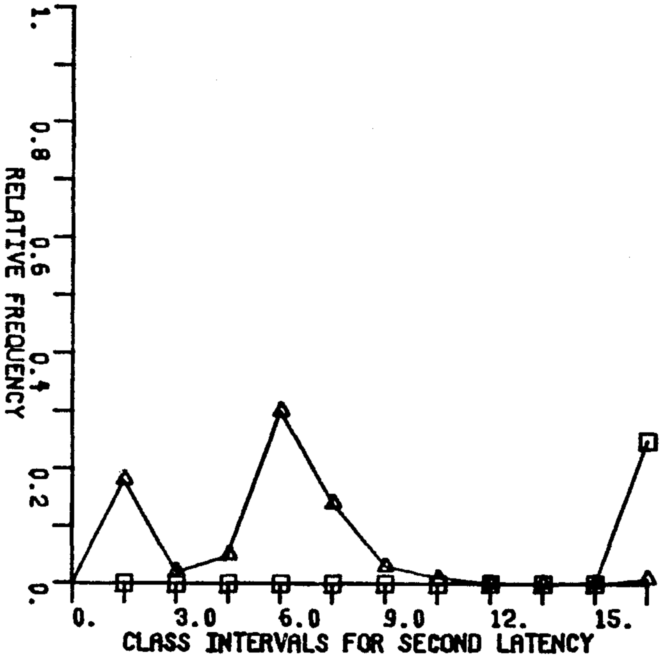
CLASS INTERVALS FOR FIRST LATENCY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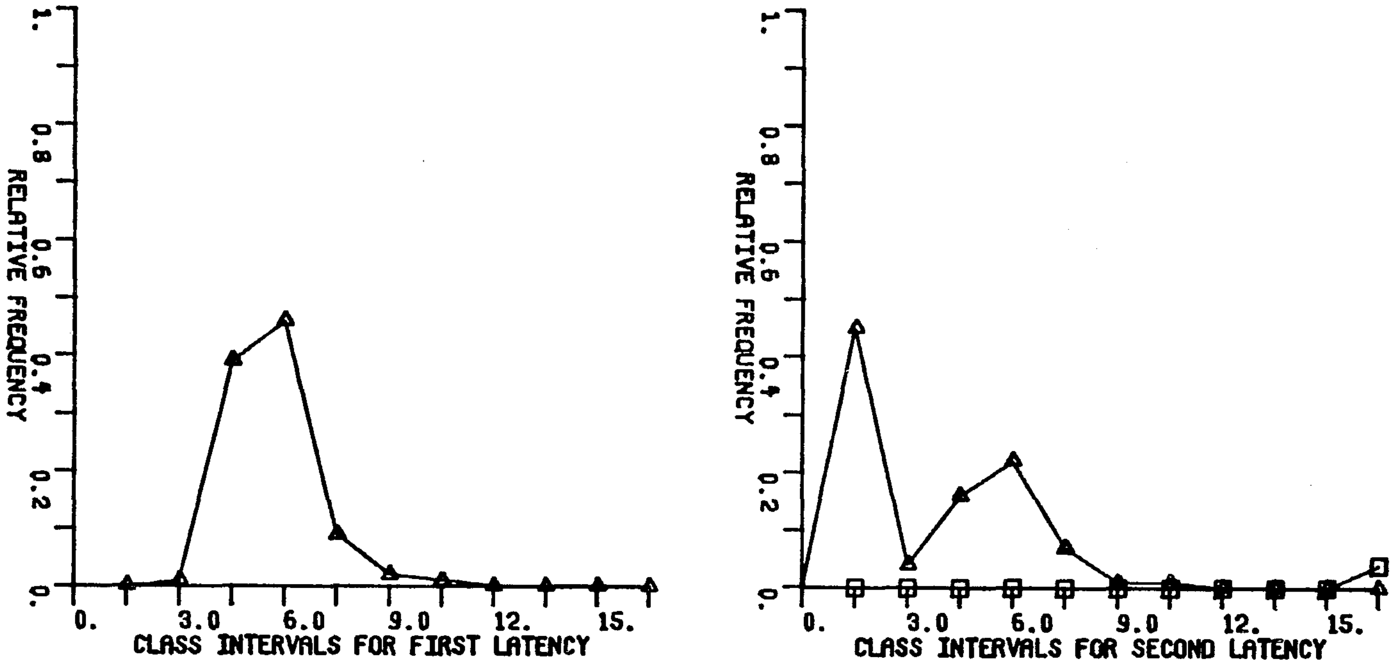
CLASS INTERVALS FOR SECOND LATENCY

R-4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CLASS INTERVALS FOR FIRST LATENCY
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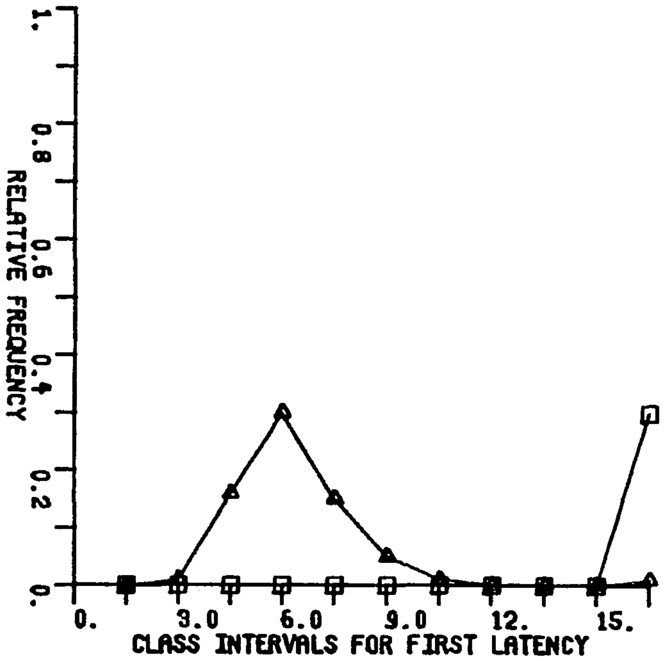
CLASS INTERVALS FOR SECOND LATENCY

R-4 (redet)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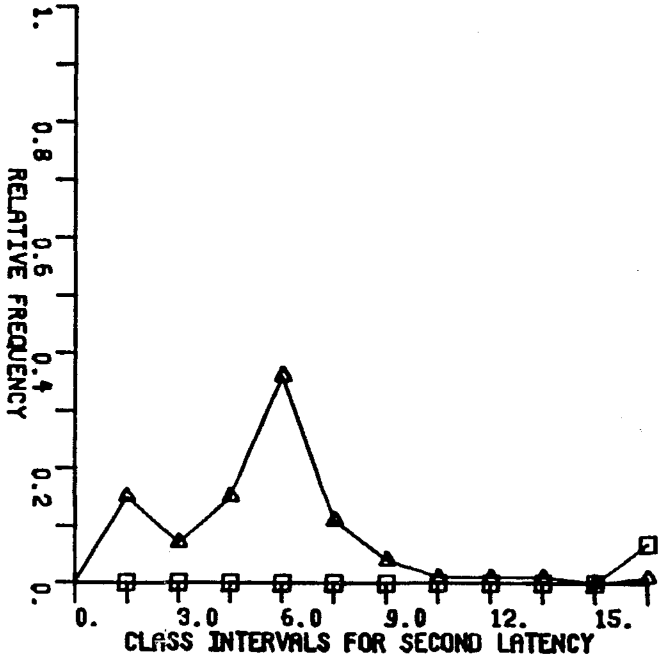
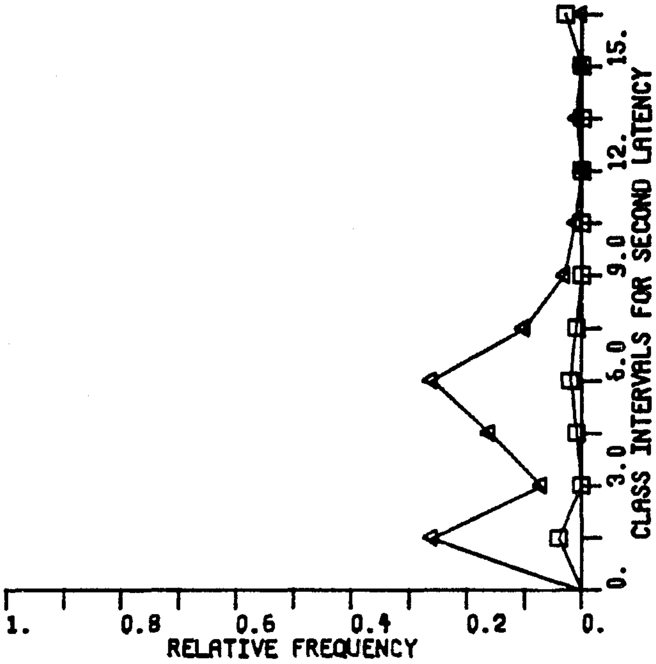
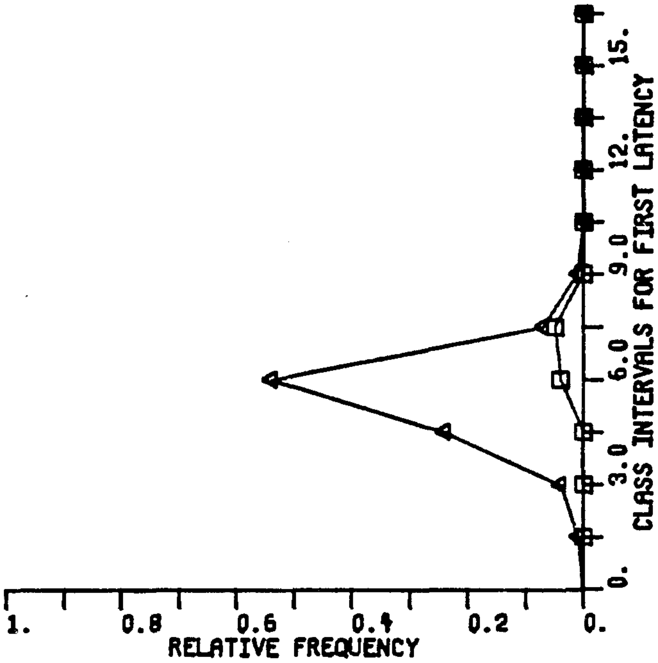
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

