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EXPERIMENTAL STUDIES
OF PERCEPTUAL PROCESSES

Progress Report, September 1965

SECTION ONE

Covering Section, Budgets

SECTION TWO

I. Complex discriminative behavior in chimpanzees.

II. Fixed ratio reinforcement of large units of behavior.

III. Deferred reinforcement.

SECTION THREE

I. Signal detection psychophysical research.

II. Signal detection in the design of operant experiments.

III. Other research.

SECTION FOUR

Neurobiological program.

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INSTITUTE FOR BEHAVIORAL RESEARCH

SILVER SPRING, MARYLAND

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SECTION THREE

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INTERRELATIONS OF SIGNAL DETECTION AND OPERANT RESEARCH

The present section reports a series of experiments which are part of a program in which procedures derived from operant research are extended to relevant problems in signal detection research, and in which procedures derived from signal detection research are extended to the design of experiments in relevant operant areas.

This part of the progress report is submitted by Israel Goldiamond, Ph.D., principal investigator; John Thomas, Ph.D., and Stanley Pliskoff, Ph.D. (now at Arizona State University), research associates; Albert Miller, M.A., John Quagliano, M.A., and Alan Stubbs, M.A., research assistants.

One area of commonality between the two branches of the experimental analysis of behavior described is their attention to the effects upon behavior of consequences attached to it. Operant research has developed refined procedures relating reinforcing and aversive consequences to behavior, and we have built such procedures into the cells of the decision matrices of signal detection research. Procedures for establishing and maintaining complex behaviors have also been included. Signal detection research programs its systematic relation of pay-offs to behavior in a manner which differs from the systematic relation obtaining in operant research, and we have designed some operant experiments in terms of the refined decision framework of signal detection. The latter framework turns out to provide a procedure which is applicable to many classical and novel behavioral problems beyond the investigations in audition and vision with which it is usually associated.

This part of the report is divided into three sections:

1. Signal Detection Psychophysical Research:--This section reports research in which ROC curves have been obtained from both baboons and humans. Comparative curves have been obtained on identical tasks, as well as other data on differing tasks. Procedures have been developed which have established and maintained rational behavior over extended periods of time in baboons. Such behaviors, when humans are involved, are considered complex decision behaviors, since they are governed, not by consequences attached to one response rather than another, but by optimization criteria involving net gains into which there enter the complex of consequences in a decision matrix; these are related to uncertain states of the environment in terms of a strategy which can be specified. Both false alarm penalties and hit gains have been systematically varied with human observers. The procedures developed indicate the possibility of extending such advanced perceptual methodology to animal research in perception and decision processes, both as basic research, and to provide baselines for other research.

2. Application of TSD to the Design and Analysis of Operant Conditioning Experiments:--The research extends the Theory of Signal Detection to the design and analysis of experiments in operant behavior. Behaviors and problems studied thus far with pigeons include matching to sample, delayed responding, stimulus change, discrimination of elapsed time, discrimination of own behavior, switching behavior, and concurrent schedules.

3. Other Experiments:--Research is reported in other visual phenomena in which the interest is, at the present moment, primarily in the class of phenomena themselves. These include phenomena typically considered subjective, such as Purkinje after-images and subjective color, with animals as subjects. Apparatus is being constructed for control and analysis of eye-movements in humans. Research is also reported on the use of visual stimuli as conditioned reinforcers and other variables involved in maintenance of behavior.

GENERAL INTRODUCTION

The research reported involves the relation of procedures developed in both signal detection research and operant research to problems typically identified with each of these areas. Both animal and human subjects are being used for independent studies and for studies in which identical procedures have been applied for comparative purposes.

Although the consequences of behavior enter into both operant research and signal detection research, where they are conceptualized as reinforcement and pay-offs respectively, there are differences between their use of consequences which affect the design and data. In operant research, given two alternative response classes, and two alternative consequences, differential reinforcement refers to the systematic relation of consequence A to response A, and consequence B to response B. Where the alternative behavior which is defined as appropriate varies (as in responding Left or Right when the matching stimulus changes position), the relation described holds if response classes A and B are redefined to include appropriateness-inappropriateness. Stated otherwise, consequence A is still attached to response class A (which now comprises responding Left when stimulus left, and Right when right) and consequence B to response class B (Left when right, and Right when left). Such differential reinforcement has been used to shape and maintain behavior, and highly efficient procedures for the programming and maintenance of complex behavior in animals and people have thereby been developed. Signal detection pay-offs are characterized by their use of decision matrices. In this type of research, as in operant research, these may be two alternative response classes, but their relation to the pay-off differs. In this case, two consequences A and B are attached to response A, but two other consequences, C and D, are attached to response B. Stated otherwise, there is risk attached to <u>either</u> of the alternative responses, and the risks differ. In the case where appropriateness was discussed, this means that there are two different consequences attached to the two appropriate behaviors, and there are two other different consequences attached to the inappropriate behaviors. Thus, responding Left when left will produce a different consequence from responding Right when right, and there are two different types of errors, exemplified by Type I and Type II errors. The operant case described is thus the limiting case of the more general decision one where consequences for both types of errors are the same, and consequences for both types of corrects are the same.

There are many situations where the decision type of consequences may be applicable. For example, when we recently moved, the choice was not the gain attached to moving as opposed to the loss attached to staying. Rather, moving had gains and losses, and staying had gains and losses attached of a different kind. In decision theory, these consequences are handled in a matrix, with some optimization rule established to govern the best behavior. This may not be the particular reinforcement attached to a behavior, but a net gain in terms of a matrix. As we shall see, in one of the present experiments, the pay-off (or reinforcement) was increased from 5 cents to 50 cents. Nothing else was changed, but the behavior was unaffected. The result was related to decision outcomes.

Classical psychophysics dealt with the alternative response classes of Yes and No for detection of a signal. These procedures were used to obtain psychophysical curves and measures of sensitivity such as the threshold. The Theory of Signal Detection applies decision theory to this Yes-No process. Many of the problems which had hitherto been considered integral to perceptual research have turned out to have been functions of procedures which masked variables built into the decision design. One of the aims of the present research is similarly to use decision processes in the design of operant research, on the assumption that experiments so designed and analyzed may produce gains similar to those produced in perception, and to rationalize some of the problems currently found.

The losses and gains entered into the decision matrices of signal detection theory have by and large been monetary. Such losses and gains obviously cannot be used with animals. Accordingly, the present research reports the development of effective systems of pay-offs which can be used for both animals and humans. These systems of pay-offs provide not only the basis for comparative data, but capitalize upon advances in operant research, and make available for use in perceptual research this technology of shaping and maintaining complex behavior.

THE PARADIGM USED

The research to be reported is systematic, and it may be parsimonious to state the commonalities in advance, rather than to describe each set of conditions for each experiment.

The decision matrix.--A decision matrix is involved in each experiment in the first two parts, signal detection research, and application of TSD to design of operant research. The matrix is as follows:

	Event I	Event II
Response A	False Alarm: Consequence 1	Hit: Consequence 2
Response B	Quiet: Consequence 3	Miss: Consequence 4

The responses, which may differ in each experiment, are indicated in the rows. Response A may be Yes, or Left Key, or Small, or switching to a new key, etc. Response B may be No, or Right Key, or Large, or remaining on the present key, etc. The exact response will be defined at the outset of each experiment.

Events.--In each experiment to be reported, there are two states of the environment. These are indicated in the column entries. These states of the environment relate to what is normally considered the purpose of the experiment. In a signal detection experiment, for example, the alternative states may be the presentation of noise alone, or the presentation of signal-plus-noise. In a matching to sample experiment, the presentation in the match may be a stimulus which matches the sample or a stimulus which does not match the sample. In estimation of time, the conditions may be a short time interval or a long time interval. In delayed responding, the situations may be a delay or a nondelay, and so on.

Consequences of relation of behavior to events.—A 2 x 2 matrix is thus established in which there are 4 cells, AI, AII, BI, BII, which correspond to the occurrence of Response A in the presence of Event I, and so on. In the signal detection experiment, the responses may be Yes and No and the events may be noise and signal-plus-noise. The occurrence of the response Yes in the presence of noise defines a false alarm, and in the presence of signal, a hit. The occurrence of No in the presence of noise defines a quiet or correct rejection; in the presence of signal, it defines a miss. In the match-to-sample case, the organism can respond Left or Right, and the events are that the correct match is in the Left or Right key. He can thus be correct in two ways and incorrect in two ways. In operant research both ways of being correct are treated as one, as are both ways of being incorrect. An S^{Δ}/S^{D} ratio is formed. Our data indicate that this method of analysis produces different results from the design called for by decision theory, which requires different entries in each of the four cells. The operant procedures can thus be viewed as a limiting case of the more general decision behavior. The two correct entries in the table can be arbitrarily labeled hits and misses, and the two incorrect can be labeled as false alarms and quiets, depending upon the design.

The entries in the four cells are consequences, reinforcing or aversive, or pay-offs. The hit cell notation may be Fixed Ratio 14, 5¢. This means that every 14th Yes response when the signal was presented produced a nickel. The false alarm cell notation may be Time Out 15 seconds. This means that every Yes response when noise was presented resulted in the apparatus becoming inoperative for 15 seconds. Another notation is Advance, usually for quiets. This means that the presentation goes out, without gain or loss, and the next presentation is ready. These matrices involve the blending of operant and signal detection procedures. Each entry is derived from the operant literature. The combination is derived from decision research as is, as we shall see, the outcome.

The ROC curves.—In many signal detection experiments, the false alarm contingency is made the independent variable. The hit may be reinforced by a nickel; the quiet may result in zero gain, and the miss may result in a 2¢ loss. Obviously, the only gain which the organism can make is through responding Yes. Accordingly, losses are inserted into the false alarm cell and the size of this loss will govern the number of Yes responses the organism makes. If the penalty is considerable, the organism may say Yes very infrequently, and if the penalty is low, he may Yes more frequently.

Since the 50% Yes point is the threshold, and the number of times he says Yes is governed by the penalty for false alarm, the threshold will be a function of the severity of penalty attached to false alarms, and the threshold will vary while the organism is equally sensitive to the stimulus. The curve which presents hit rates as a function of false alarm rates is called an ROC curve or receiver operating characteristic curve. This curve is the locus of all possible pairings of false alarm rates and hit rates, at a given signal-noise ratio. As the penalty for false alarm is relaxed, the false alarm rate will increase, and so will hit rate; the curves link the specific values of each. An alternative name that has been suggested for this curve is the isosensitivity curve; although the response rates differ at each point, the subject is equally sensitive at all points on this curve.

For each change in signal-noise ratio, differing ROC curves will be drawn, and the net result will be a table with a family of curves. From such a table, an infinite number of psychophysical curves can be drawn.

Such detection tables and ROC curves may also be plotted for match-to-sample research and for time estimation curves, as well as the other problems to be reported in this presentation.

Control of presentation.--The stimulus presentation, whether it is an absolute bar to be responded to as large or small, or a pair of stimuli one of which must be chosen, is governed by the subject in all experiments to be reported. He presses a button or pecks a key which then produces the presentation stimulus. This occurs in all cases except when there is a time out penalty. Here, the presentation device is inactivated for the period of the time-out. This means he cannot produce the stimuli in whose context a response may produce reinforcement. In the Advance case, the presentation goes out, and the next presentation response produces the next stimulus.

Signal-noise ratios.--The signal-noise ratio refers to what is called the stimulus dimension along which discrimination occurs.

In the psychophysical experiments of this series, noise was defined Gaussianly by bars (see next section), and signal was an increment to each bar. In the operant experiments, the signal-noise dimension varied. It was different periods of time in discrimination of elapsed time, differing number of responses before a light went out in discrimination of one's own behavior, differing periods of time since a light changed in delayed responding, and the like. The experiments suggest that the model can be applied to the design of a variety of operant experiments.

In TSD research, there is considerable overlap between the two distributions whose elements must be differentiated (a presentation, such as a radar blip,may be identical for both a Russian and an American plane; objectively it belongs to one class or the other), providing for the risk of false alarm. As the penalties are increased for false alarm, the model calls for the observer to raise his criterion, and settle at some stimulus, beyond which one response is given, and below which another. The criterion chosen is related to optimal resolution of the decision matrix entries. This will be discussed in greater detail in the psychophysical section.

USE OF FADING PROCEDURES

Throughout many of the experiments, fading procedures have been utilized. Where a difficult discrimination is to be made, the fading procedure involves establishing a simple discrimination first; and when the discrimination controls the organism's behavior without error, elements of the new dimension are gradually added as the older dimension is gradually withdrawn in a systematic manner, so that eventually the behavior comes under the control of the new discrimination. The transition from one dimension to the other occurs without error. The complex discriminations discussed here were established by such methods, and we have developed research procedures which establish and maintain complex discriminations in animals and people for use in such signal detection and other discrimination research. The procedures would seem to have applicability for a variety of discriminative tasks and represent another one of the implications of operant technology to psychophysical research.

A. SIGNAL DETECTION PSYCHOPHYSICAL RESEARCH

A detailed description of the apparatus, the rationale, and the more general procedures has been presented in the preceding progress report and in the general introduction. Accordingly, the present statement will present only those features of these which are necessary to explain the present procedures and findings.

General Statement and Derivative Procedures

The general procedures for all the experiments to be reported in this section are the following: The presentation of the stimulus is controlled by the subject who presses a button ad lib; light is then presented on a translucent screen illuminated from behind, which has the shape of a bar. Depending upon the area covered by the light, there will be presented a bar which may range in size from a very small one to a very large one.

The subject has two keys (or buttons) to press which are related by the experimenter's program to the size of the bar. Initially the large and small presentations were quite distinguishable. If the bar was small the left response was appropriate and if it was large, the right response.

At the present stage the series of frames for slides for which the small or large response is appropriate contain many overlapping elements. Stated otherwise, some of the frames for slides in the small distribution are larger than some of the frames for slides in the large distribution, with the reverse also holding.