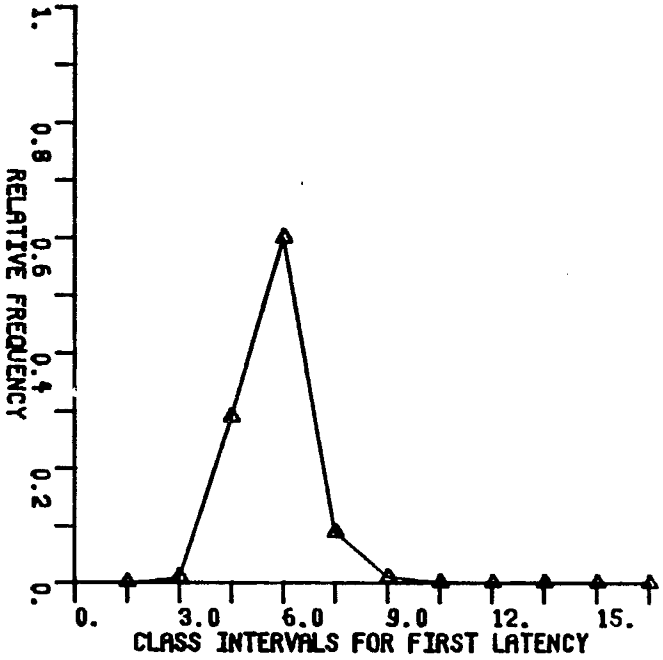

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

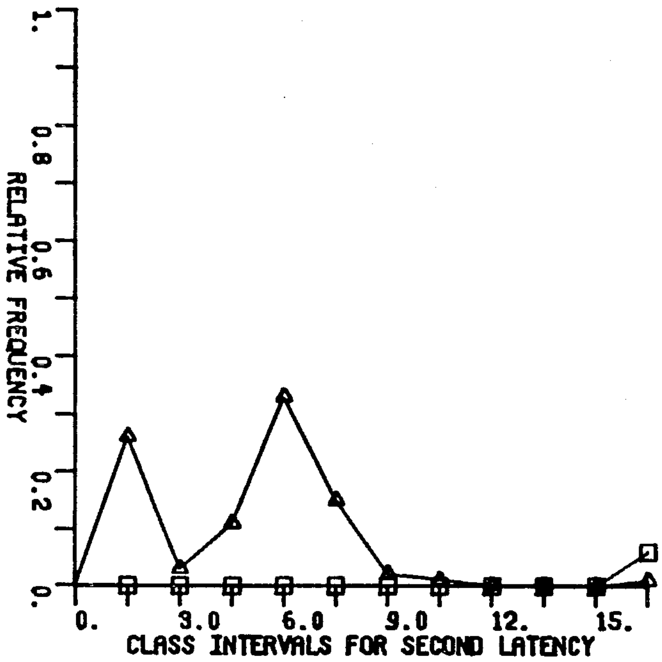
R-5


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

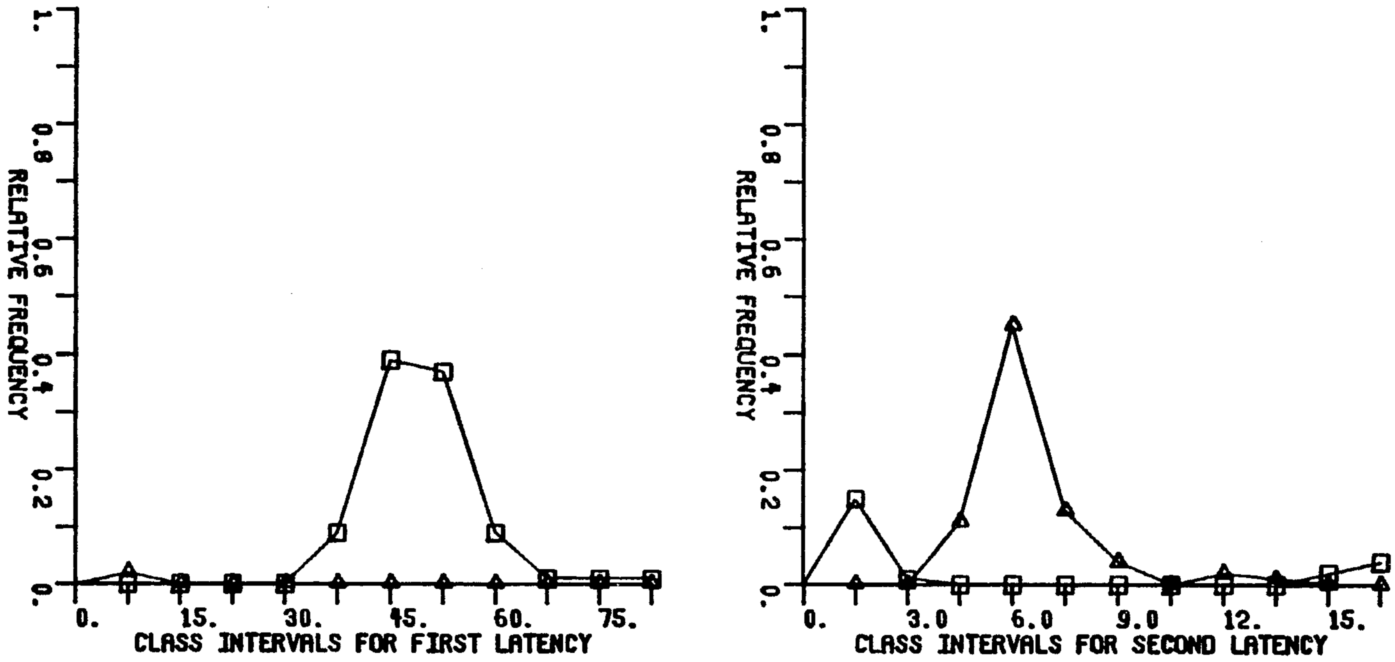
R-5 (redet)