The distribution whose mean bar is smaller than the mean bar of the other distribution is considered noise, and the other distribution is considered signal-plus-noise, giving the decision matrix presented

Relation to classical psychophysics

In one type of classical psychophysical experiment, the observer may be seated before a screen which is constantly illuminated. Although the illumination has been carefully set by some instrument, it may, nevertheless, vary randomly around some mean. Large fluctuations will be rare and the more typical fluctuations will be small. If the fluctuations are randomly distributed, this background illumination may be defined as noise, with Gaussian distribution. A tone is sounded, and the experimenter then either flashes a light on that screen or does not flash a light on that screen. The subject's task is to indicate whether or not the experimenter flashed a light on the screen during that tone, the judgment period. If the presentation by the experimenter was sufficiently small, it may occur when the fluctuation of the background light produced so small a background presentation that (a) background-plus-light were less intense than (b) a high random fluctuation of background alone. In the case of a the observer may say No, a miss. He might say Yes during b, a false alarm.

This situation is often encountered in threshold studies, and the degree of difficulty of decision is attested by the fact that the definition of the threshold as the point of 50% detection of the increment implies missing it 50% of the time. When the increment is smaller, it is detected less than 50% of the time, and if it is made larger, it is hit increasingly more, producing the familiar psychophysical ogive. This classical psychophysical procedure is one of the more refined ones; variations such as the Method of Limits, staircase and up-down methods, etc. may be used to derive similar curves.

There have been numerous precedural and interpretive difficulties related to threshold and sensitivity studies. Many of these are reconciled by the application of the Theory of Signal Detection. Here the subject can make two kinds of errors, calling the background an increment and calling the increment a background, and can also be correct in two ways. His behaviors will be a function not only of the size of the increment (the usual psychophysical consideration), but also of the consequences attached to the behavior. If, for example, he is penalized very severely for reporting a background as an increment, he is likely to call out increments far less often than otherwise. He will want the increment to be very large before he labels it as such, since when it is smaller he is more likely to be in error and is therefore likely to be punished severely. Accordingly, his 50% point will occur at a much higher increment level, and he will have a higher threshold and appear to be less sensitive.

Relation to present research

In the present research, the small bars are distributed Gaussianly and correspond to the background illumination. Very small and very large ones are rare. The distribution of small bars thus meets the requirements of noise according to the theory of detection. The larger series is formed by adding a fixed increment to each bar in the noise series. Accordingly, each signal bar is slightly larger. The distribution of large bars must be Gaussian (since it is based on the noise bar) and meets the requirements of signal-plus-noise in the theory.

Eleven series of large distributions have been developed, in which the increment to the basic noise distribution is progressively increased in steps of 1/4 inch. Accordingly, where the increment is extremely large, the smallest signal-plus-noise presentation is larger than the largest noise presentation. As the signal increment gets smaller, the overlap between the two distributions is increased. Where the increment is very small, only the smallest noise presentation can not be confused with a signal-plus-noise presentation, and only the largest signal-plus-noise can not be confused with a noise presentation. The others could be in either category. These eleven sets of signal-plus-noise distributions have been prepared for both binomial and Gaussian distributions. Figure 1 presents the binomial distributions for the noise and various signal-plus-noise series. The curves are "tents". The Gaussian curves would be the familiar normal curves; the binomial curves lend themselves to more ready illustration. The abscissa is the size of the given bar expressed in an arbitrary unit, and the ordinate indicates the number of times that presentation will appear in a given series. The numbers at the tops of the distribution indicate the number of increments above zero (noise) which characterizes that distribution. From this figure, we can see that with a bar whose size is 7, the odds are 6 to 5 that it came from the noise distribution as opposed to the distribution whose increment was 1. The odds are 6 to 1 the distributions are noise on an increment of 5.

For a given signal-noise ratio, and for a given decision matrix, strategies can be worked out which will produce the optimum net gain

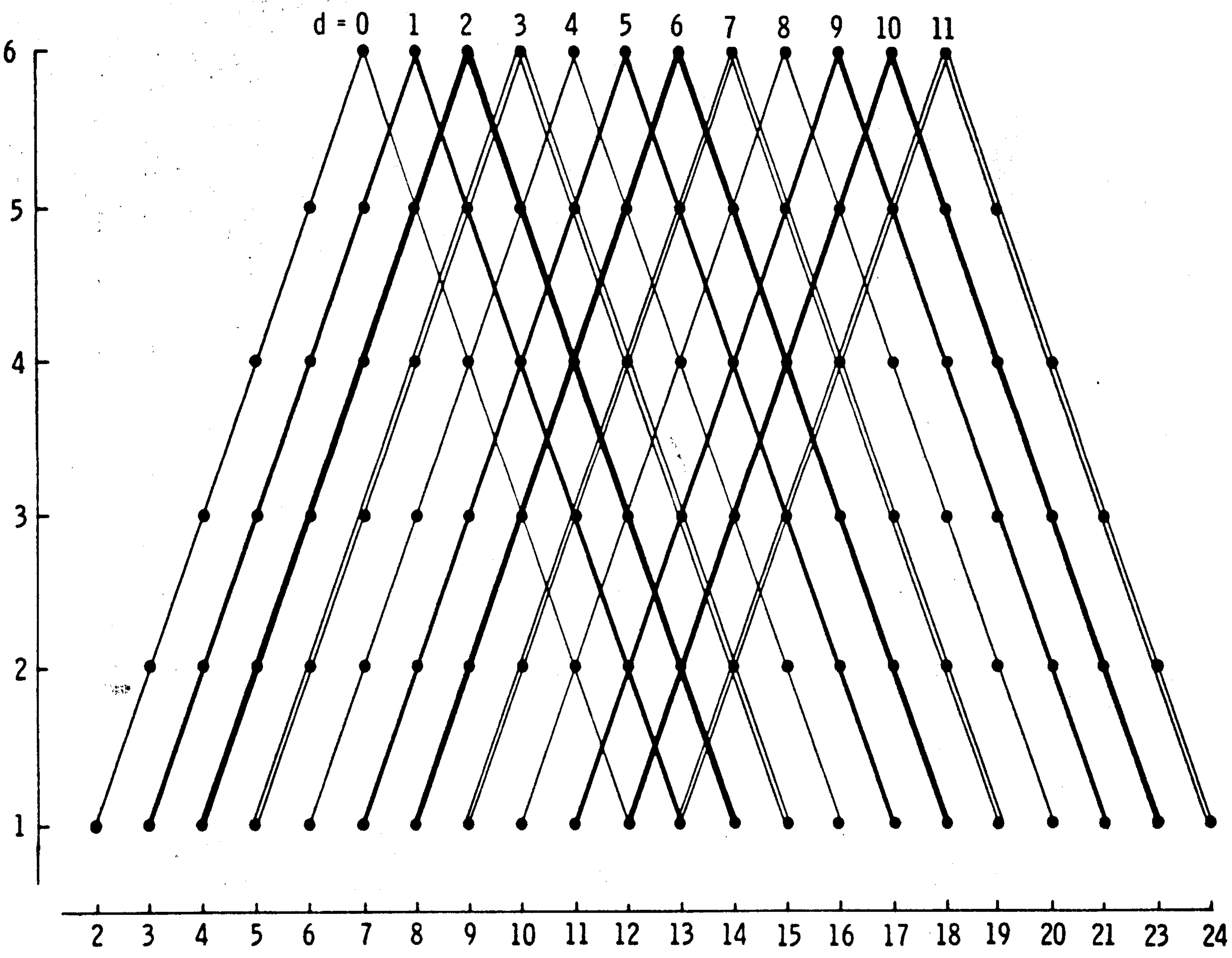


Figure 1. Binomial distributions for noise (d=0), and various signal plus noise distributions used (d=1 . . . 11)

for the observer. The strategy involves setting a criterion bar size, and calling everything above it signal, and below it, noise. If there are very low penalties for false alarm, and high gains for hits, the criterion should be set low. For the reverse, it should be set high. The optima can be analyzed mathematically.

The bars meet all the theoretical requirements of noise and signal-plus-noise of TSD. The difference is that the major elements are explicit: the distributions are explicitly Gaussian since the frequencies of the different sizes are established according to Table. The signal increment is exact because it is filmed that way. The dimension of change is unidimensional for the same reason-- all the bars are the same width, but their height varies.

EXPERIMENT ONE: HUMANS AND BABOONS

The decision matrix for the human experiment is the following:

	Noise	Signal-Plus Noise
Yes (left button)	Time-out 5-120 sec.	FR 14 5 cents
No (right button)	Advance	Time-out 2 sec.

The matrix indicates that the only response which produces reinforcement is the Yes response when the signal is present. The reinforcement was on a fixed ratio of 14, that is, 14 correct detections activated a counter whose points were worth a nickel to the subject. The penalty for responding Yes in the presence of noise, that is, false alarm penalty, was a time out which was fixed <u>during</u> a session, but was the independent variable between sessions. It ranged from five to 120 seconds. At the latter value, if the subject made an inappropriate Yes, all equipment became inoperative and he could not work to produce the stimuli in whose presence he might get reinforced. Responding No in the presence of noise is a quiet, and the stimulus presentation went off; the apparatus was immediately readied for the next presentation. A miss, defined as stating No in the presence of the signal, was penalized by a two second time-out.

The decision matrix for the baboon experiment is the following:

	Noise	Signal-Plus Noise
Left Lever	Time-out 2-120 sec.	FR 5 1 pellet
Right Lever	Advance	Time-out 2 sec.

It is evident that this matrix is practically identical to the matrix used for the humans. The major difference, of course, is the reinforcement. This was one pellet of food distributed on a fixed ratio of five, this is, five hits had to be made before the pellet was given. The penalty for false alarm is practically identical to that for humans and the consequences of quiets and misses are identical.

Figure 2 represents a classical psychophysical curve obtained for SN4 with one of the animals. The distributions used were 0 (Noise) and 4 represented in Fig.1. It will be noted that as time-out is increased from five seconds to 120 seconds, the psychophysical curve becomes steeper and the threshold higher. ROC curves for the two other baboons run under the same procedures are presented in Figures 3 and 4. The highest pointson the ROC curves represent the two second time-out and the lowest points represent 120 second time-out,with points between having intermediate values. As the penalty for false alarm diminishes, the probability of false alarm is raised, as is the probability of correct detection.

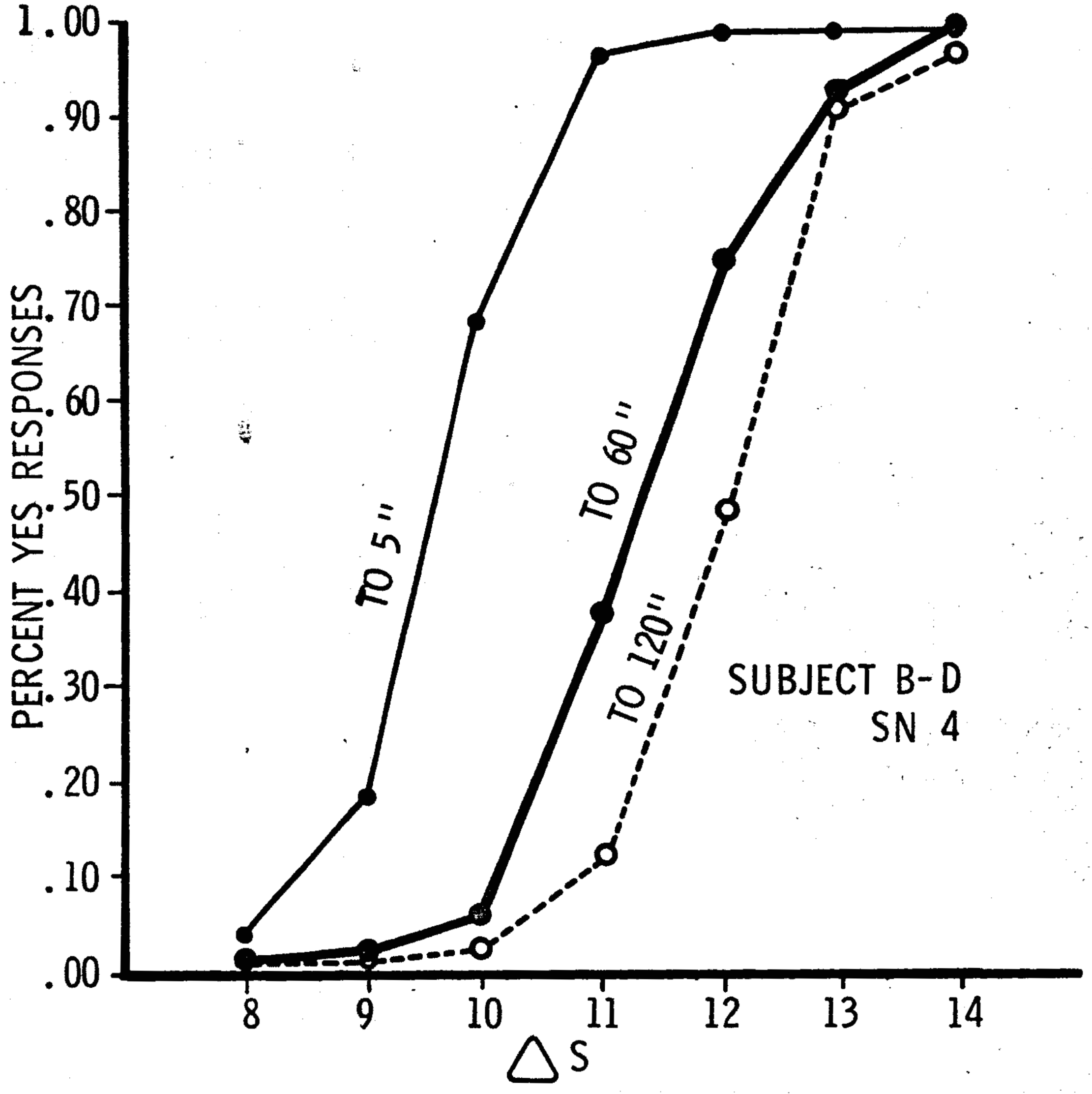


Figure 2. Classical psychophysical curve obtained from baboon under different conditions of penalty for False Alarms. The stimulus presentation distribution is the same. Note rise in threshold as a function of penalty.