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

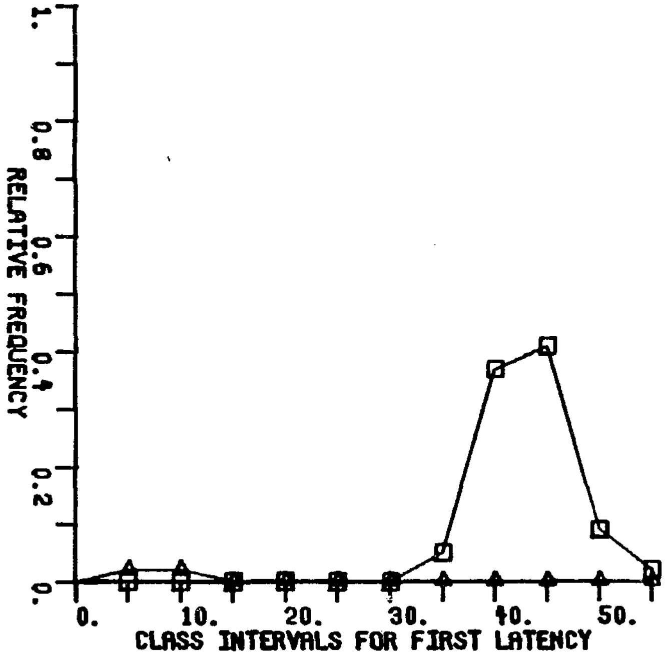

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

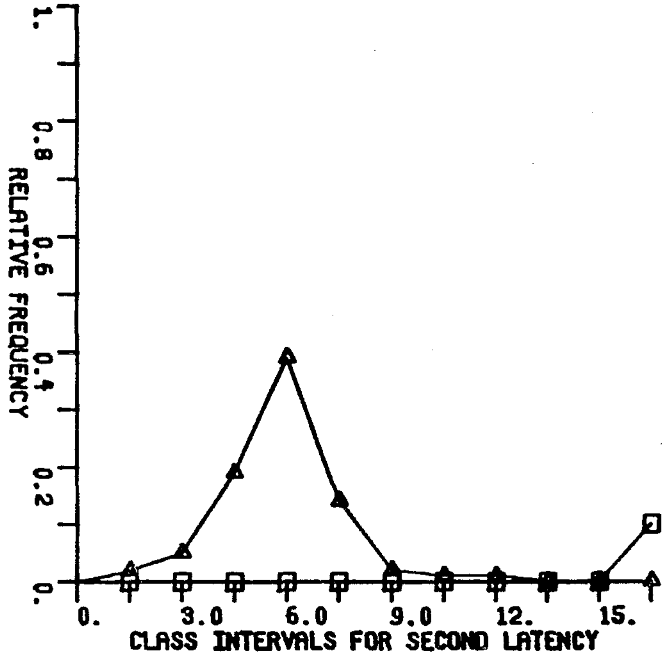
40 secs:0.75

R-1

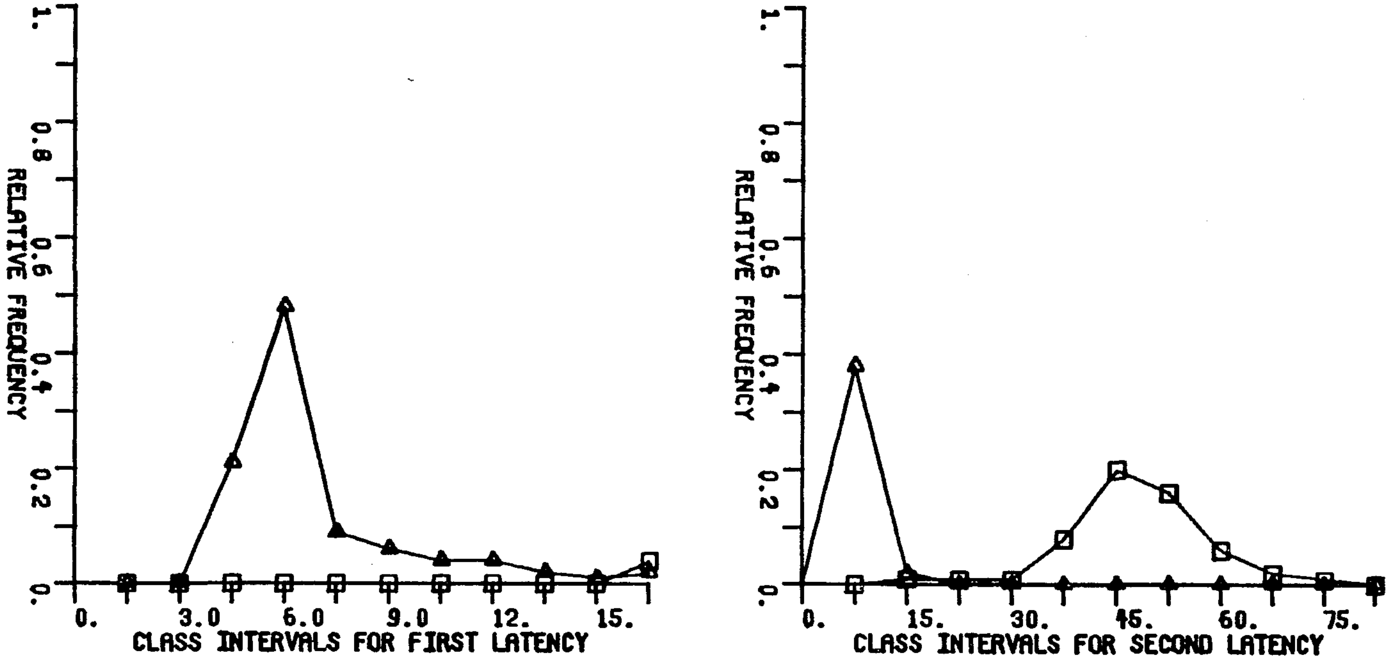

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-2

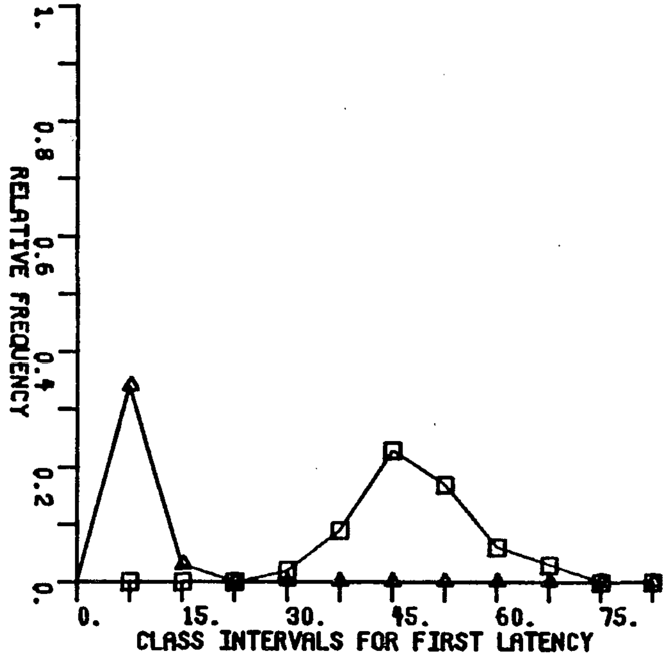

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR FIRST LATENCY

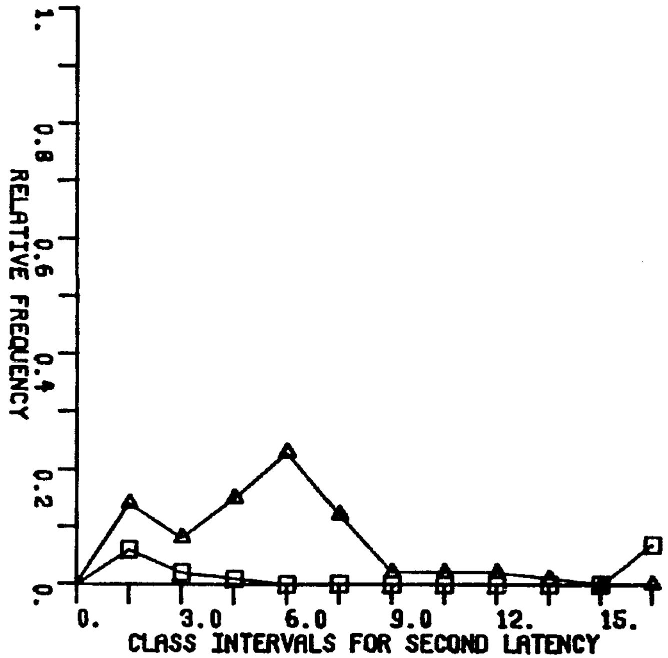

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-3

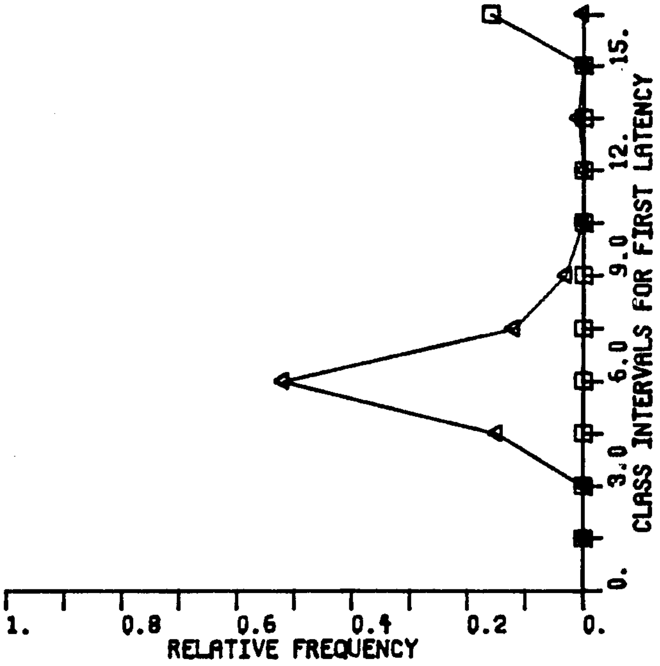

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR SECOND LATENCY

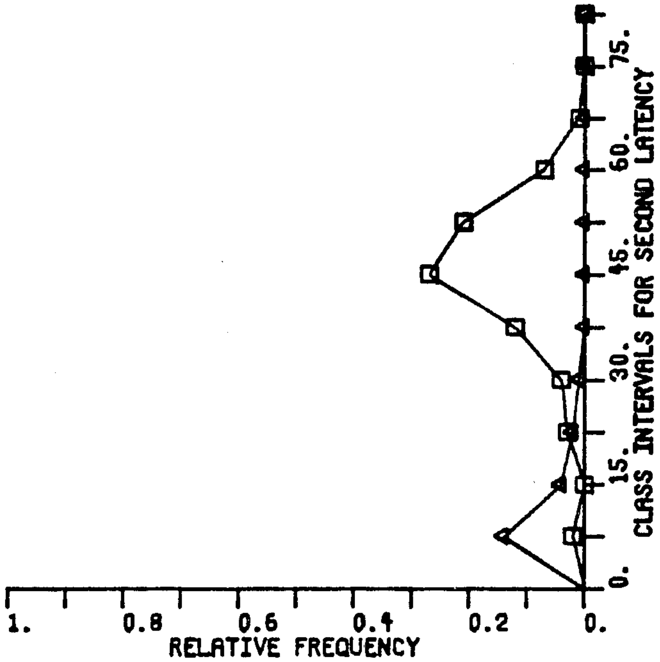
R-4


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

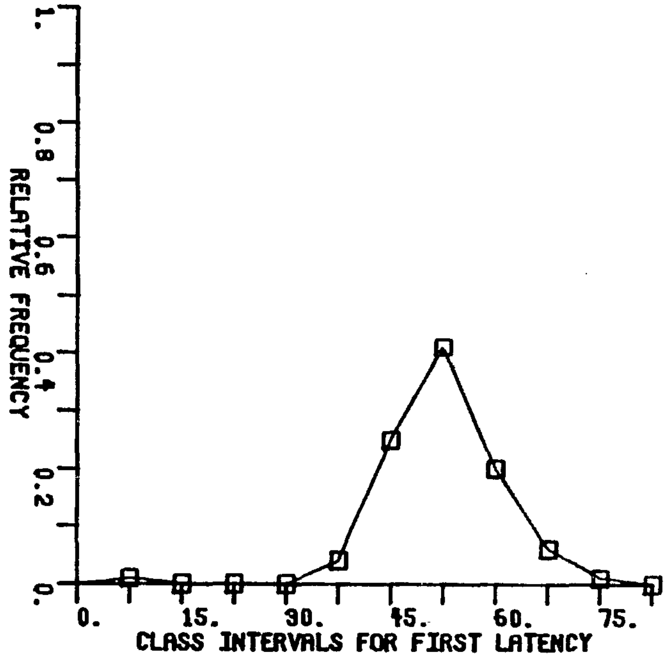
R-5

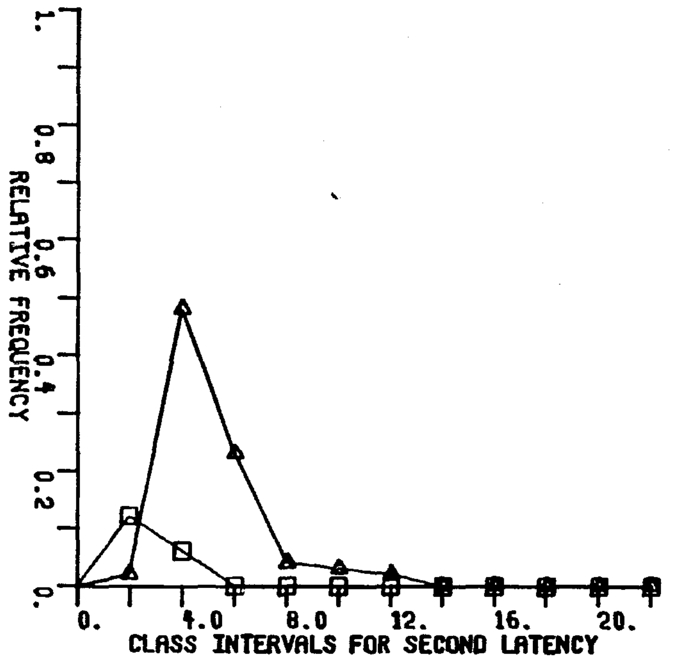

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
15.
30.
45.
60.
75.

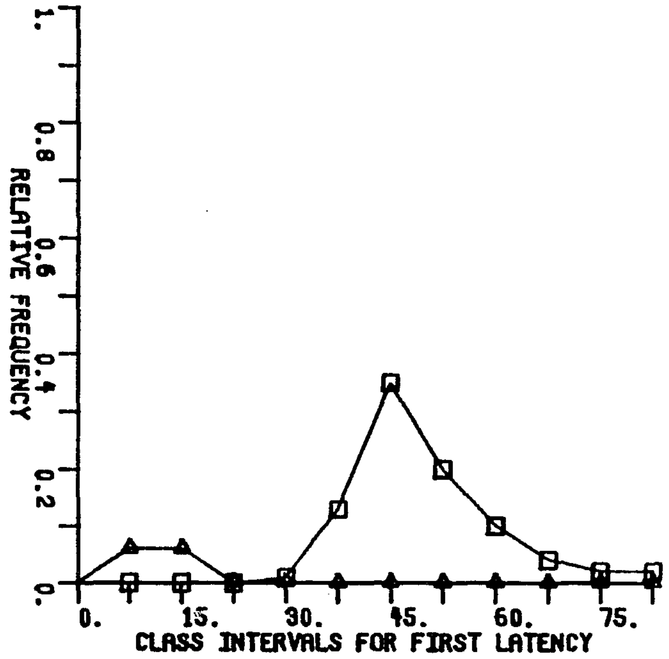
40 secs:0.95

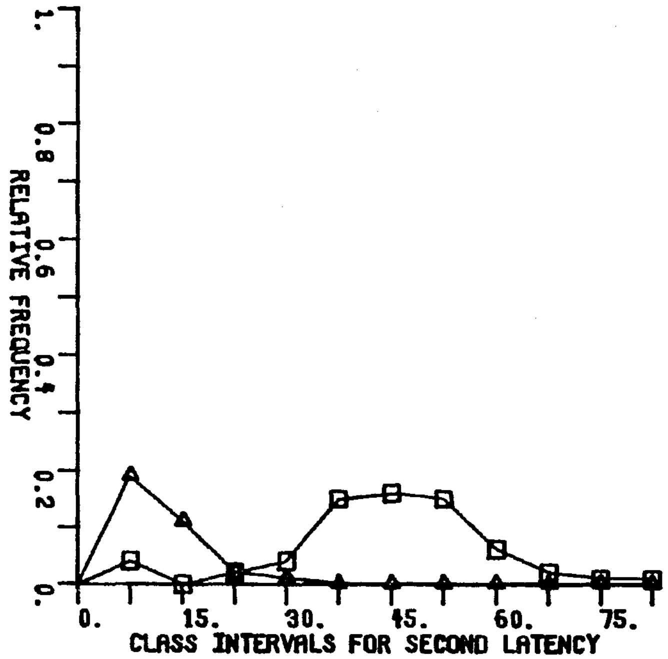
R-1


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY

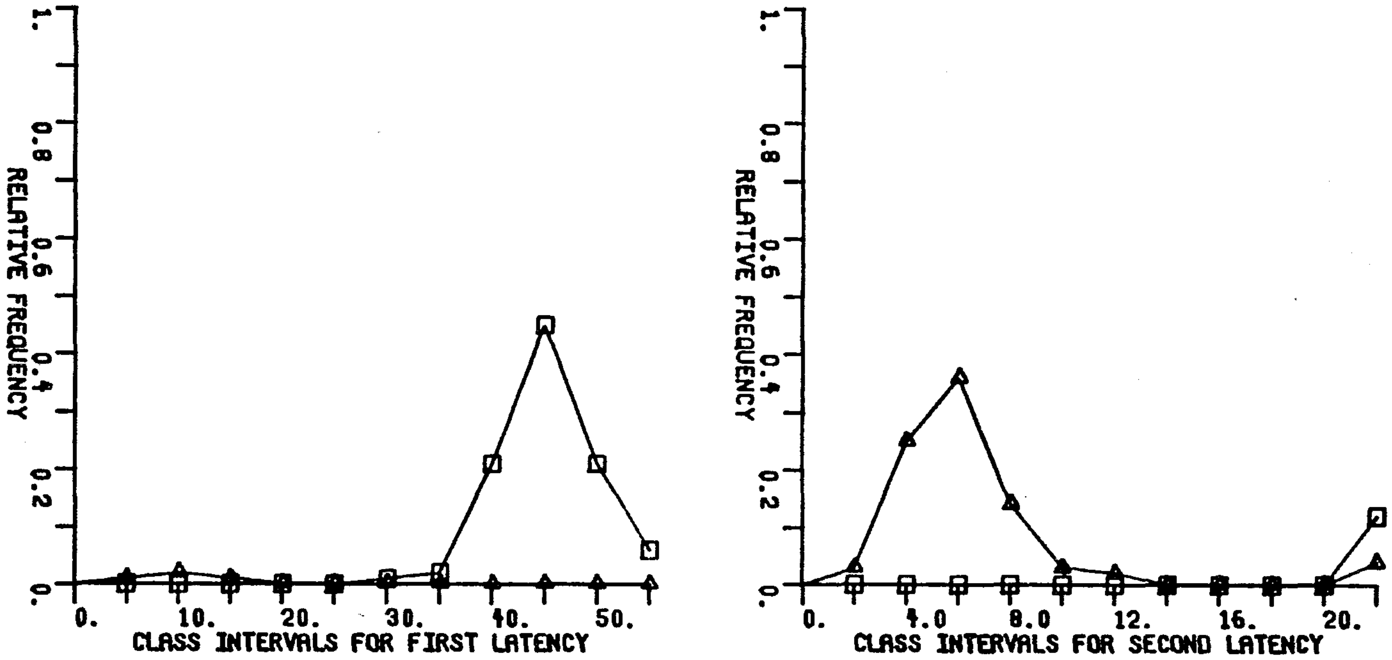

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
4.0
8.0
12.
16.
20.
CLASS INTERVALS FOR SECOND LATENCY

R-1 (redet)

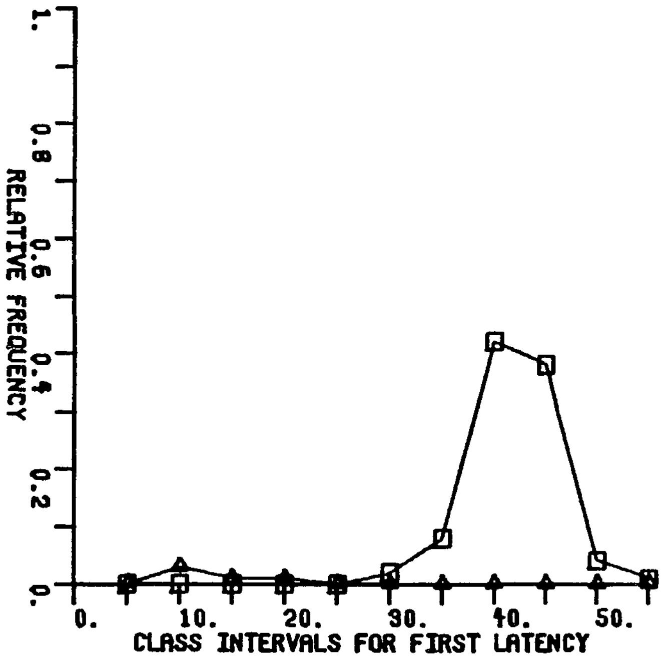

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY

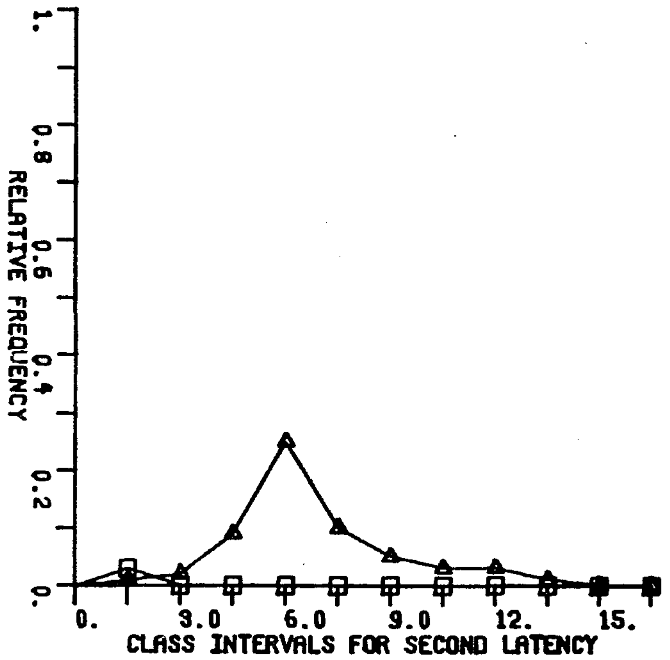

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR SECOND LATENCY

R-2

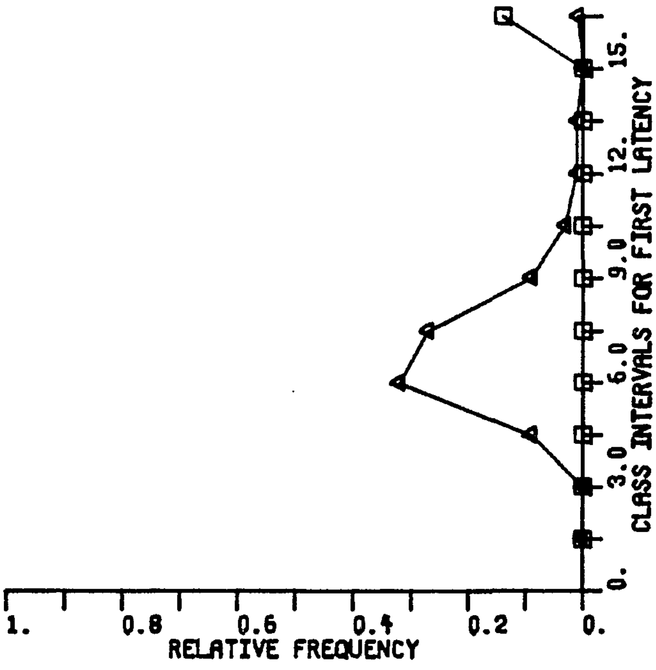

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
4.0
8.0
12.
16.
20.
CLASS INTERVALS FOR SECOND LATENCY