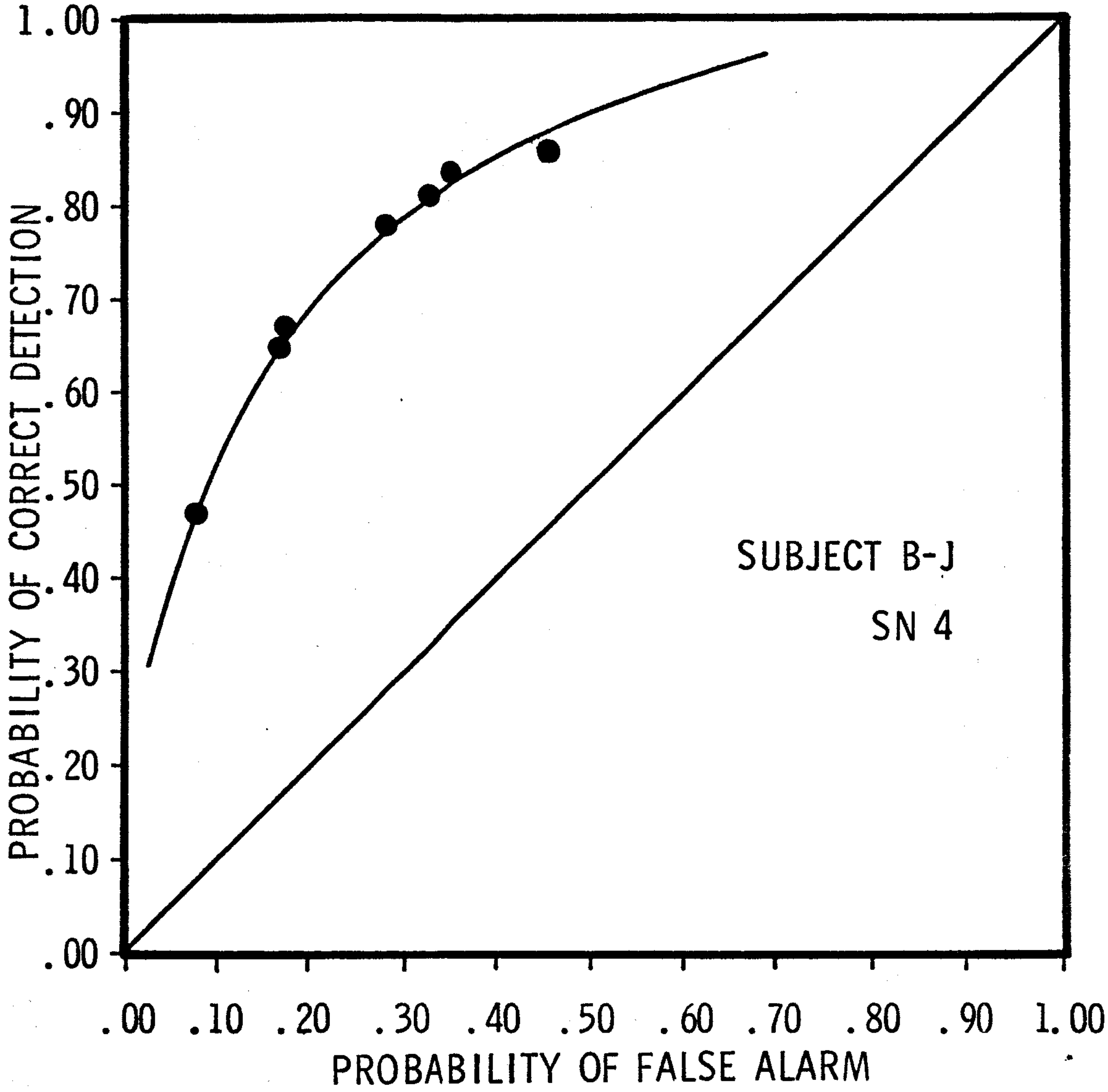


Figure 3. ROC curve obtained for baboon at one signal-noise ratio.

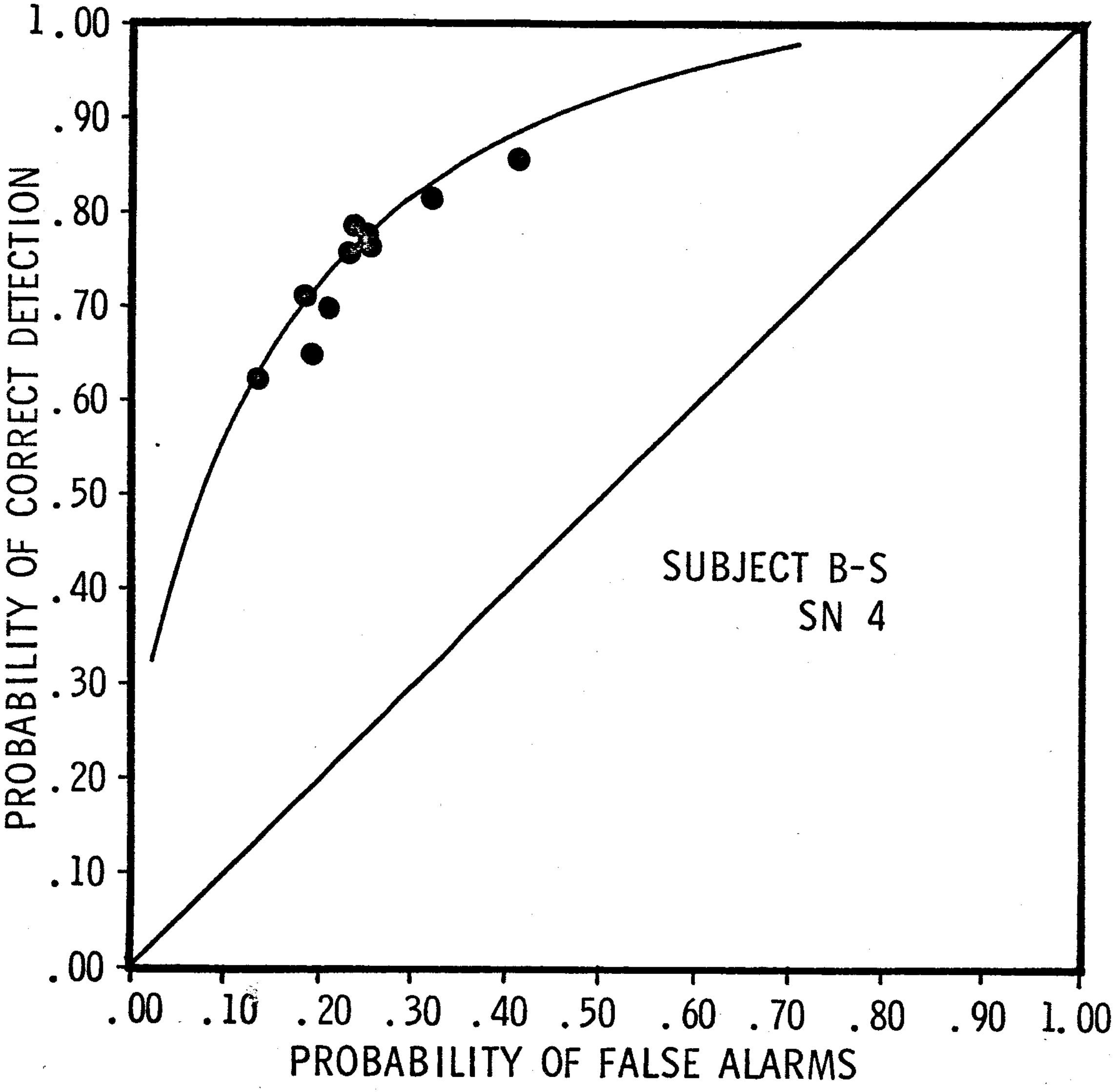


Figure 4. ROC curve obtained for third baboon at same signal-noise ratio.

A comparison of the curves for the two baboons shows them to be practically identical, although B-J has a greater range indicating a larger change in his criterion for given time-out values, especially at the long time-out durations. For example, at 120 seconds time-out this baboon has a correct detection rate of .47 and a false alarm rate of .08, while at the same time-out value, the other baboon, B-S, has a correct detection rate of .62 and a false alarm rate of .14. The fact that the curves fall practically on the same line however, indicates that they are equally sensitive. Thus the ROC curves for these baboons can be used to differentiate perpetual sensitivity from response bias factors. Although their response styles and sensitivity to consequences differ, the ROC curve indicates this is the source of the differences rather than any difference in sensitivity, which is identical.

The data to be presented next involve comparison of the most sensitive human subjects with one of the baboons, both baboons chosen for this section having been equally sensitive.

Figure 5 presents the ROC curves for both organisms. The lowest point is the rate obtained at the maximum time-out, namely, 120 seconds, and the highest point represents the curves obtained at the minimal time-outs. The ROC curves are indistinguishable, indicating that the baboon and the human subjects are equally sensitive. The data also suggest that both are responding to optimize net gain in accord with the requirements of decision theory for that signal-noise ratio. Their optimization is not that of the ideal observer, a computer, but the baboons are optimizing as well as the human observers.

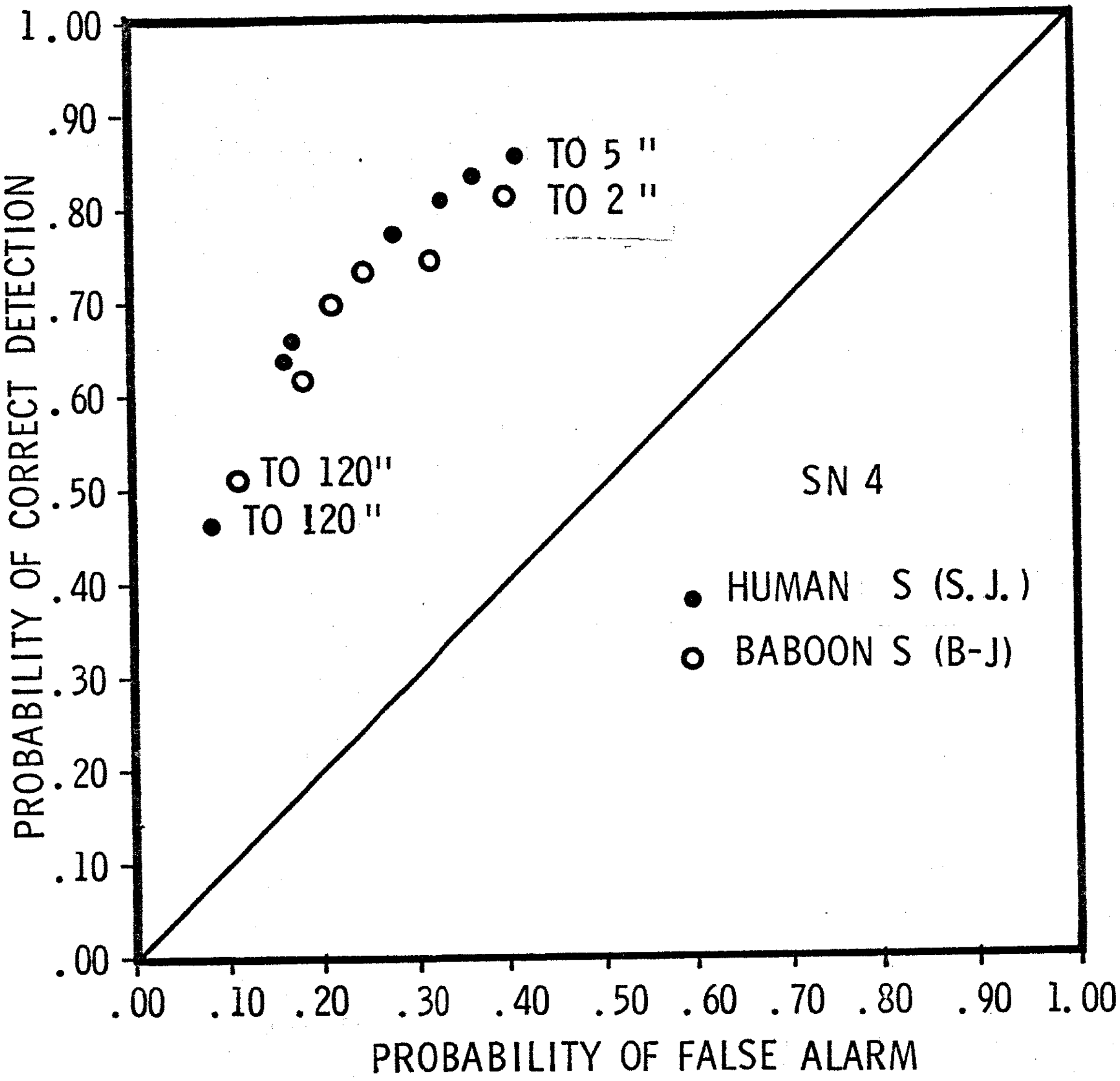


Figure 5. Comparison of human and baboon subjects on same tasks. Both organisms respond according to the requirements of decision theory for that signal-noise ratio.

EXPERIMENT TWO: VARYING THE HIT PAYOFF

In this experiment the payoff for hits was varied as well as the penalty attached to false alarms. Two conditions were run, described by the following matrices::

	Noise	Signal-Plus Noise
Yes	Time-out 120 sec.	FR 14 5 cents FR 15 50 cents
No	Advance	Time-out 2 sec.

Yes	Time-out 10 sec.	FR 14 5 cents FR 14 50 cents
No	Advance	Time-out 2 sec.