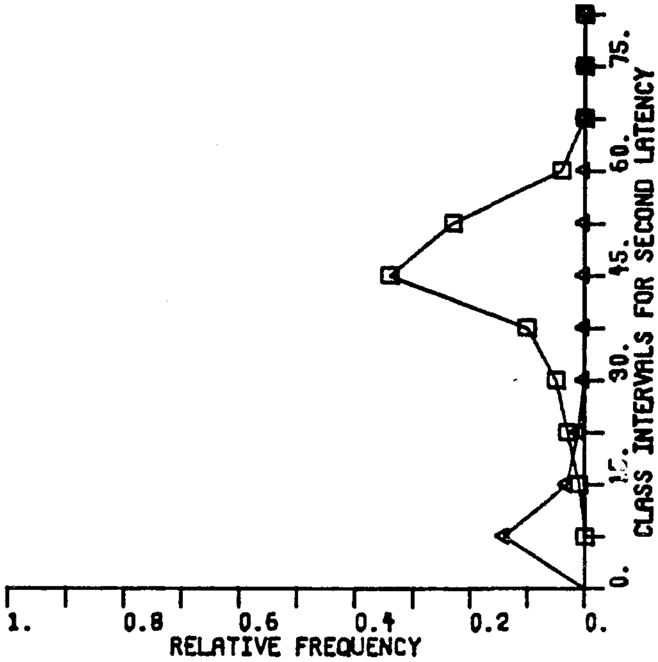
R-2 (redet)


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR FIRST LATENCY

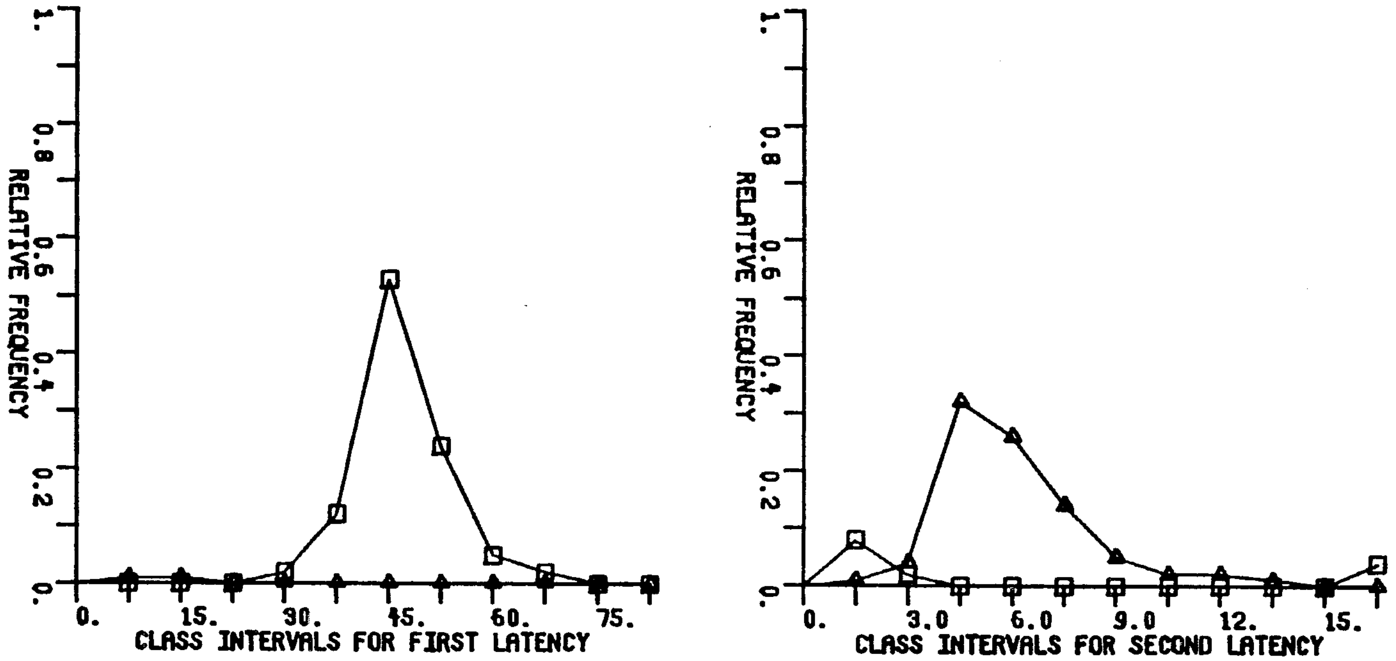

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-3

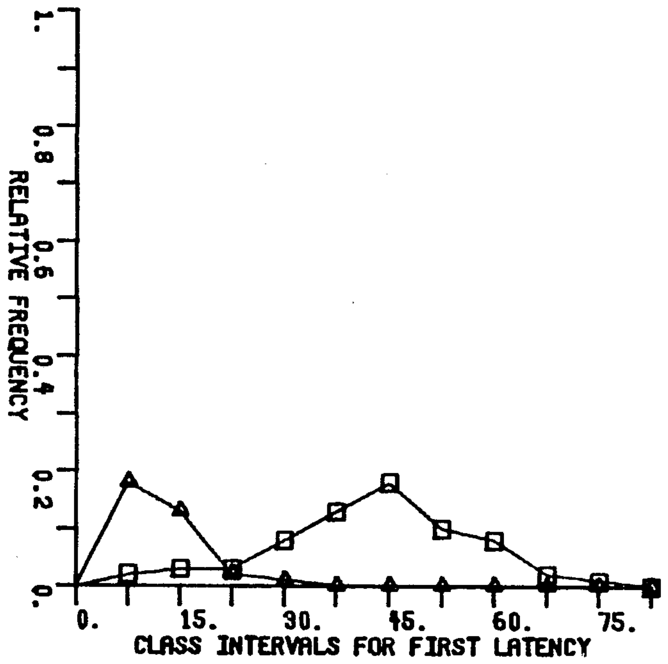

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.

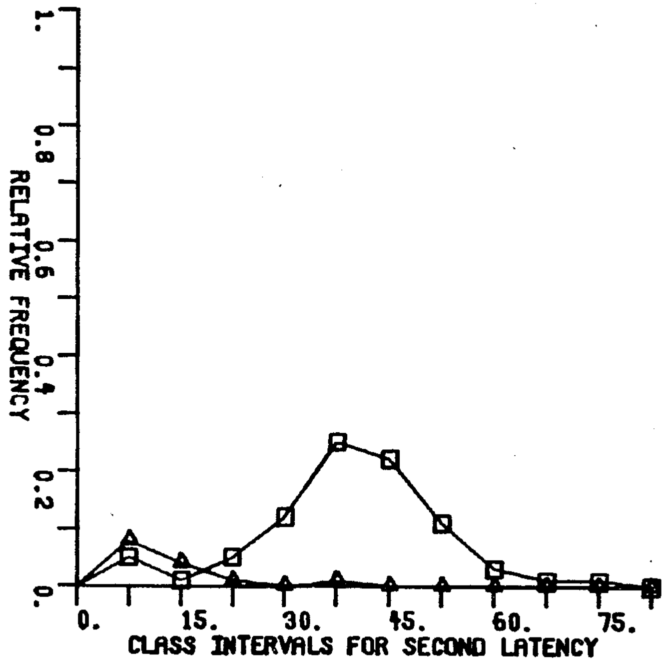

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
15.
30.
45.
60.
75.

R-4


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

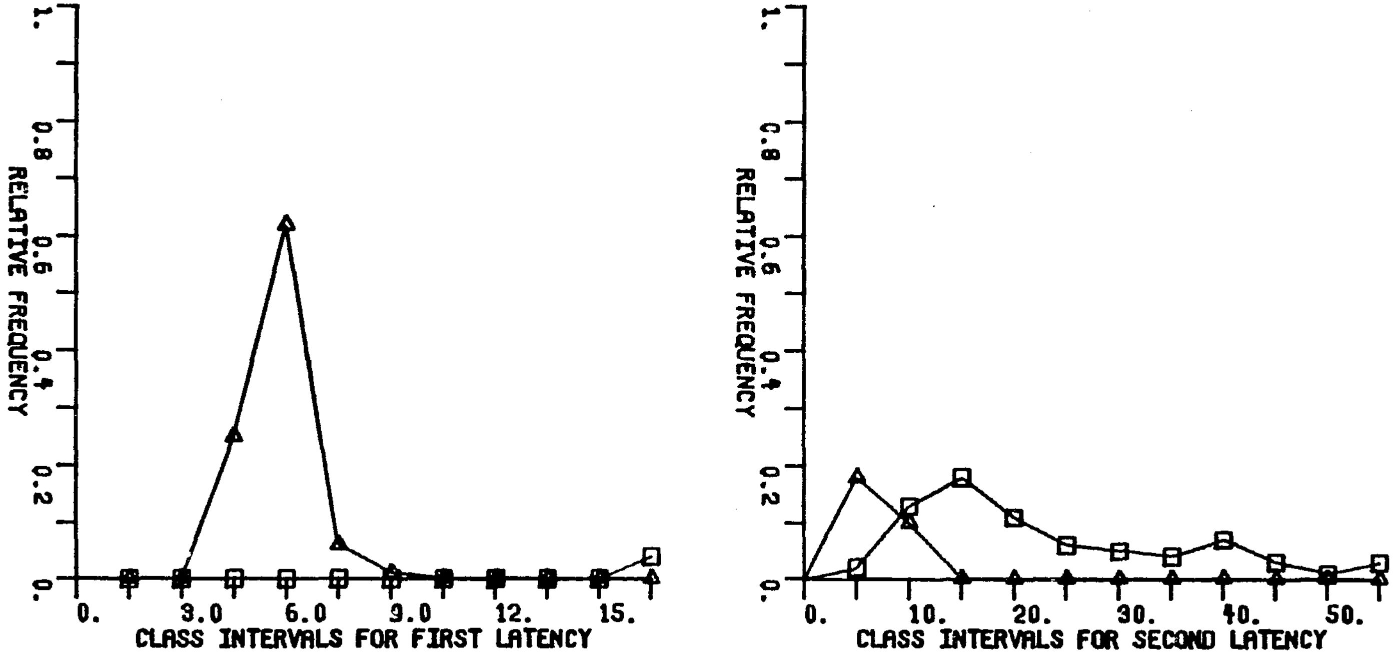
R–5


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR FIRST LATENCY

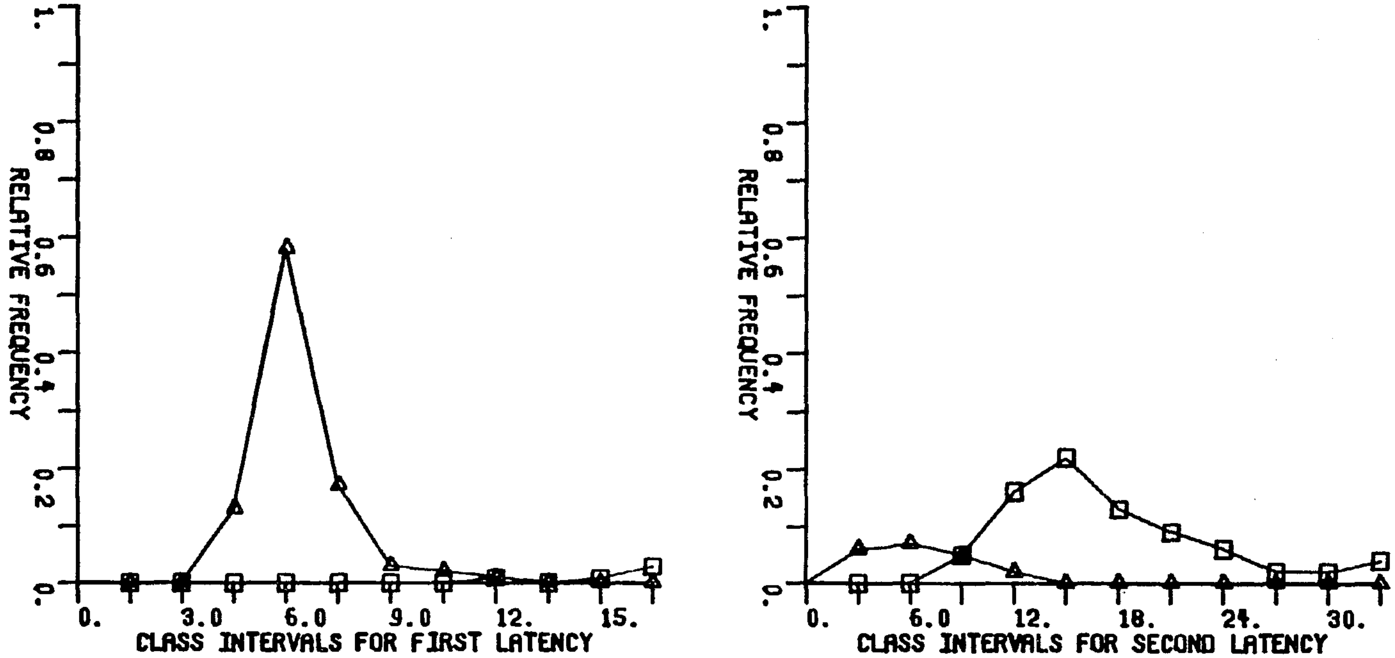

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
15.
30.
45.
60.
75.
CLASS INTERVALS FOR SECOND LATENCY