As can be seen, two payoffs were used for hits. One was 5 cents for every fourteenth correct detection, and the other was 50 cents for every fourteenth correction detection. These were systematically related to two time-out penalties for false alarm, 120 seconds time-out, and ten seconds time-out, giving four conditions. Figure 6 and Figure 7 present the classical psychophysical curves for subject SJ at SN3, with Figure 6 under conditions of time-out of 120 seconds, and Figure 7, the time-out for false alarms of ten seconds, under both reward conditions. As can be seen from these two curves, the subject's psychophysical function was not affected by the changes in reward values. If the two curves are superimposed, however, it will be seen that his behavior was affected by the false alarm penalties. At 120 seconds time-out, the curve represents less detection and an increasingly higher threshold than at ten seconds time-out.

The identities of these two curves under different conditions of reinforcement should not be interpreted to mean that consequences are not effective. The subject presents the stimuli to himself ad lib. Assuming that he can make a certain number of presentations within a given time, and assuming that he can make money on some of these presentations, then time represents money to the subject. When we increase the pay-off from five cents to fifty cents, we are thereby increasing the monetary value of time. Hence, each moment of time becomes all the more precious and the penalty for false alarm rate is accordingly increased in a manner exactly analogous to the pay-off gained from hits. Hence, differences in reinforcement at a given cell do not affect performance. Rather, it is their effects upon the net gain that do so. These not being different, behavior is not affected.

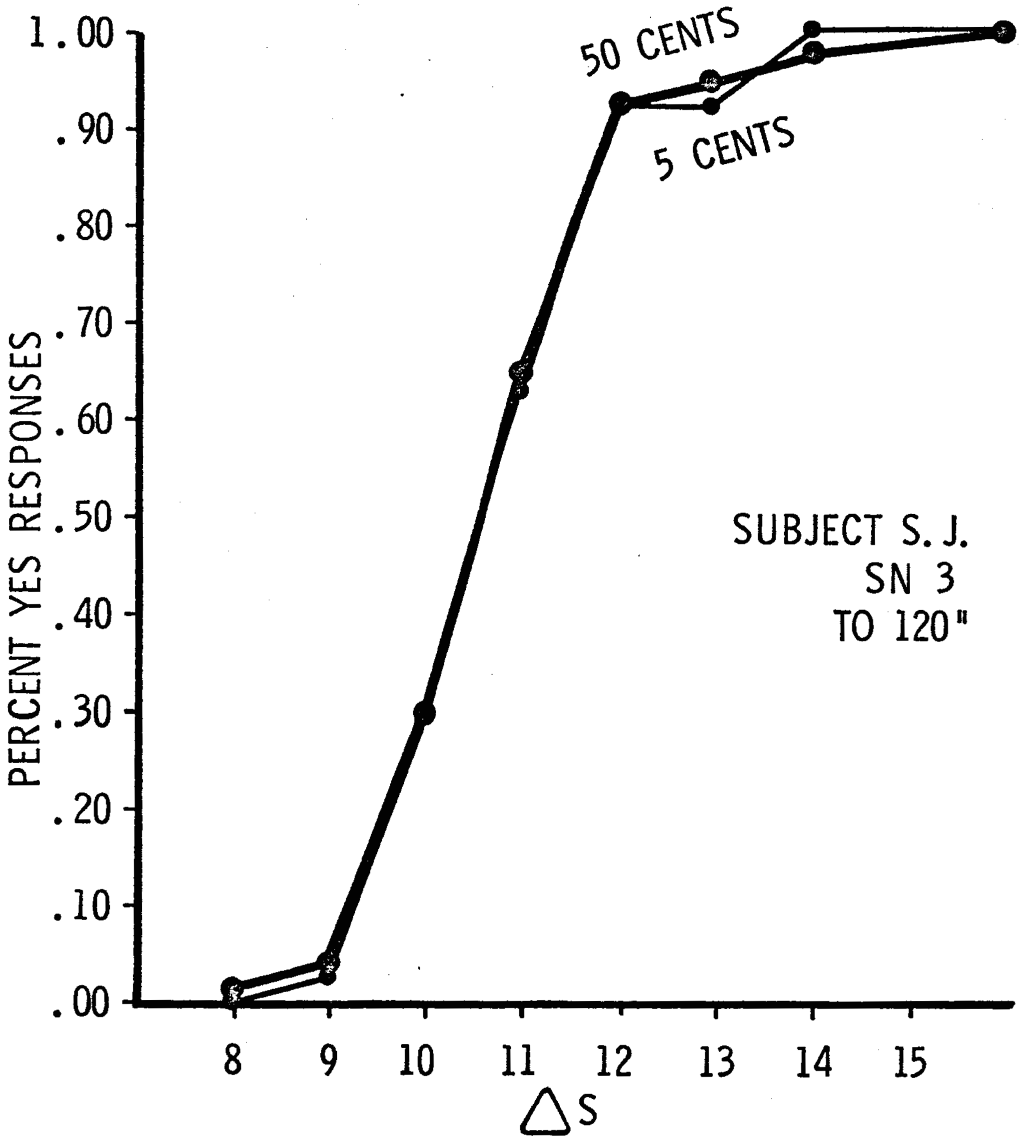


Figure 6. Variation of reinforcement magnitude does not affect response of observer at Time Out 120".

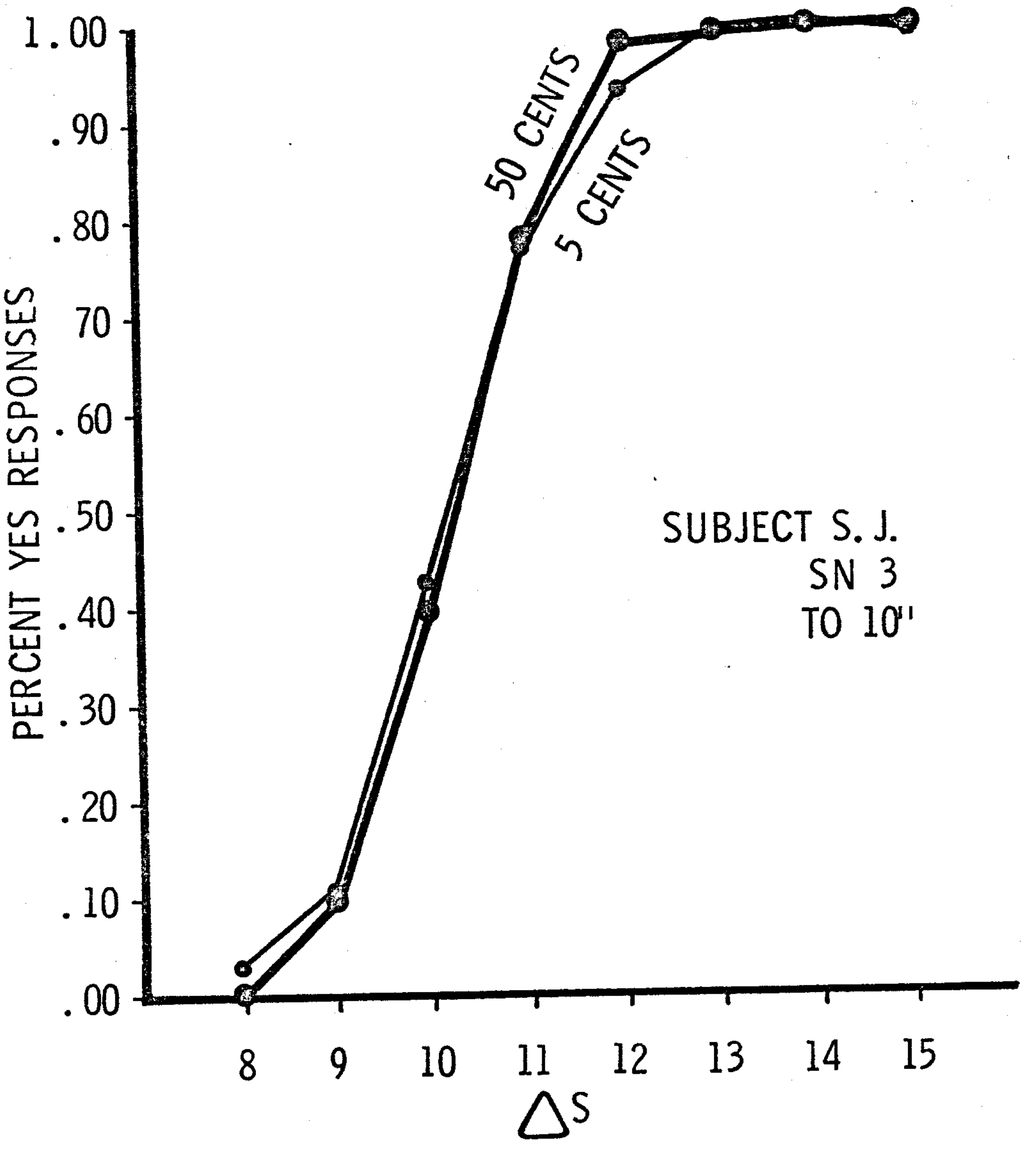


Figure 7. Variation of reinforcement magnitude does not affect response of observer at Time Out 10".

Figures 8 and 9 represent the psychometric performance of a different subject, SR under SN3 detection conditions. In Figure 8 the time-out is 120 seconds, and the higher curve is five cents with the lower curve fifty cents pay-off. Paradoxically, increasing the pay-off for hits decreased performance. In Figure 9, the time-out panalty is ten seconds and the situation is reversed. Making the pay-off higher increases rate. Superimposition of the curves under a ten second penalty and a 120 second penalty indicate that the increase in penalty produced steeper curves with higher thresholds. The reversals in the psychometric data from this subject suggest that he is not as good an observer as the preceding subject. This difference may be due either to his sensitivity or to his response pattern. Figure 10 presents the ROC curves for these two subjects under similar pay-off for hits. Again, the upper points represent low time-outs, and the lower points high time-out. The curve of SJ is the upper curve. As defined by ROC curves, he is a more sensitive subject than SR. He is also more consistent, as indicated on the monetary variable curves.

The effects of increasing magnitude of reinforcement would appear to be complex. A higher reinforcement magnitude may also induce a subject to take larger risks in making a false alarm. This can benefit the subject whose performance is further from the theoretical optimum, as subject SR demonstrates.

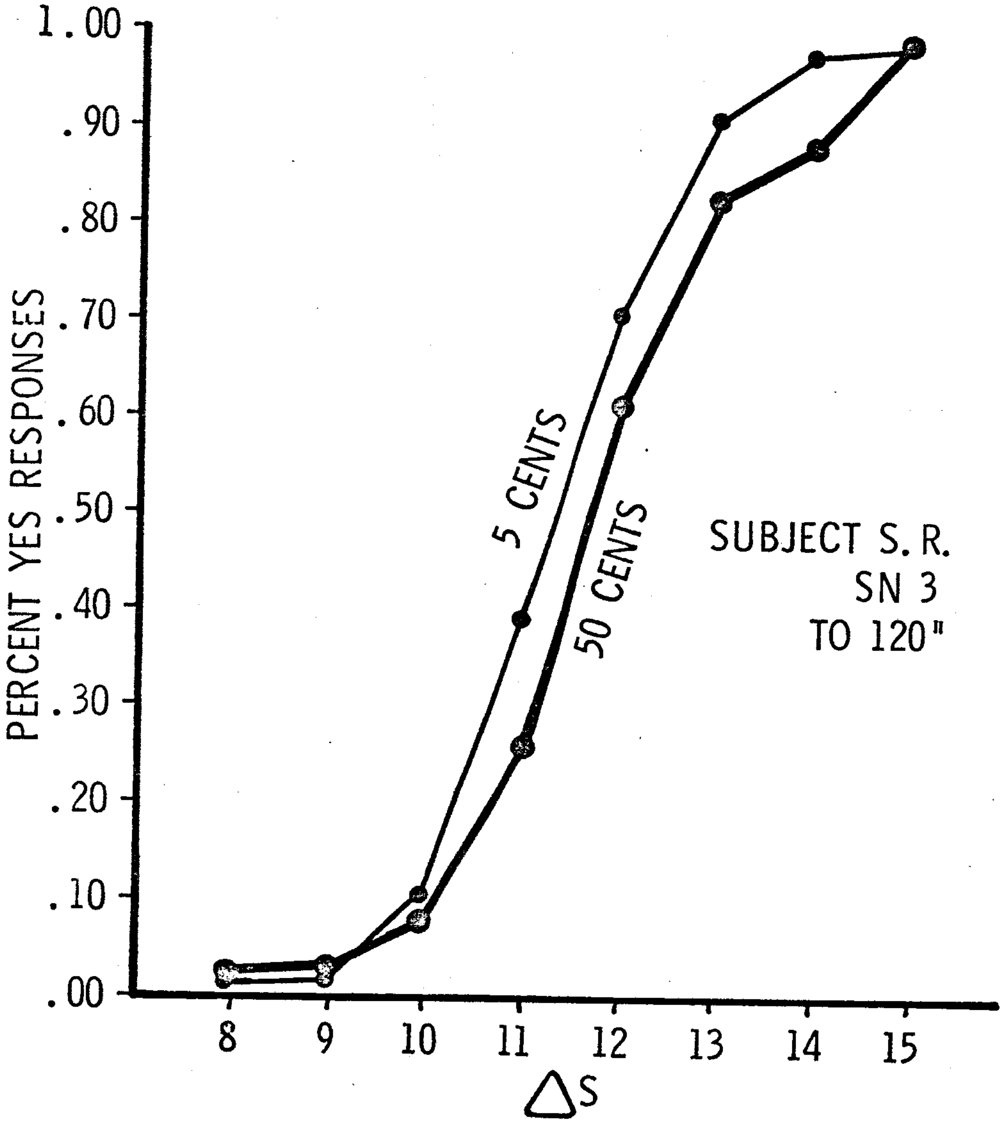


Figure 8. Effects of varying reinforcement upon a different subject. Time-out penalty is 120".

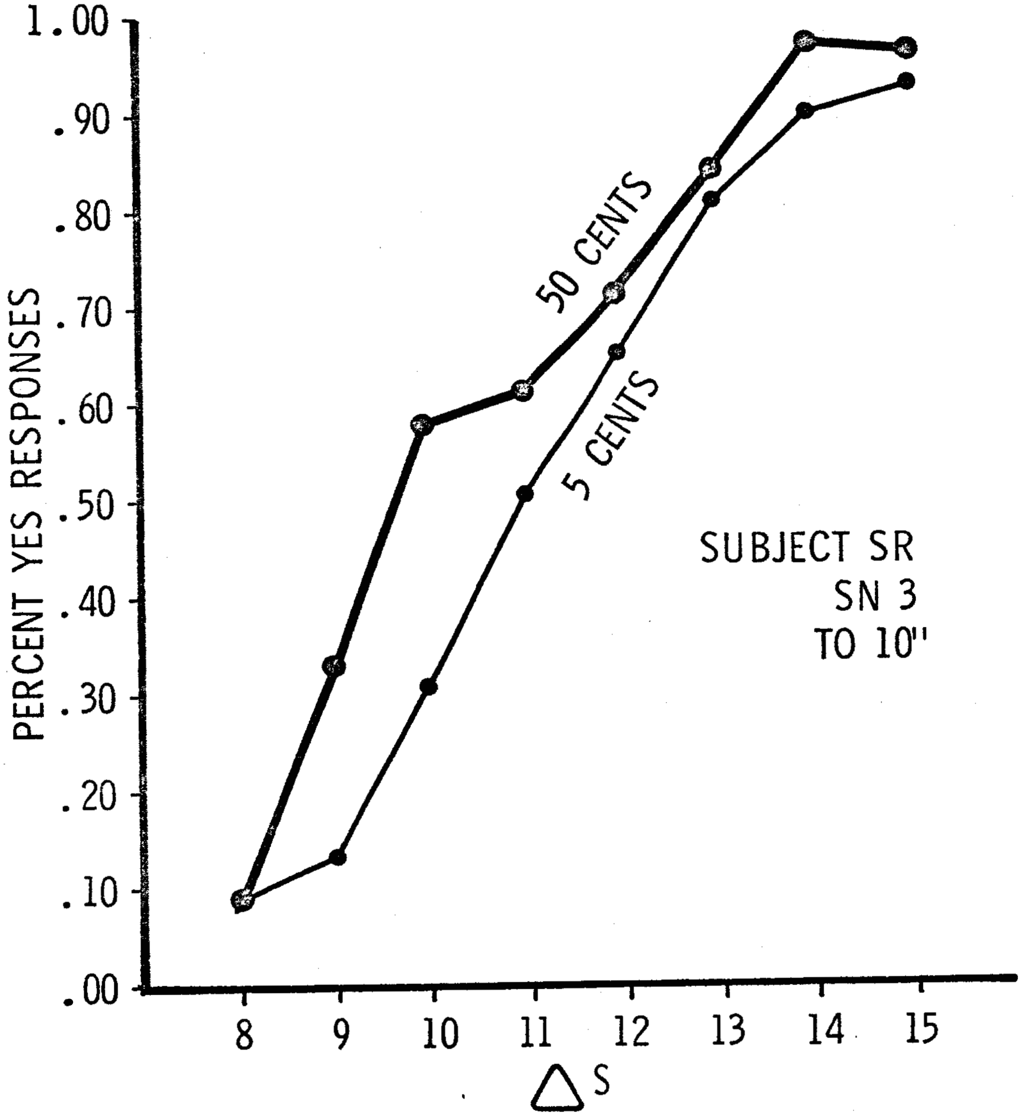


Figure 9. Effects of varying reinforcement upon same subject; time out penalty is 10".

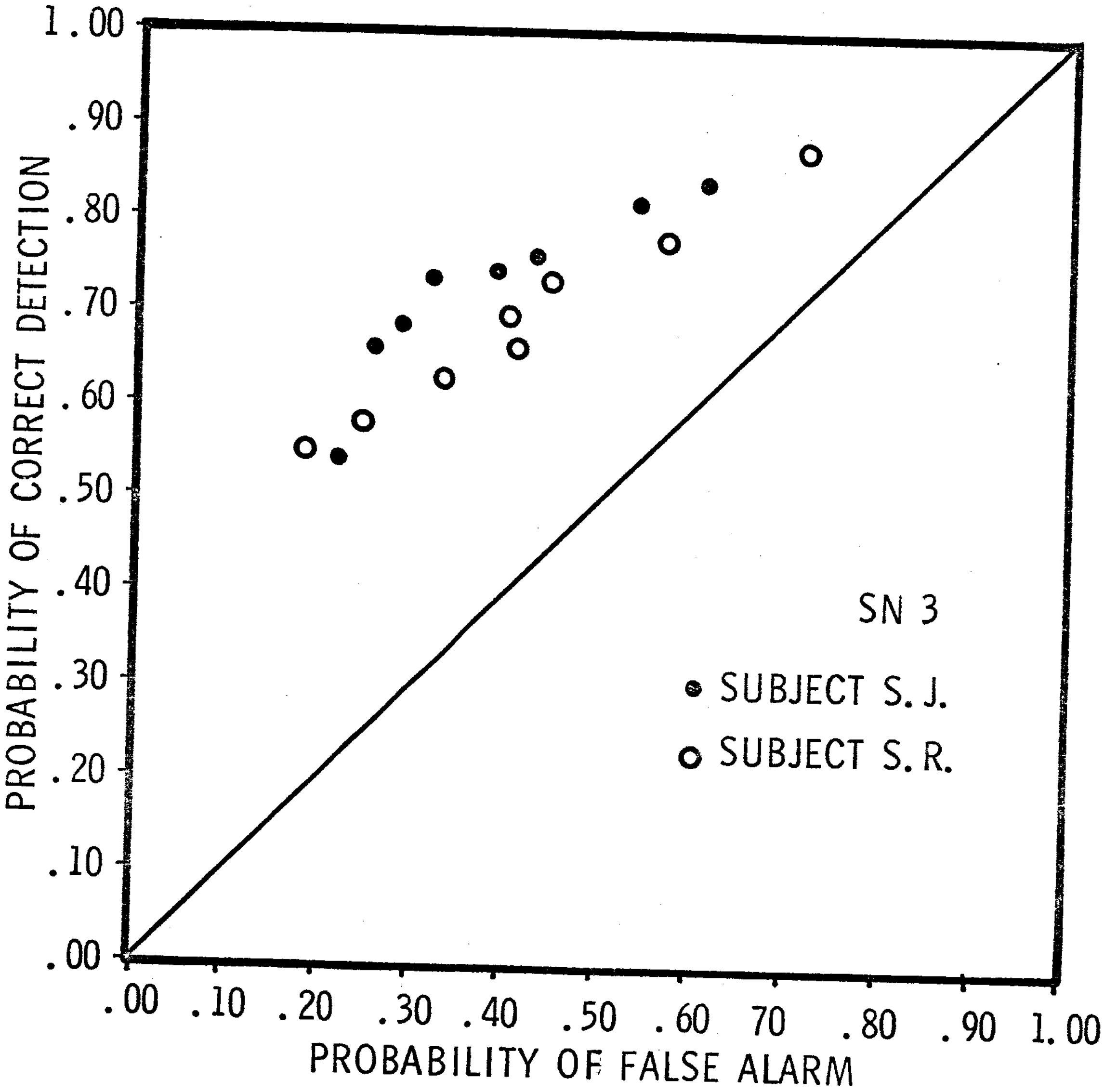


Figure 10. Comparison of the two observers. The more consistent subject, S.J., is also more sensitive.

In order to determine this tendency it will be necessary to look at local relative rates of responding in a finer-grained analysis. It is possible, for example, that the subject who showed no overall change with the higher magnitude did so because a local rate change produced no noticeable change in reinforcement frequency because he was already behaving close to the theoretical optimum. Future research will explore these relationships further.

OTHER EXPERIMENTS

ROC curves have thus far been obtained for four SN ratios with human observers. Comparisons of the same observers under two different SN ratios are presented in Figures 11 and 12. Ideally, all SN ratios should be sampled. Such an ROC series would present a series of curves, from which an infinite number of psychophysical curves could be drawn. Time-out decreases as the points increase, and this is made the parameter in Figure 13, which presents psychometric functions for one observer at one SN ratio. Although the observer is equally sensitive at each time-out, the thresholds differ. Psychophysical curves in the classical tradition would require a sampling from several SN ratios, but the relation of thresholds to time out would remain as depicted here.

From the classical psychophysical curves it is impossible to indicate whether the differences of thresholds for the two subjects are functions of the differences in sensitivity or functions of response biases produced by the differing consequences. However, each of the ROC curves is the locus of all possible response bias for a given signal-noise ratio, and such comparative ROC curves can actually differentiate sensitivity from response bias. The rationale is the following: Suppose one subject for a given signal-noise ratio produces a ROC curve identical to that which another subject would produce for a different signal-noise ratio. Both curves are the locus of all possible response biases, therefore, the response bias contributions to the variance are identical. Hence, the differences between

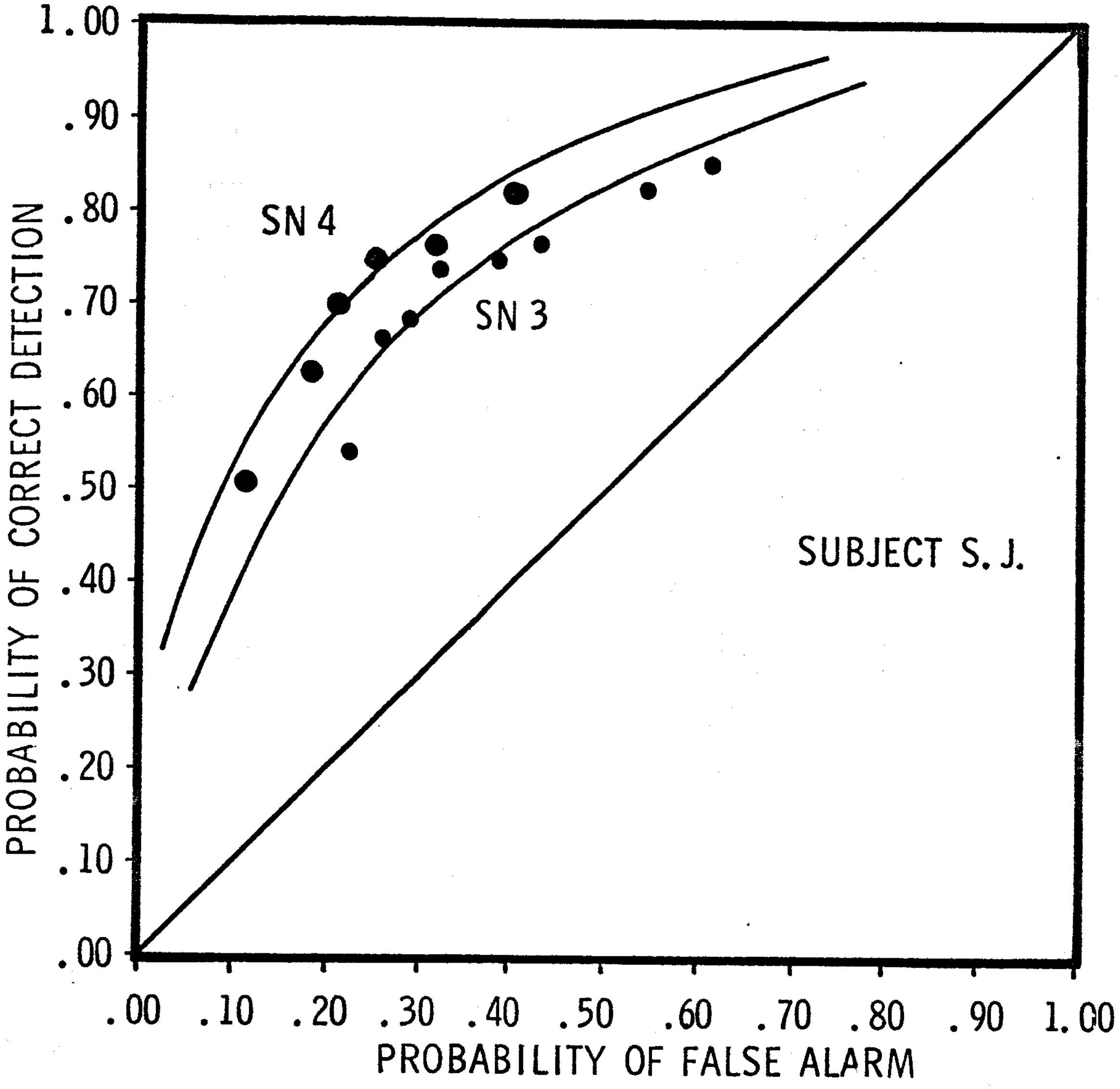


Figure 11. ROC curves for two SN ratios for S.J.