10 SECS:0.50

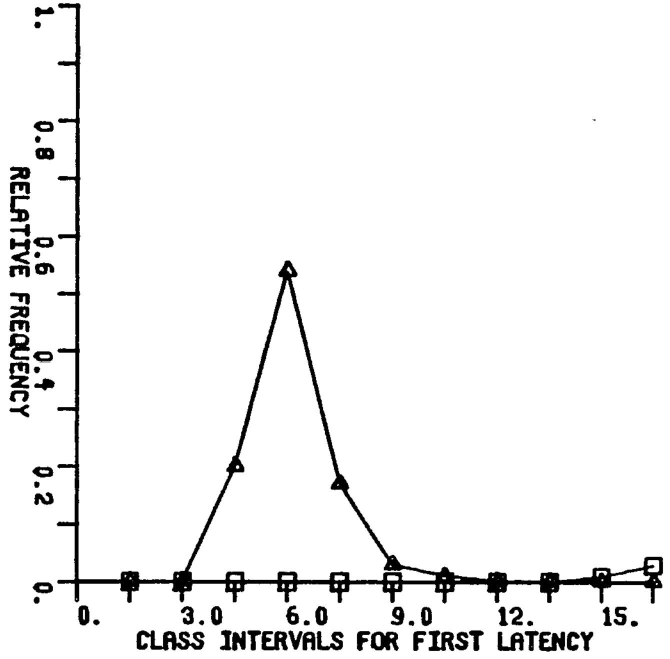
R-1

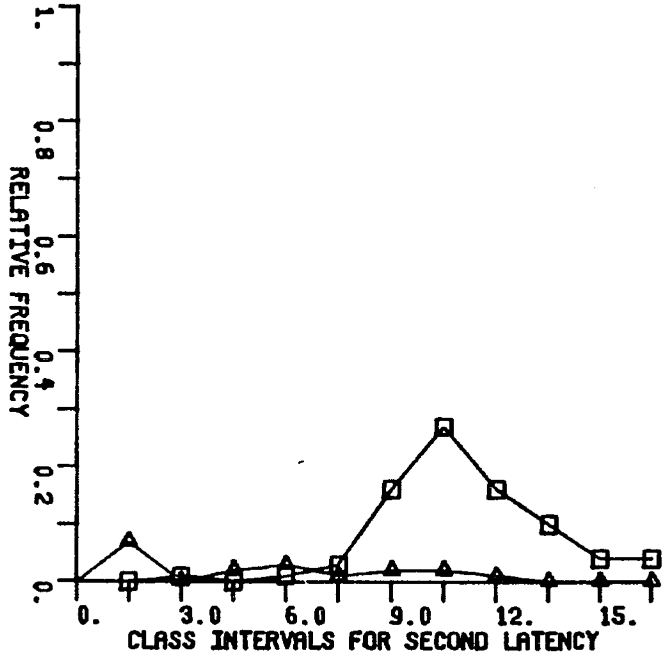

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR SECOND LATENCY

R-1 (redet)

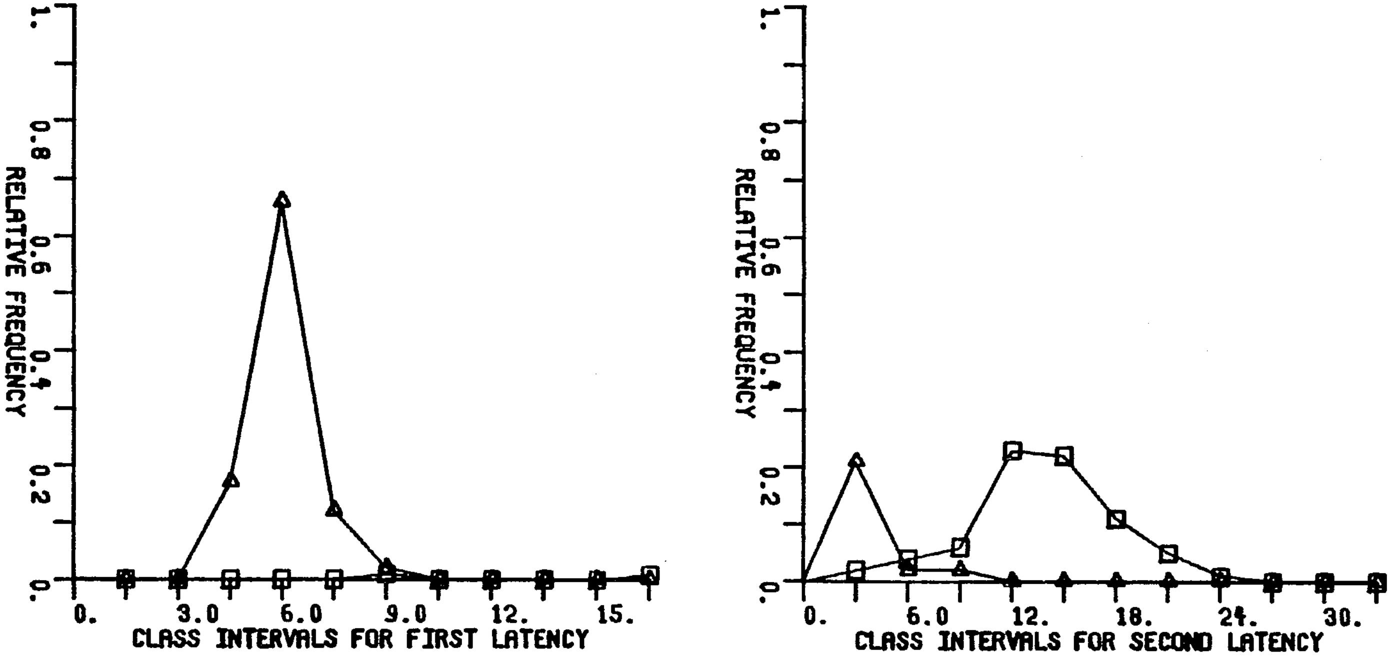

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
6.0
12.
18.
24.
30.
CLASS INTERVALS FOR SECOND LATENCY

R-2

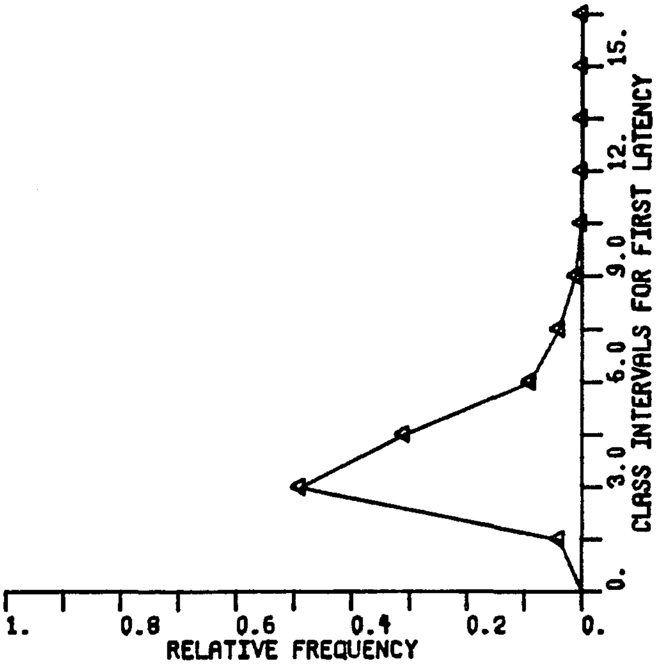

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

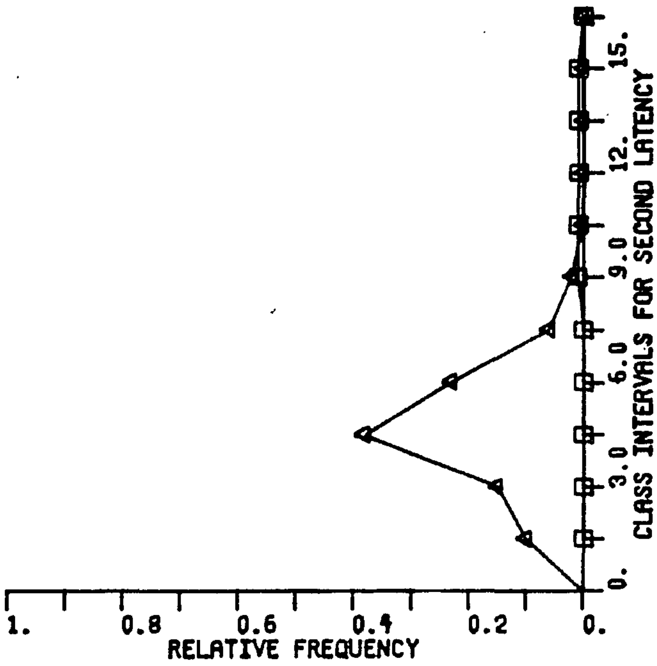

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-2 (redet)

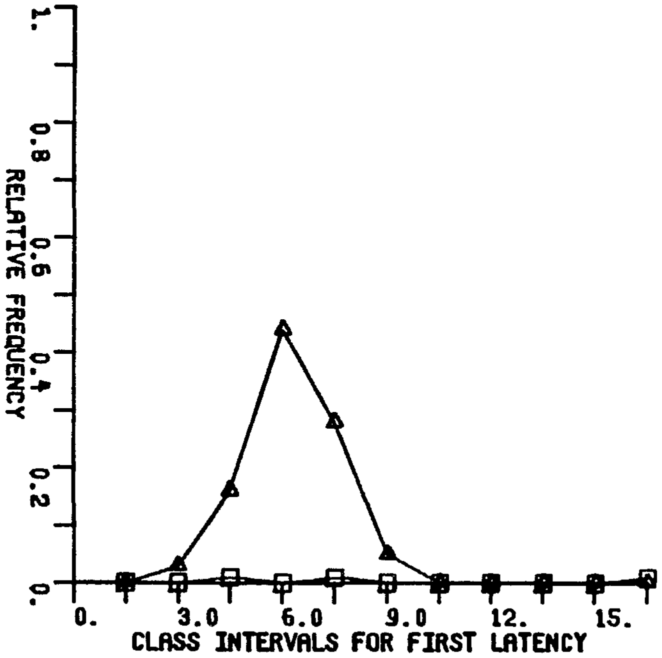

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
6.0
12.
18.
24.
30.
CLASS INTERVALS FOR SECOND LATENCY

R-3


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
3.0
6.0
9.0
12.
15.

R-3 (redet)


RELATIVE FREQUENCY
0.
0.2
0.4
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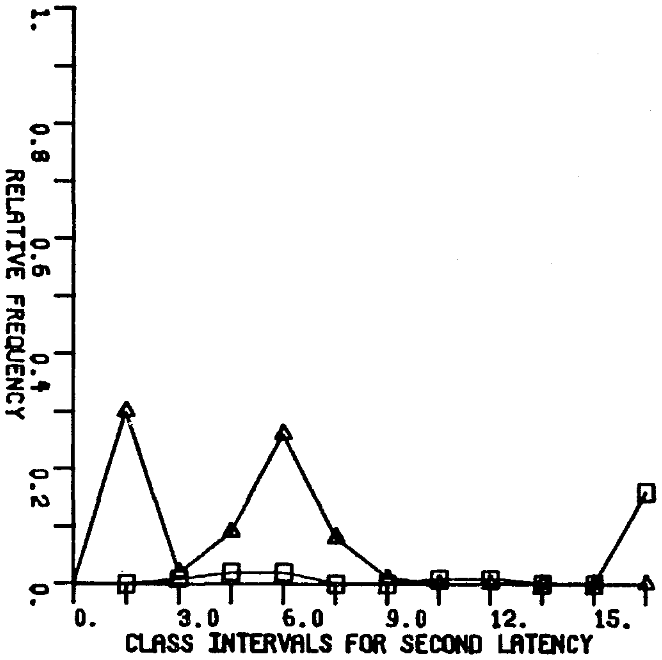
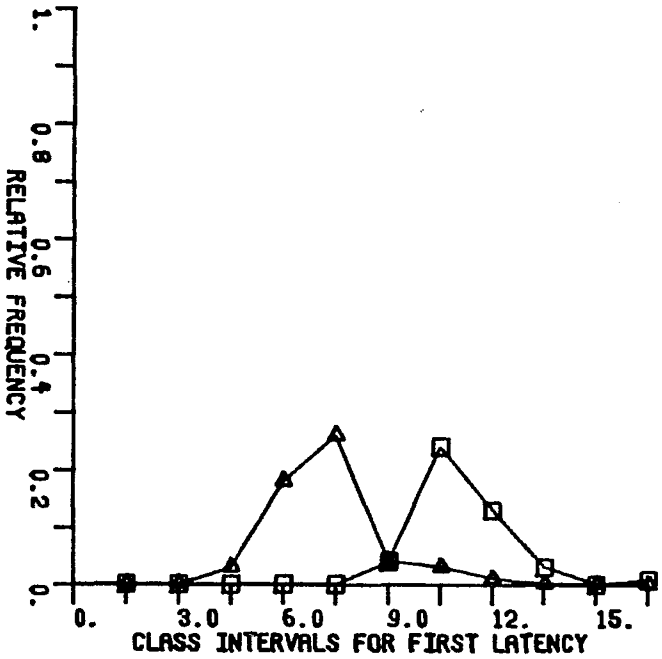
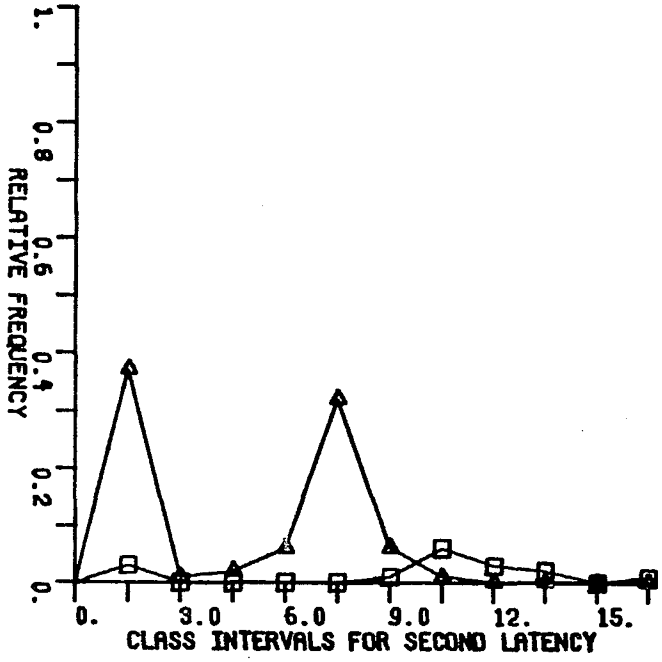
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