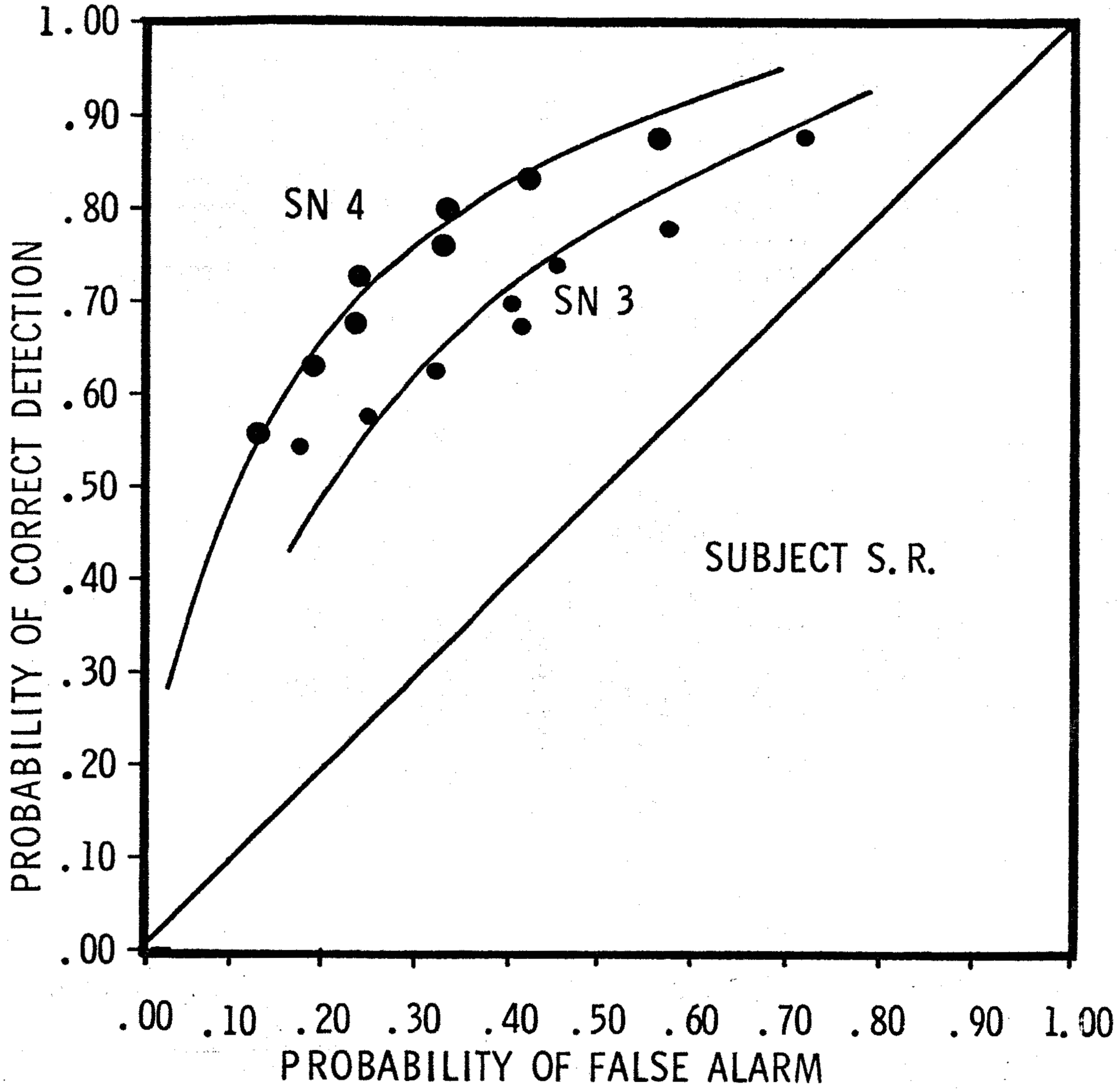


Figure 12. ROC curves for two SN ratios for S.R.

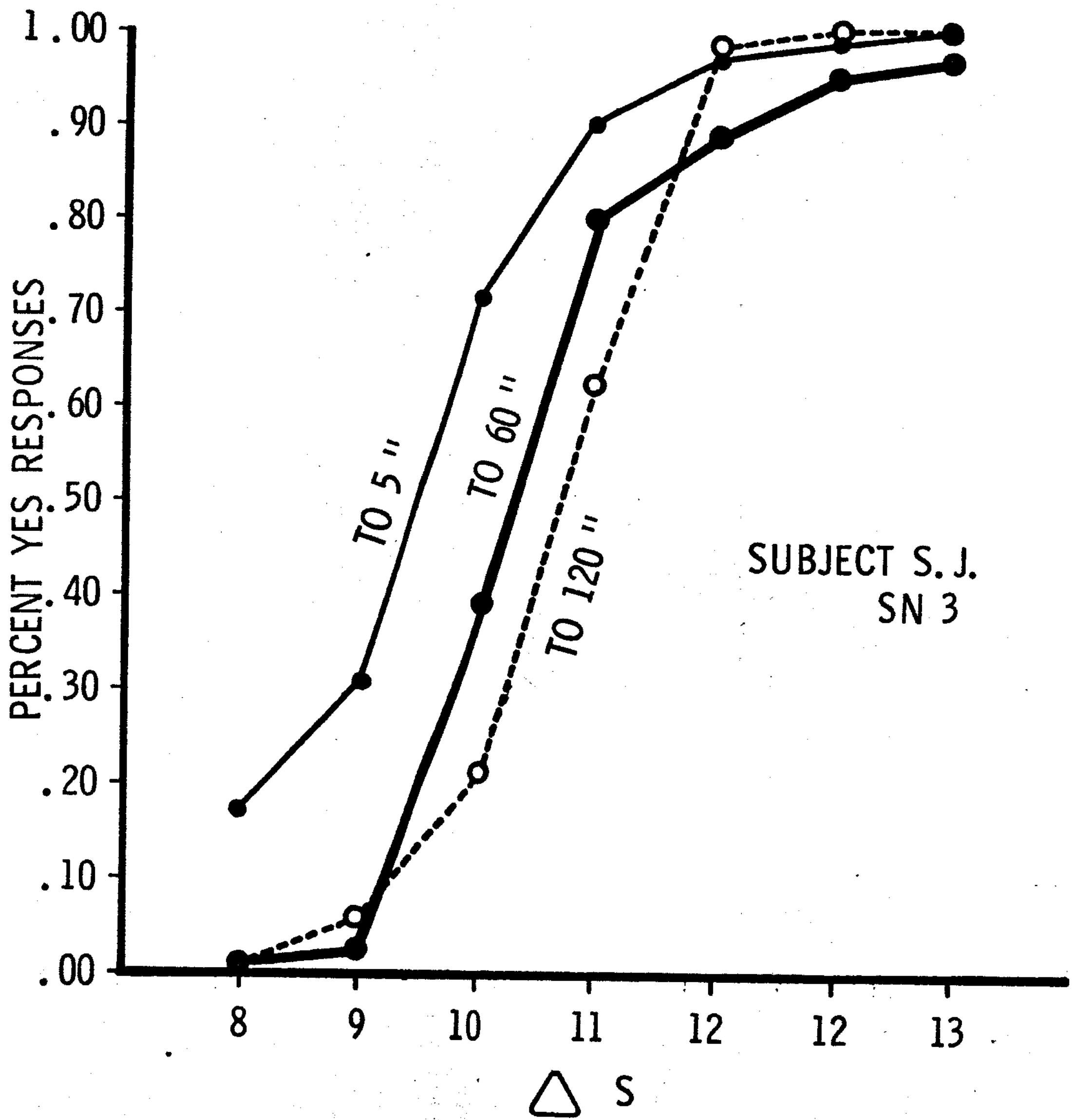


Figure 13. Psychometric functions, with time out the parameter.

the two may be related to their sensitivity. This sensitivity can be numerically described by answering the following question: What filter would I have to put over the more sensitive subject to degrade his performance to that of the less sensitive subject? If the filter is a 90% transmission filter, we might state that one subject was 90% as sensitive as the other.

Not only can subjects be compared to each other in this manner but they can be compared to an absolute called **Ideal Observer**. The Ideal Observer represents a computer with information as to the signal and noise distributions who would optimize net gain throughout his performance by choosing appropriate criteria, and thereby produce ideal curves. The Ideal Observer can provide a yardstick for the definition of sensitivity.

Although the illustrations used came from Figure 1, containing binomial distributions, the data reported in the preceding experiments involve stimulus distributions which were Gaussian. These film sequences were prepared as a result of experience with prior sequences in which the distributions were based on the expansion of the binomial theorem. The binomial distribution had about six hundred frames, but the normal distribution has 1558 frames in each distribution. For each SN ratio a separate set of distributions must be filmed and considerable effort has been expended in the preparation of such distributions.

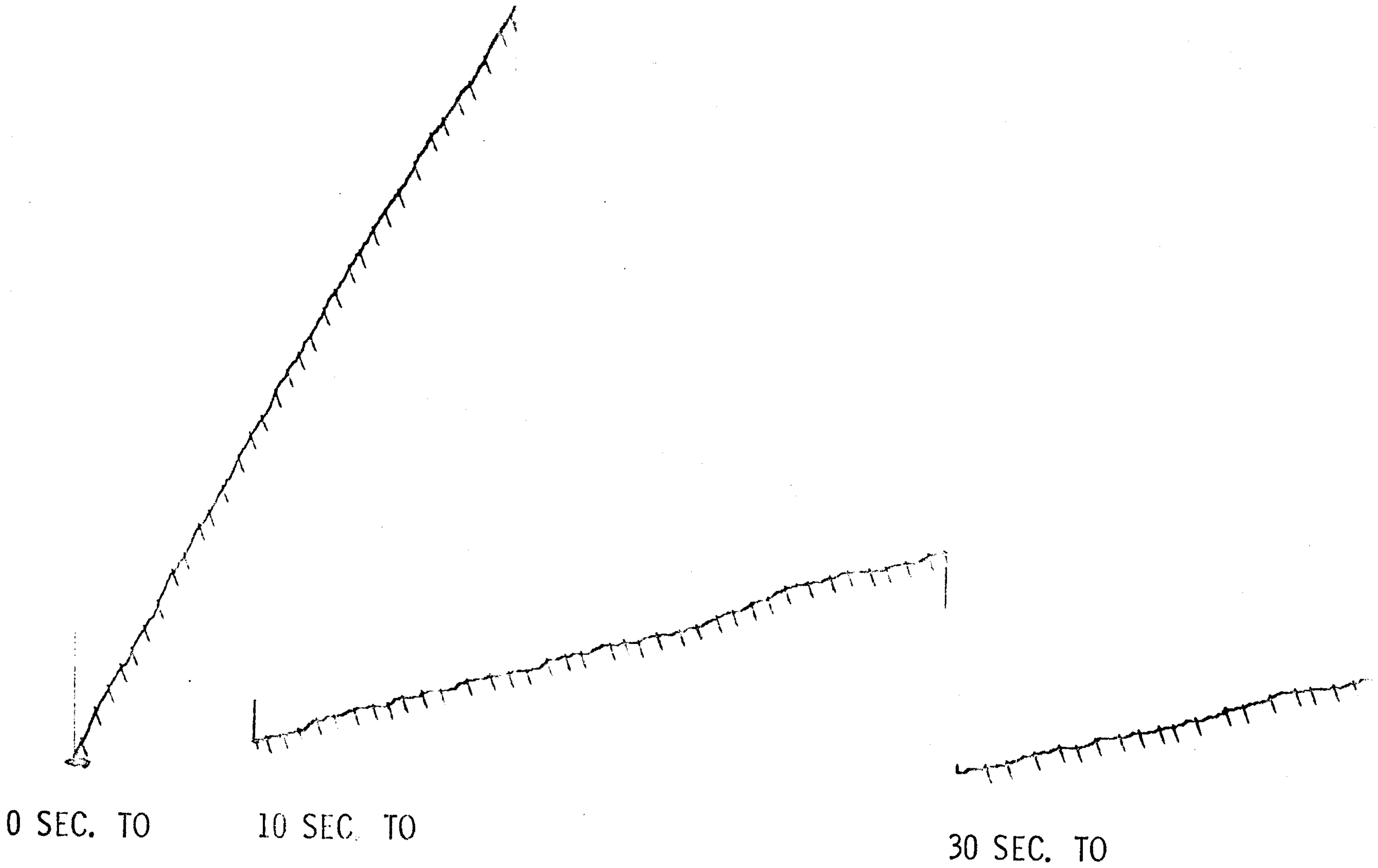
Although the binomial experiments have been completed, the actual curves obtained will be presented in the final report. The data indicated the importance of attention to minutest details. There was, for example, very little change in baboon behavior from a two second time-out to a 30 second time-out for false alarms. It was surmised that the baboons had learned some of the sequences in the binomial distributions. Substitution of a film sequence based on a Gaussian distribution immediately differentiated these two, and other, penalties.

GENERAL COMMENTS: CUMULATIVE RECORDS

The foregoing experiments involve automated equipment. Each frame of the film not only projects a vertical bar but is also coded for photocells which indicate its distribution, its order, and its SN ratio. Readings from the photocells activate transducers which are connected to circuits coordinated with the subject's responses. All presentations, effects of responses, and their interrelations are automatic.

The data are recorded on counters as well as on seven cumulative re orders, as Figure 14a-g indicate. Recordings for time-outs of 0 seconds, 10 seconds, and 30 seconds are presented. These curves are from the binomial distributions, which contained serial effects.

False alarm rates under these conditions are presented in Figure 14a. As can be seen, the higher the penalty attached to false alarm, the lower the false alarm rate. Figure 14b presents the corresponding detection rates. As the false alarm rate is decreased, the number of hits also decreases.



FALSE ALARMS

Figure 14a

H.M.