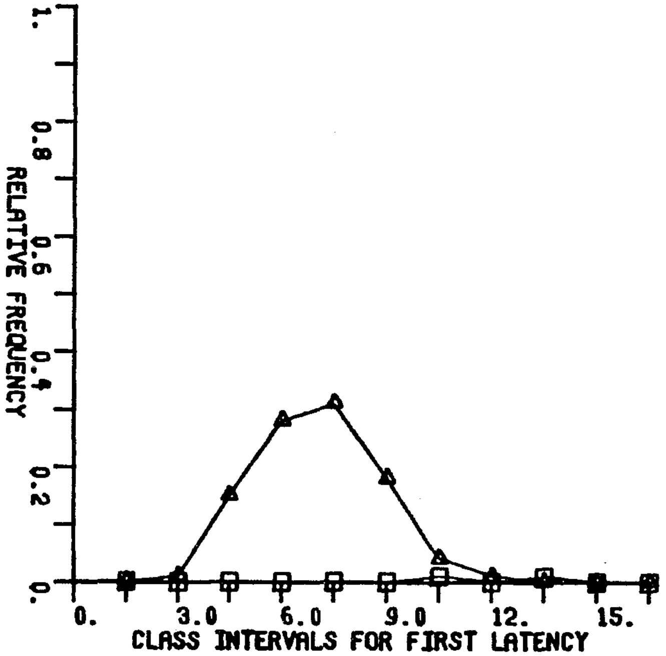

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

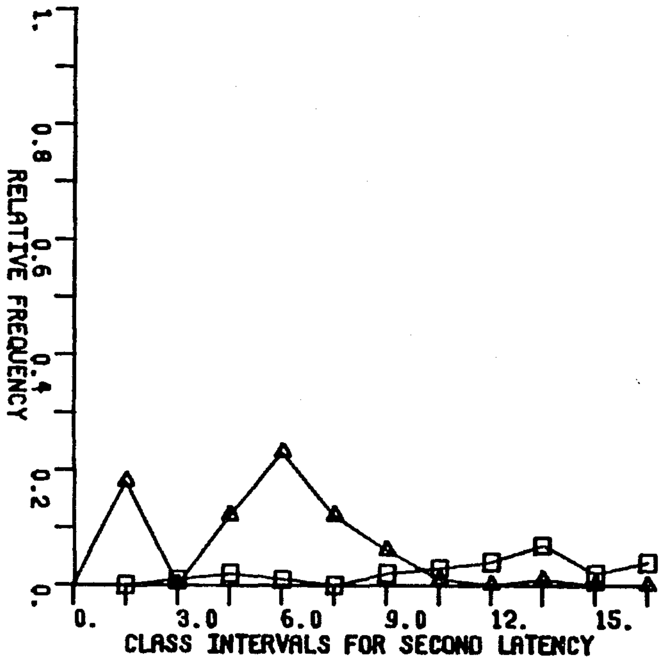
R-4


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

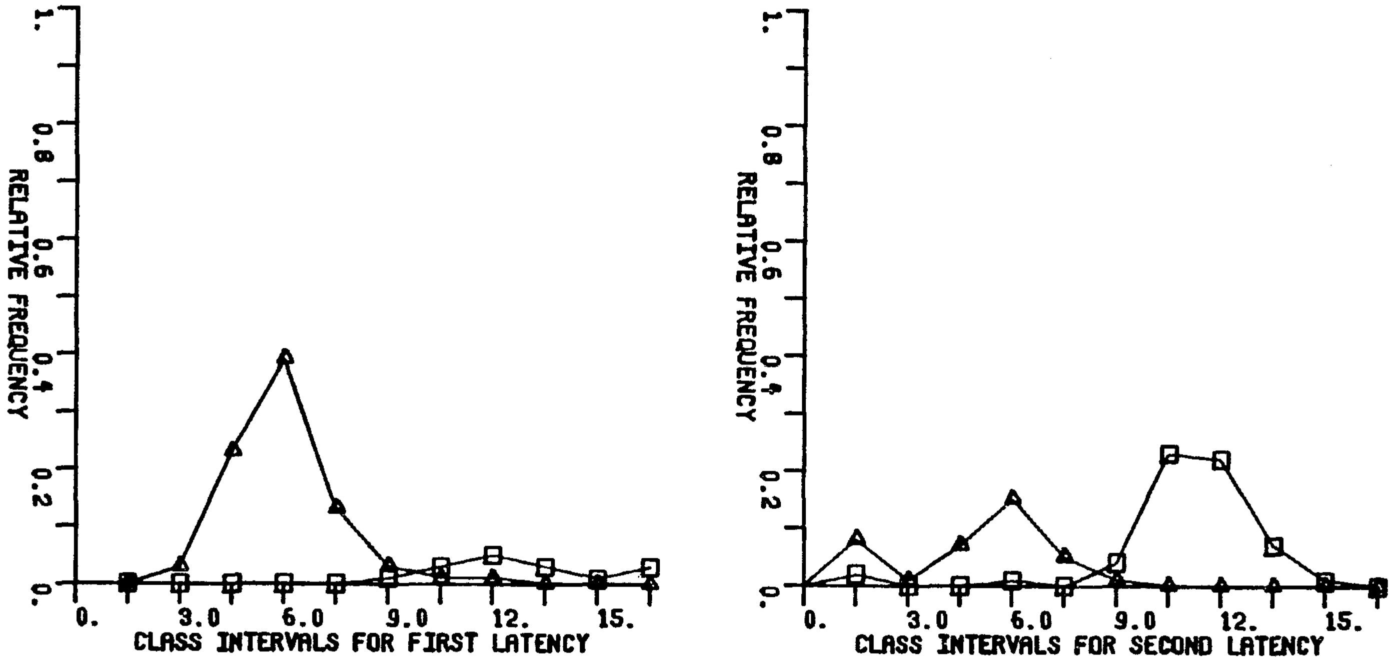

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-4 (redet)

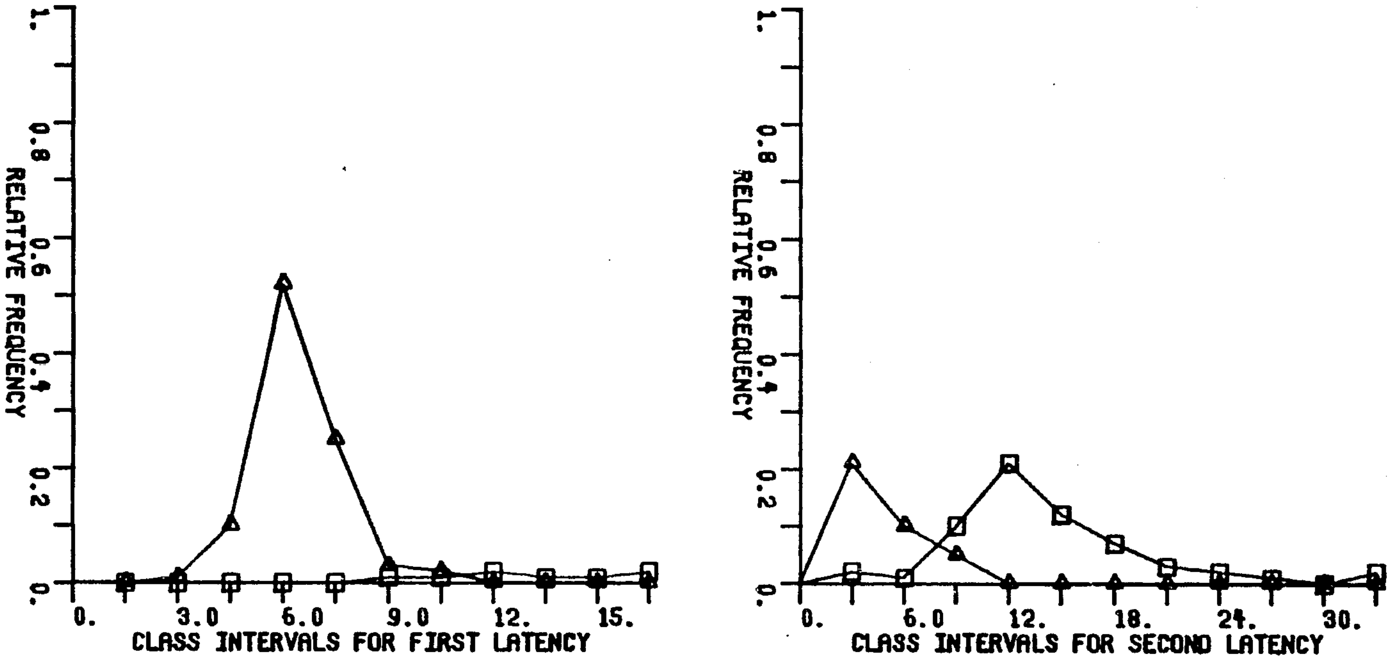

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-5

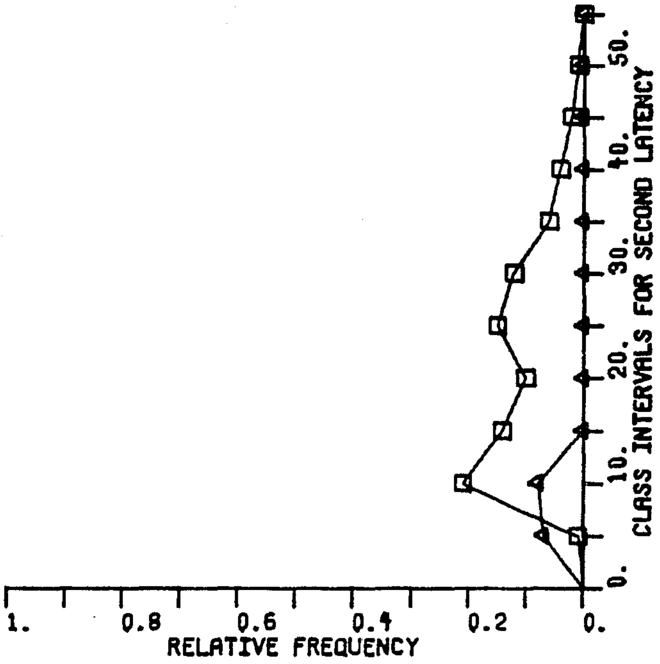

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

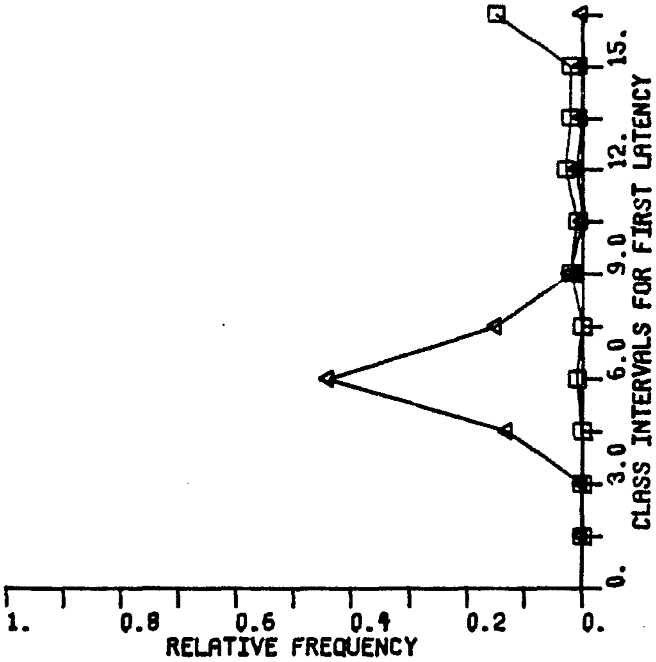
R-5 (redet)



RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
6.0
12.
18.
24.
30.
CLASS INTERVALS FOR SECOND LATENCY