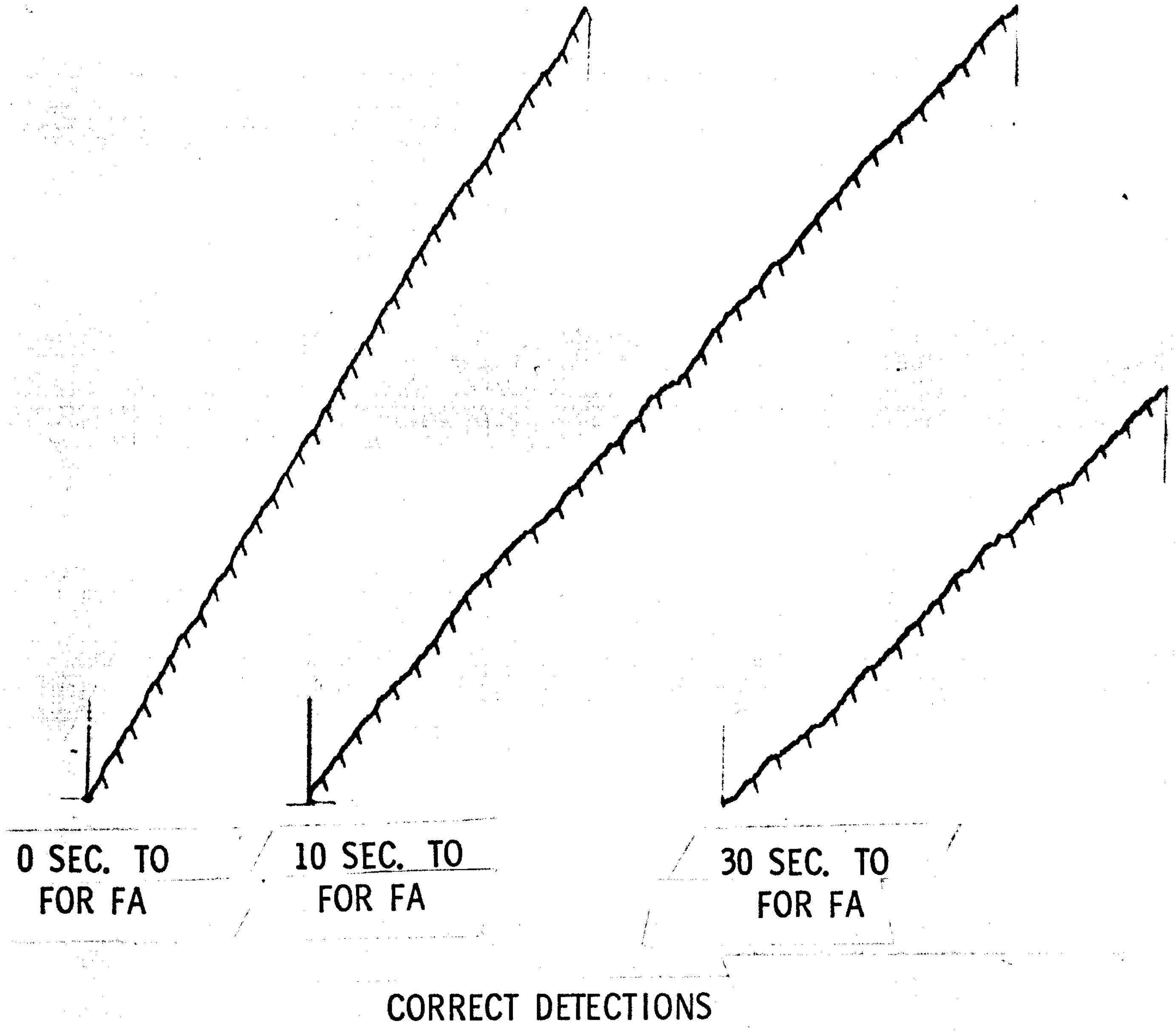
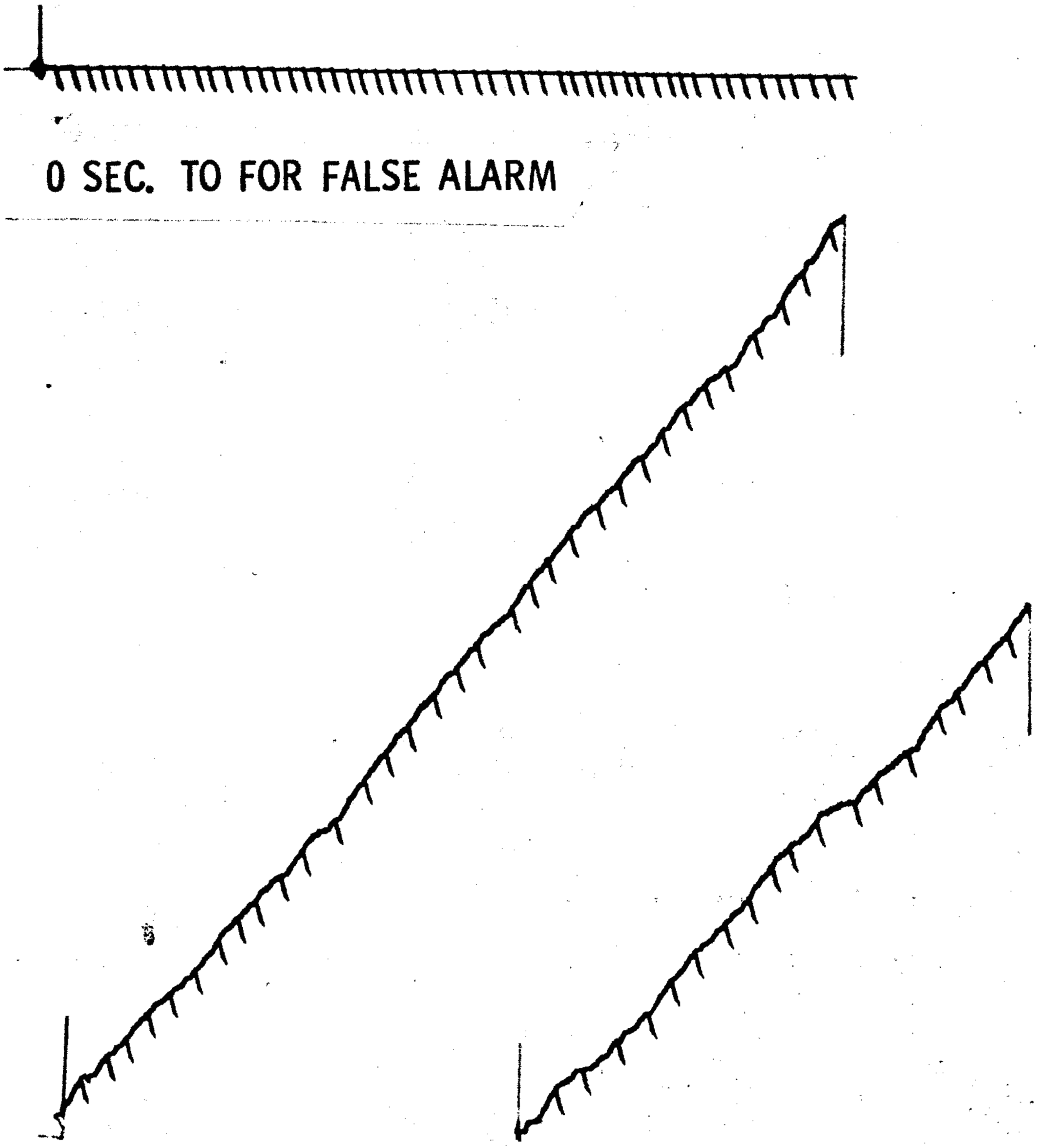


Figure 14b

H.M.



0 SEC. TO FOR FALSE ALARM

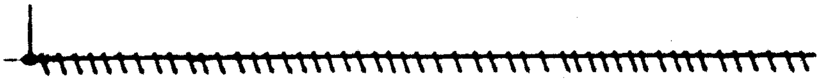
10 SEC. FOR FALSE ALARM

30 SEC. TO FOR FALSE ALARM

QUIETS

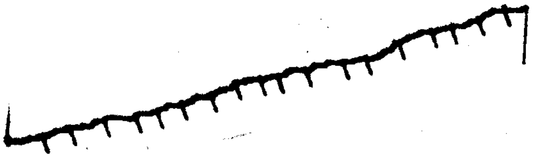
Figure 14c

H.M.



0 SEC. TO FOR FALSE ALARM

10 SEC. TO FOR FALSE ALARM



30 SEC. TO FOR FALSE ALARM

MISSES (NO TIME OUT CONTINGENCY)

Figure 14d

Figure 14c represents the quiet rate under these conditions. It will be noted that when there is no penalty attached to false alarm, there are no quiets. As the false alarm rate is increased, the number goes up. The number of misses is also a function of false alarm rate, indicated in Figure 14d.

The S^{Δ} and S^{D} responses are presented in Figures 14e and 14f, respectively. The S^{Δ} responses are the summation of the two types of errors and the S^{Δ} responses are the summations of the two ways of being correct. Although the S^{Δ}/S^{D} ratio is generally related to detection, it loses data by combining these scores. At times this loss in data may distort the data since we have obtained S^{Δ}/S^{D} ratios which result in different conclusions from those obtained by inspection of the ROC curves (presented in preceding report).

The number of present responses as a function of the different false alarm rates is indicated in Figure 14g. As can be seen the rate of subjects' responses is also a function of the penalties attached to false alarm rate. The higher the penalty of the false alarm rate the less likely the subject is to present himself with a stimulus for judgment.

H.M.

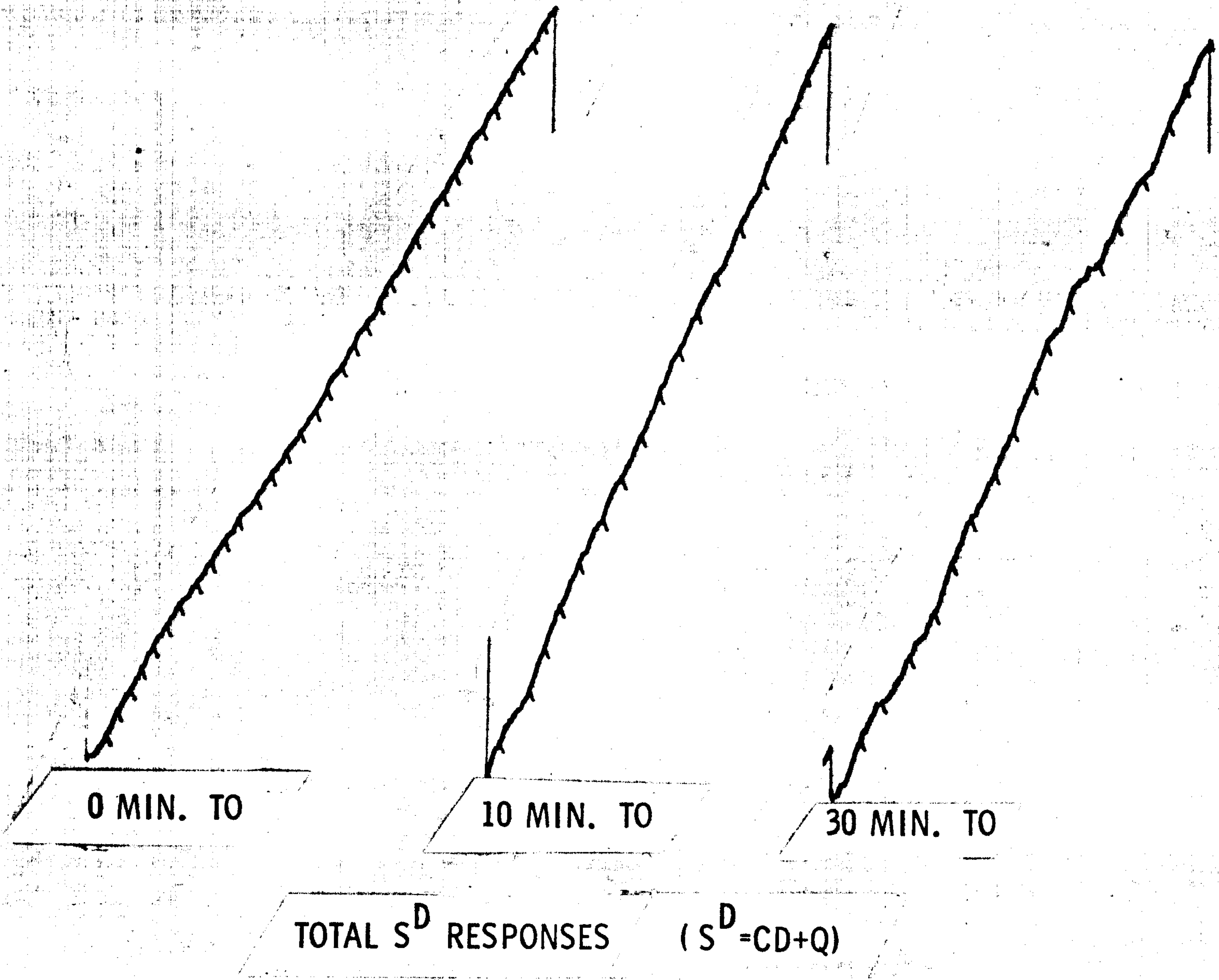


Figure 14e

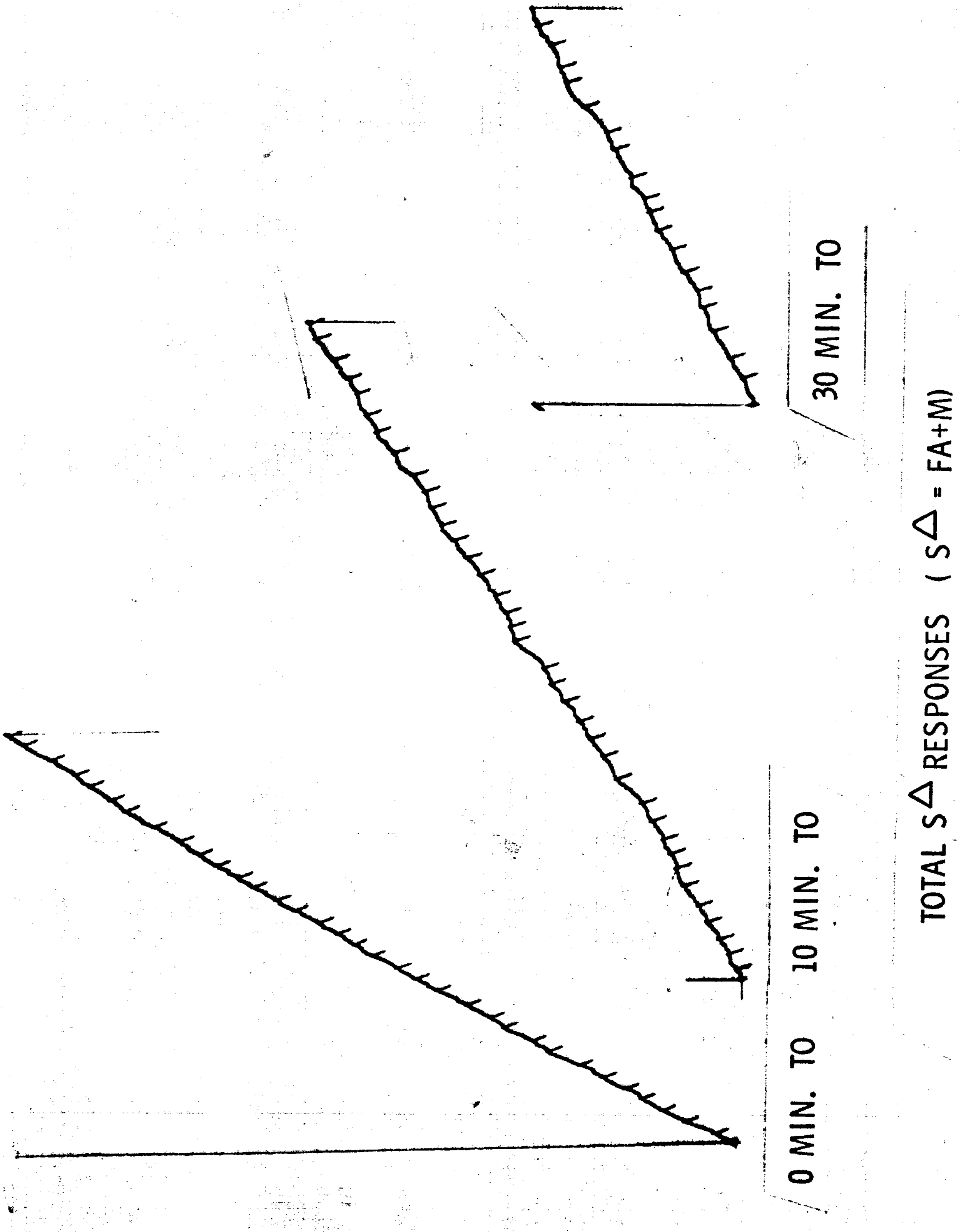


Figure 14f

H.M.