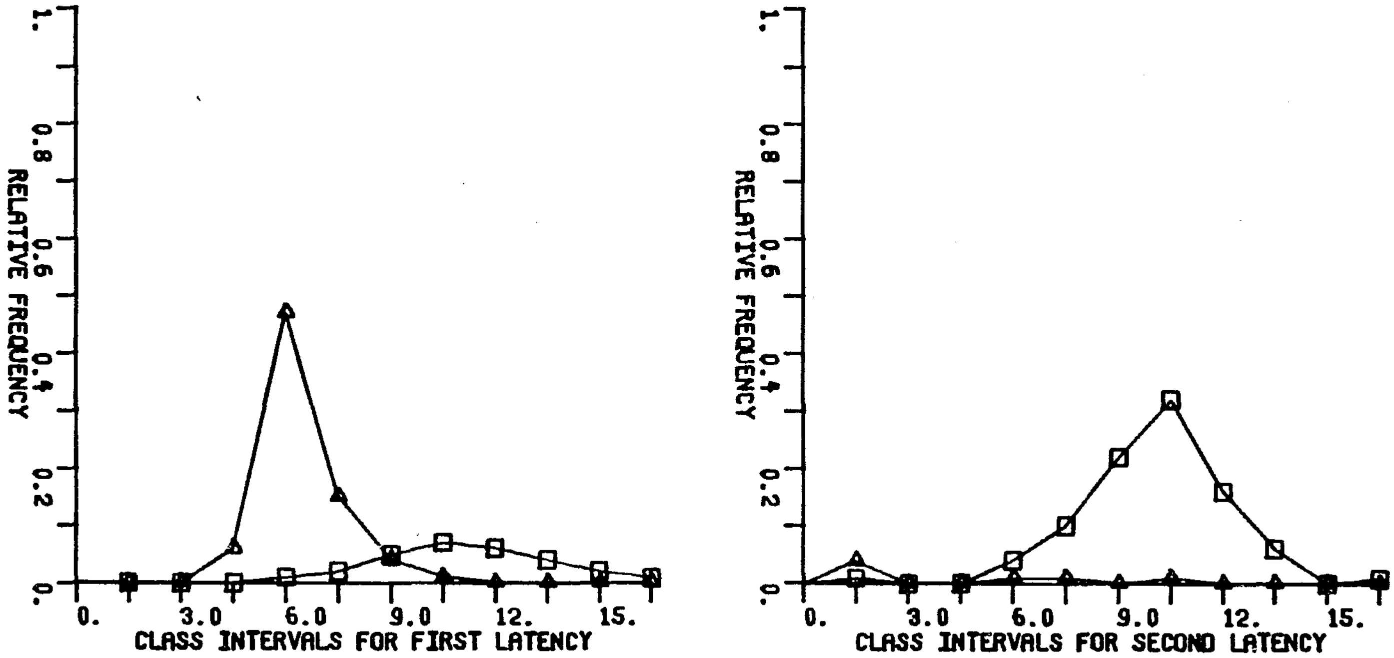
10 SECS:0.75


1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR SECOND LATENCY

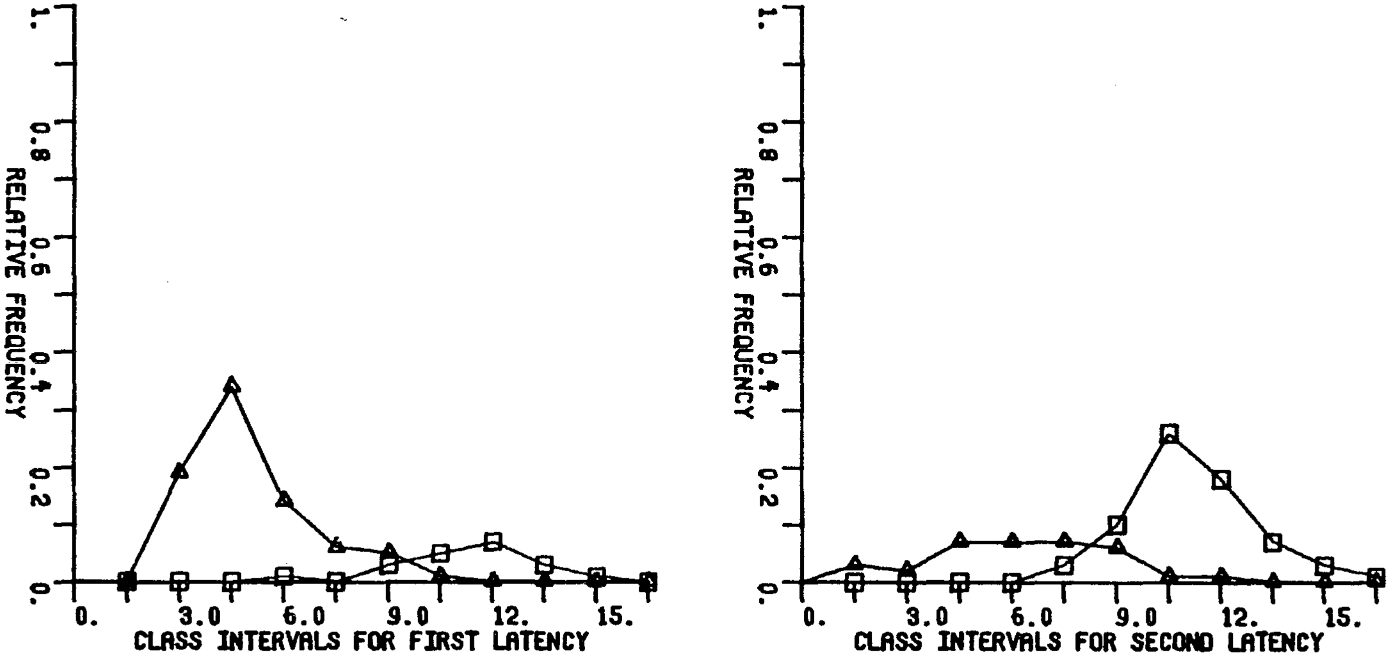

1.
0.8
0.6
0.4
0.2
0.
RELATIVE FREQUENCY
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

R-1

R-2

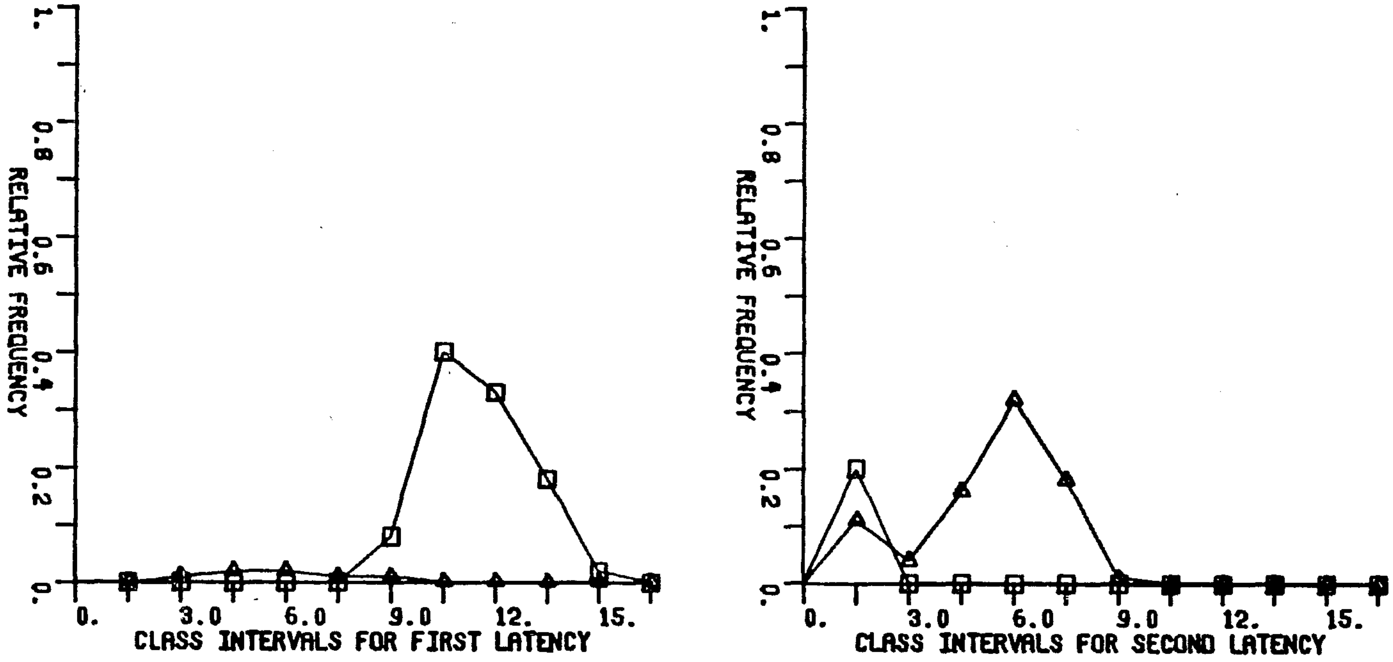

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-3

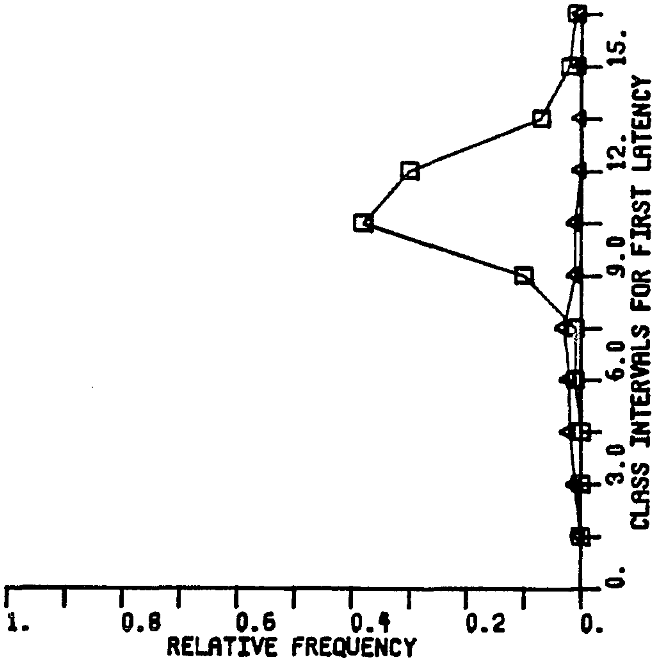


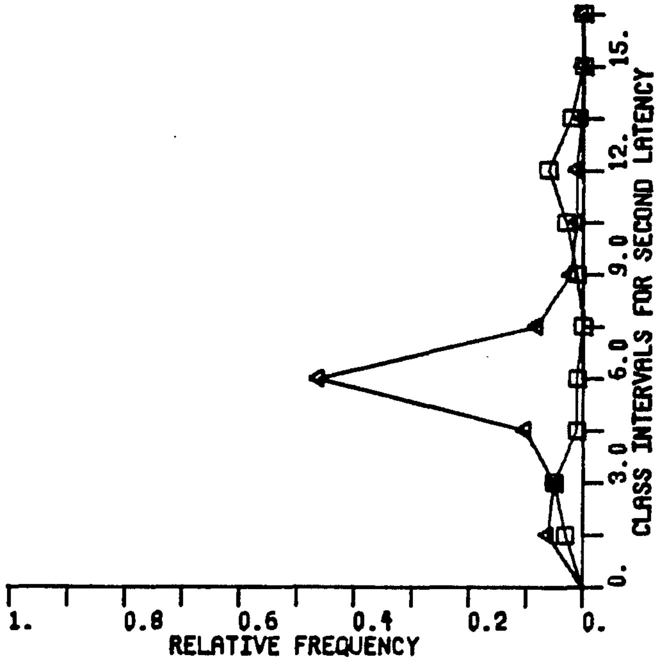
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-4


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

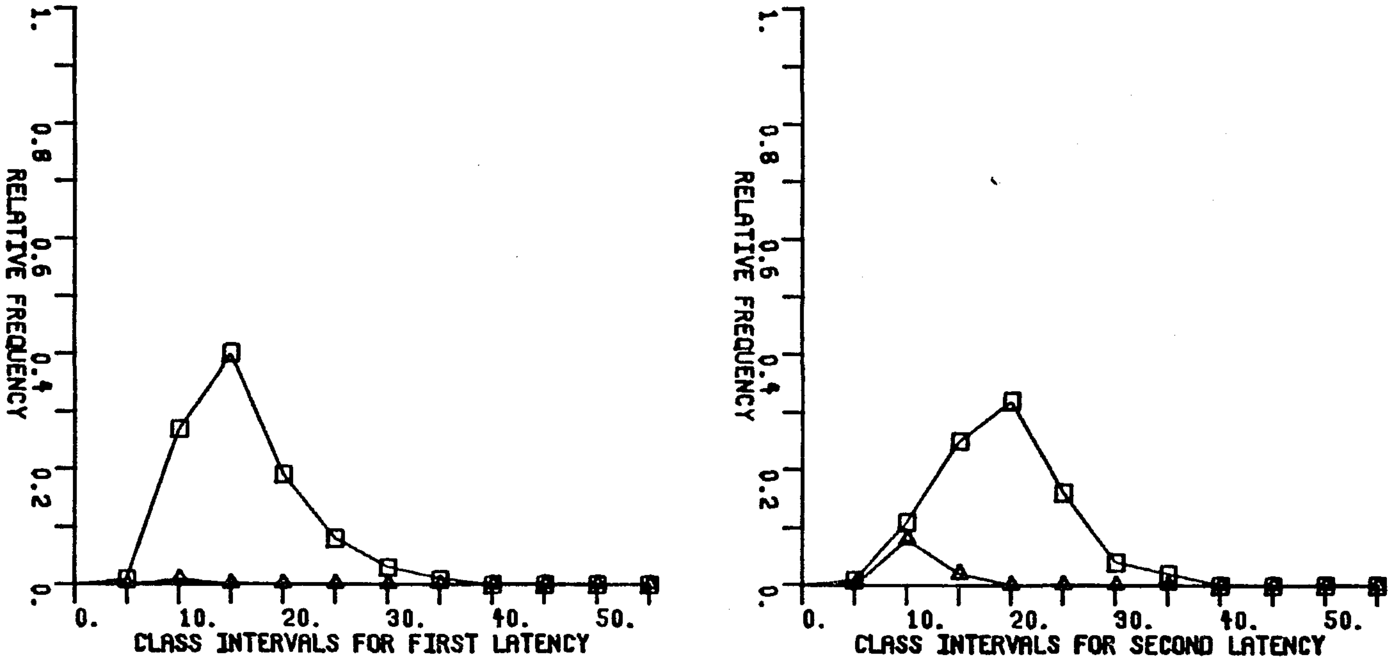
R-5


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
3.0
6.0
9.0
12.
15.

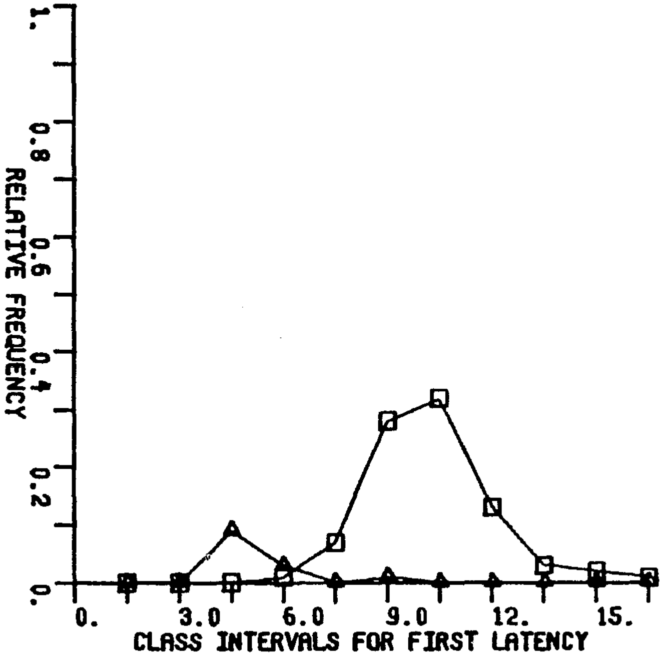
```
10 SECS:0.95
```

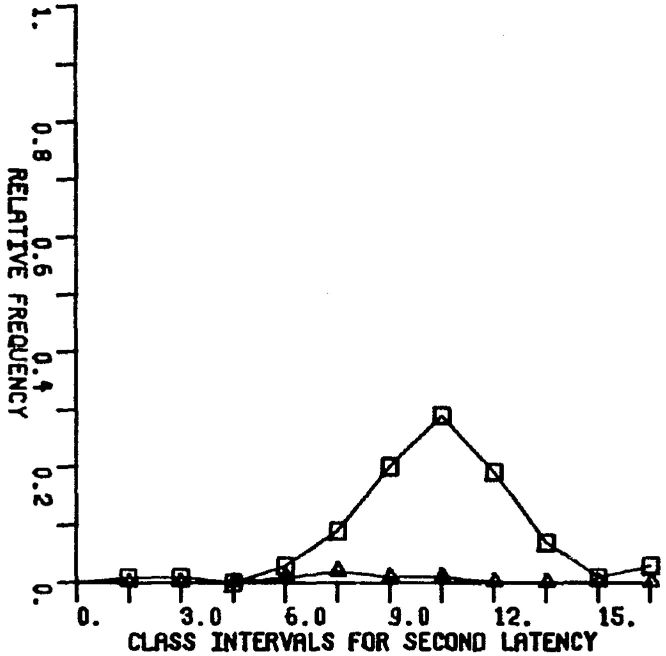
R-1



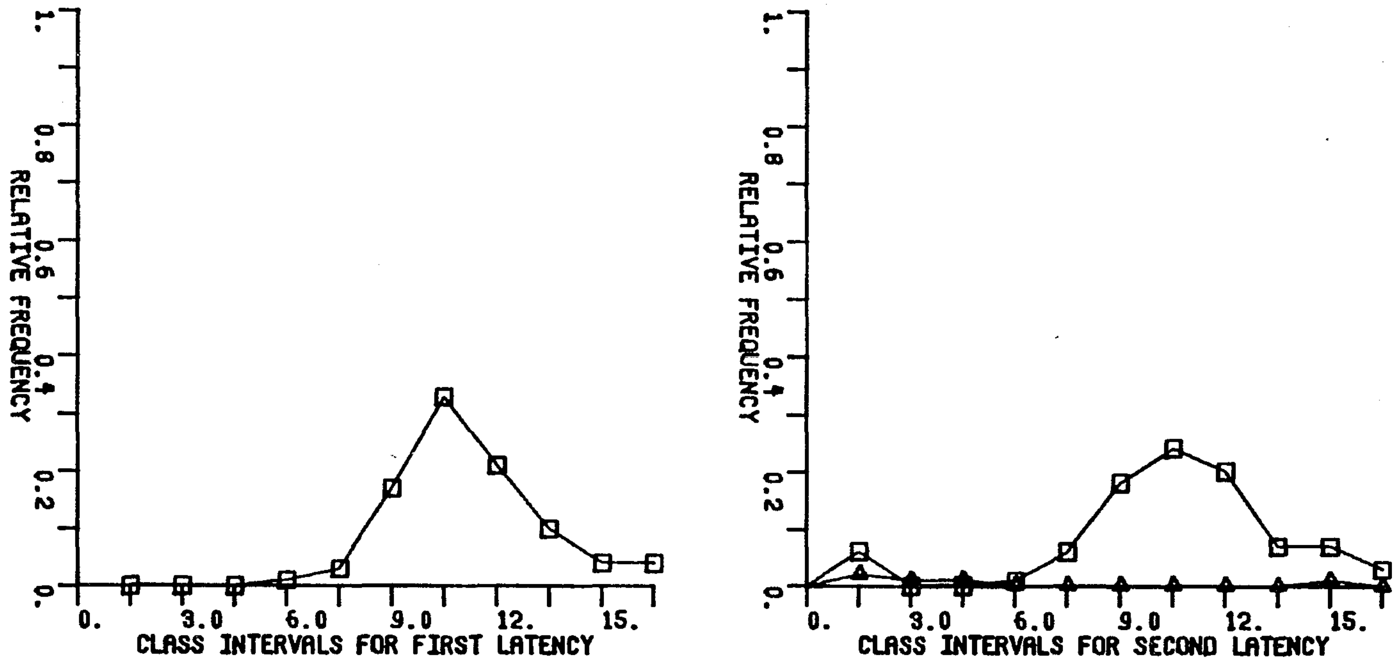
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
10.
20.
30.
40.
50.
CLASS INTERVALS FOR SECOND LATENCY

R-2

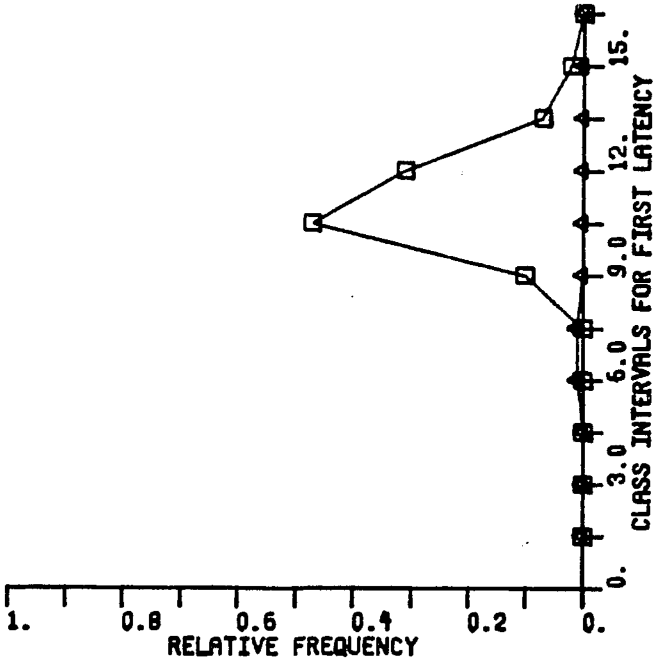

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY

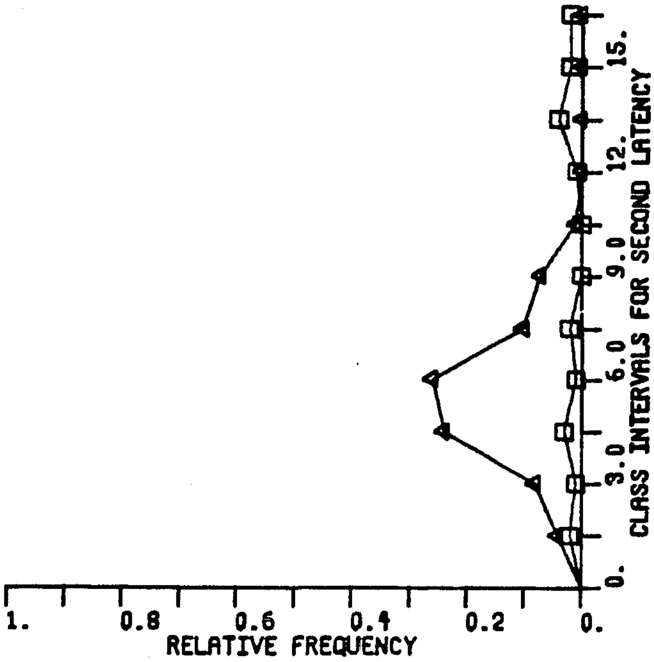

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

R-3

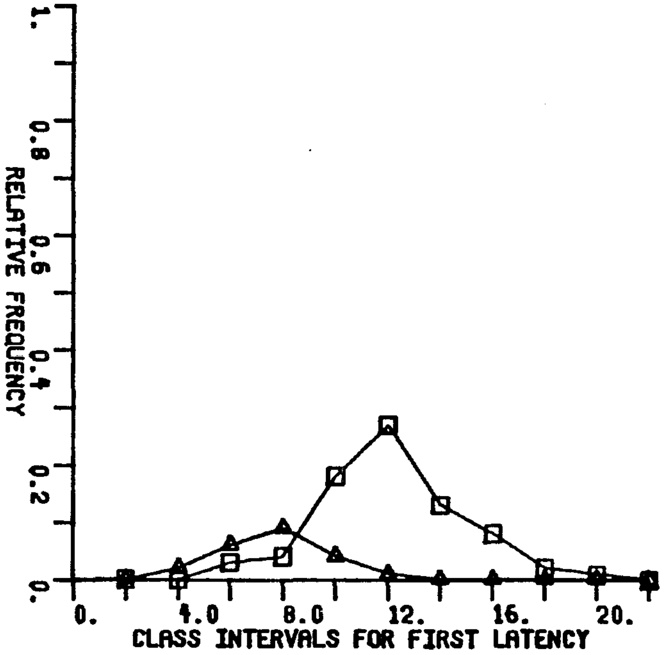

RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR FIRST LATENCY
RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
3.0
6.0
9.0
12.
15.
CLASS INTERVALS FOR SECOND LATENCY

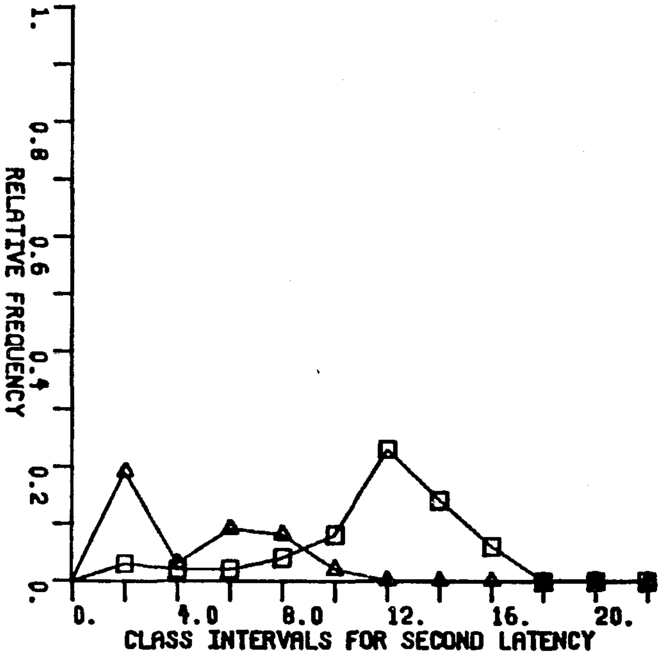
R-4


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.

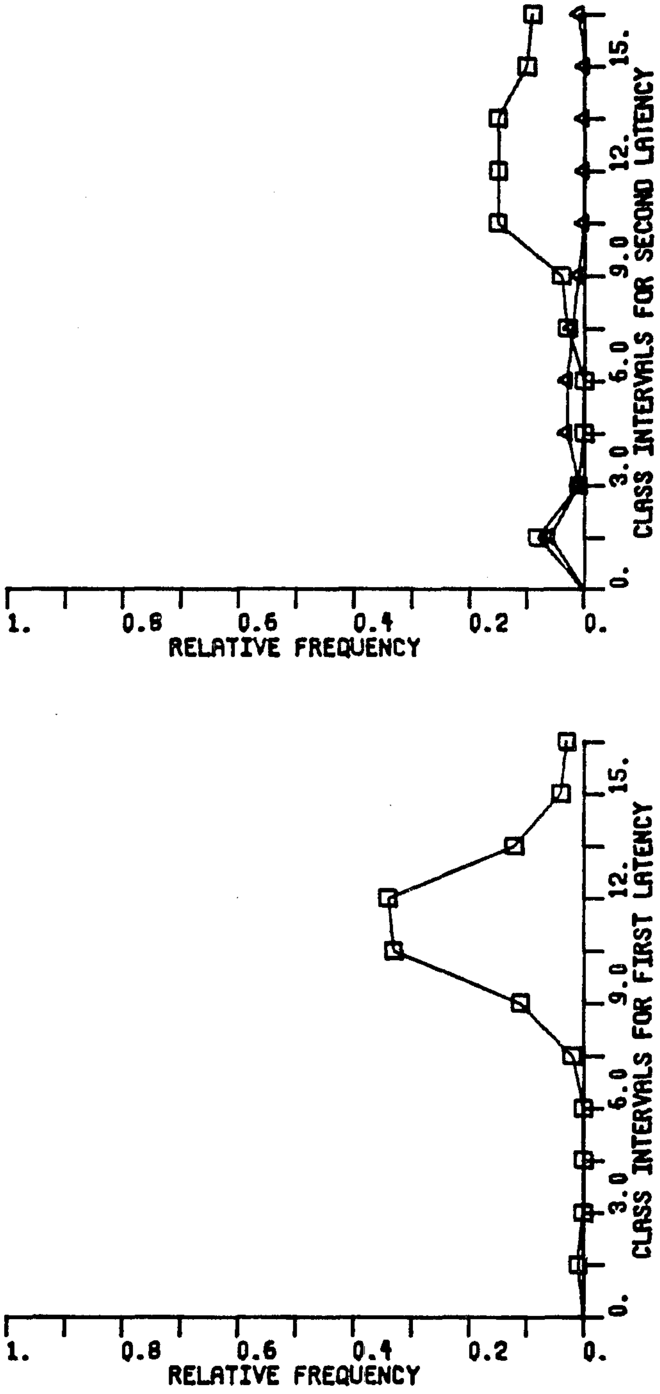

RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
3.0
6.0
9.0
12.
15.

R-4 (redet)


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
4.0
8.0
12.
16.
20.
CLASS INTERVALS FOR FIRST LATENCY


RELATIVE FREQUENCY
0.
0.2
0.4
0.6
0.8
1.
0.
4.0
8.0
12.
16.
20.
CLASS INTERVALS FOR SECOND LATENCY

R-5


RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR SECOND LATENCY
0.
3.0
6.0
9.0
12.
15.
RELATIVE FREQUENCY
1.
0.8
0.6
0.4
0.2
0.
CLASS INTERVALS FOR FIRST LATENCY
0.
3.0
6.0
9.0
12.
15.