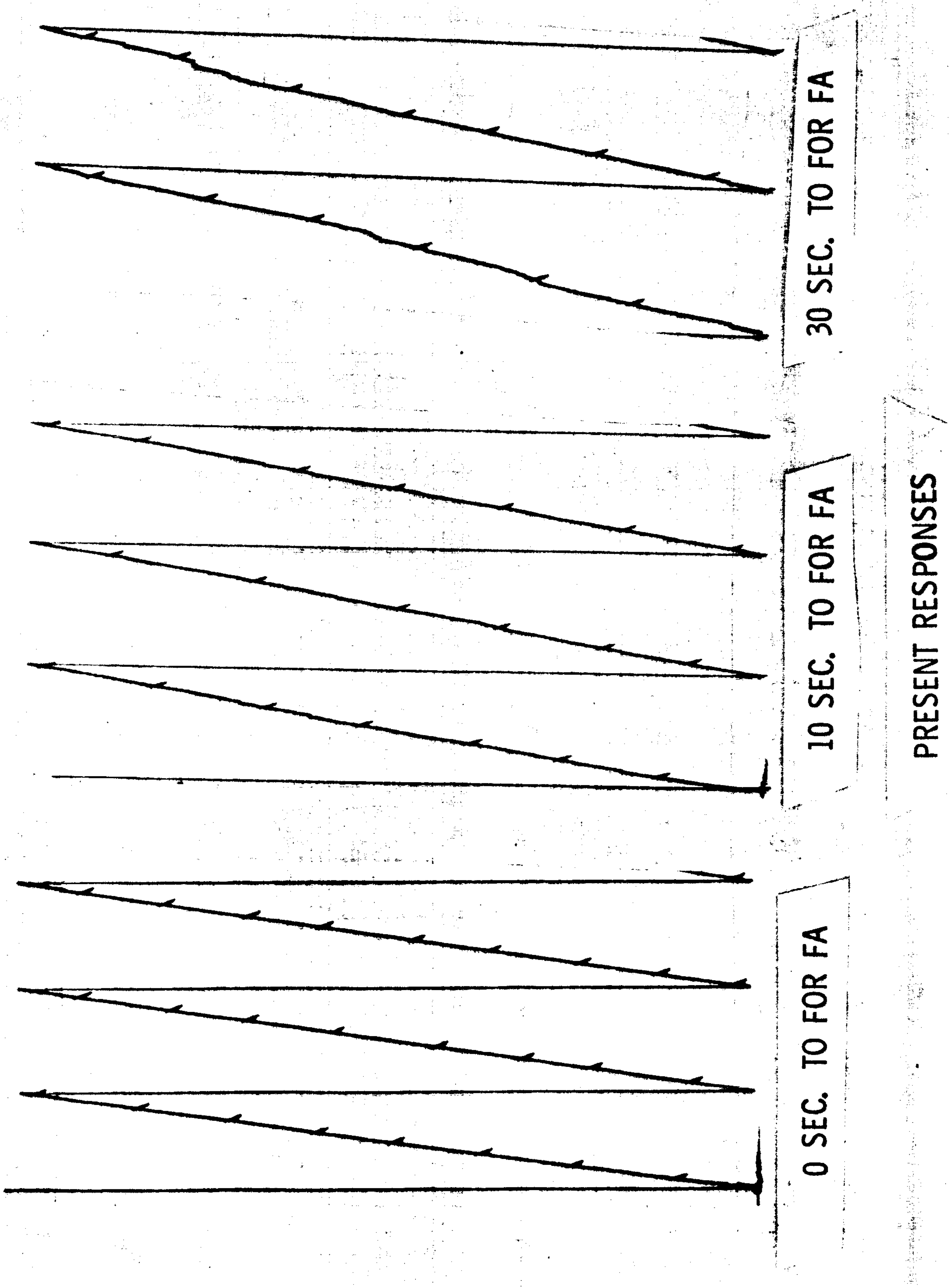


Figure 14g

FUTURE RESEARCH

1. Reinforcement Magnitude Effects

From the data collected thus far on the effects of reinforcement magnitude, there is some indication of an interaction of reinforcement magnitude and cost for an error. Under the assumption that the subject is maximizing his net gain the reinforcement magnitude should be irrelevant, since the behavior that maximizes the pay-off will maximize it regardless of the absolute value.

As indicated by the data of subject SR, whether or not a subject is affected by reinforcement magnitude may be related to the level of actual performance relative to the theoretical optimum performance.

It is proposed to explore this relationship further by manipulating the variables throughout a wider range of time-out values and reinforcement magnitudes. These procedures may also allow us to determine the nature of the decision strategy being used by the subject, and its relationship to the pay-off matrix. Luce has pointed out the lack of research in this area and its importance in assessing the nature of response biases in detection tasks.

2. Consistency of Judgments

Some data have already been collected, but not yet analyzed, to assess the consistency of judgments over short periods of time (5 min.). The data will allow us to plot ROC curves and psychometric functions in 5 minute blocks for 1 hour sessions. Green, in a study of the consistency of auditory detection judgments points out the necessity of this kind of data for what he terms a molecular psychophysics. Very little has been done thus far in the area of signal detection theory in determining sequential effects in judgments.

Our procedures and stimulus conditions are uniquely suited for this kind of study since both the signal and noise distribution are known exactly and the film presentation insures the identical presentation of the stimulus each time it occurs.

3. Extension to other SN Ratios

Since one of the problems in TSD is generating ROC curves by using large signals, we will explore this problem by extension of procedures used thus far to larger SN ratios.

4. Forced Choice Behavior

Film sequences have been prepared and another booth is now ready for running other subjects in experiments in forced choice.

The paradigm for each of these experiments is the following: Four circles are presented on a screen in an up, down, left, and right position. Corresponding to these positions are four buttons at the subject's table. One of the circles is different from the others. The different sequences include a triangle in one circle with squares in the other three circles. Locating the odd circle represents form discrimination. It is evident that color discrimination, size discrimination, concept discrimination, and a variety of other discriminations may be assessed by this method.

Forced choice behavior and Yes-No behavior have been rationalized by the Theory of Signal Detection, and these experiments would seek to extend these relations using some of the methods described earlier.

These experiments will be conducted in conjunction with the next problem.

5. Scaling of Yes-No Values

To the side of the subject's response panel containing the up, down, left, and right buttons are ten buttons arranged in a column. The first four are black followed by a green button, followed by a red, followed by four black buttons. The green and red buttons when used alone can be made to represent Yes and No, as in the preceding series of experiments. The general design would require the subject to present himself with a stimulus consisting of the four circles. He would then be required to press the forced choice button corresponding to the oddity one. The presentations will be varied in intensity, so that it will be extremely difficult for him to locate the odd figure under such conditions. There will be many more responses than where the intensity is high, since the subject is required to perform until accurate. Having made this response, the next element in the chain will require him to state Yes or No as to whether he saw the stimulus. It will thus be possible to relate signal detection, Yes-No behavior, and forced choice behavior. Different consequences will be attached to the Yes-No behaviors according to the decision matrix and to the locational behaviors. It is expected that both synchronous and asynchronous curves can be produced. The subliminal perception effect refers to accurate location in the absence of Yes responses. This has been ascribed (Goldiamond, 1958) to differences in pay-offs attached to the two classes of responses. By appropriate variation of the pay-offs, it is expected that the opposite of subliminal perception will be produced, that is, report of Yes responses in the absence of correct location or hallucination.

A second parameter to be investigated will be the scaling of the Yes and No responses. The green button and the four above it form a five point Yes scale, and the red button and the four below it form a five point No scale. The literature is replete in the scaling of Yes responses; the present study would also seek to scale No responses and attach different consequences to all of these.

6. Baboon Research

Unfortunately all three baboons, who had been trained to optimize net gain according to decision theory in a manner identical to the decision process of human observers, were asphyxiated in the tragic fire which occurred at I.B.R. this month. It is planned to reestablish a small colony of these animals for future research in signal detection and related perceptual problems. We believe that the data obtained thus far are unique.

Although the death of the baboons is a serious loss, much of the time involved in their training was spent in developing procedures to bring them to appropriate decision behavior. In the process, the experimenters learned appropriate procedures. It should be possible therefore to train the next group of baboons in less time.

The laboratory is currently being redesigned to minimize the likelihood of such losses in the future.

B. THE USE OF SIGNAL DETECTION THEORY IN THE DESIGN OF OPERANT EXPERIMENTS.

INTRODUCTION

As was indicated in the introduction, operant research and signal detection research have the commonality of stressing the role played by consequences in the maintenance and alteration of behavior. In both types of research, the consequences are explicitly scheduled in relation to explicitly specified responses. A major difference between the two types of research is that in operant research, where the responses can be classified into two categories, Response Set A and Response Set B, and the consequences can be specified into two categories, Consequence Set A and Consequence Set B, a systematic relationship between the two is normally arranged so that Response Set A will have Consequence Set A contingent upon it, and Response Set B will have Consequence Set B contingent upon it. Decision research also involves responses classifiable into two sets, Response Set A and Response Set B. However the consequences attached to each set differ from their relation in operant research. Rather, each response set will have at least <u>two</u> sets of consequences attached to it so that Response Set A may result in either a favorable or unfavorable consequence, and Response Set B may result in two consequences as well. Further, the values of the various consequences may be systematically altered, so that there are four, rather than two values involved. Decision processes involve weighing the various alternatives according to some optimization criterion. The two responses may each result in a favorable or unfavorable consequence providing a risk in either case. One response may result in high gain and a high loss, while the other response results in little gain and little loss, in which case the alternative behaviors may involve "going for broke" or "playing it safe". In all events, the experimental designs of decision theory differ from those of operant research.

The experiments to be reported in this section are initial attempts to apply decision theory to the design of operant research. This would involve requiring the subject to make two responses, as in many branches of operant research, but attaching the likelihood of two different consequences to each response, so that four distinct relations ensue. In matching to sample research, signal detection theory would suggest that the four relations are the two different types of errors and two different types of correct, whereas operant research treats as a single unit, the errors on the one hand, and the corrects on the other. Such combination has created many problems in classical psychophysics, and has produced effects which can be related to the loss of the finer details. The use of decision processes and signal detection theory for the design of operant experiments may also provide new tools for the analysis of certain problems.

EXPERIMENT ONE: DELAYED RESPONSE

This experiment concerns behavior under the control of stimuli temporally separated from the behavior, or delayed responding. Research in this area has been related to symbolic and representative processes. Morgan (1943) for example, states that "A symbolic process is indicated when the signal or cue for adjustment made is not present at the time of response". This explanation assumes that if the stimulus is not present it has somehow been incorporated symbolically in the organism. Indeed, Pavlov (1927) critizes Köhler's chimpanzee studies on a related ground, arguing that Köhler had made an invalid inference when he ascribed thinking to the chimpanzee because there was an interval of time between the chimpanzee looking at the banana and sticks, and putting the sticks together to get the banana.

Delayed response and procedures for its establishment and analysis are currently being investigated. The experimental situation is the following: in a match to sample apparatus, the pigeon is confronted with three keys. The two outer keys are dark, with the center key illuminated. Fifty responses on the center key put the center key out, simultaneously illuminating the two side keys. The center key may be brightly illuminated throughout all 50 responses, or dimly illuminated during the first 5 responses, and bright for the remaining 45. The dim initial illumination is considered the signal and the bright illumination is considered the noise. The pigeon is required to respond, after a considerable delay, to a stimulus. The right key is the key which is considered the signal response key, and the left key is considered the noise response key. This gives us the following decision matrix:

	Bright All 50	Bright Last 45
Left	Time-out 10 sec.	FR 15 4 sec. grain
Right	FR 15 4 sec. grain	Time-out 10 sec.

It will be observed that the pigeon can make two types of correct responses and two types of incorrect responses. At the present moment, the decision matrix is symmetrical, as presented above. In later stages of the experiment, the entries will be altered to be more in accord with the matrices presented in the preceding sections, so that one key will have both a high payoff and a high cost, and the other key will have less of each.

A fading procedure was used to establish control by the delay. Initially, during the signal presentation, the center key was dim all 50 of the 50 responses of the ratio. After behavior was established under these conditions, the signal presentation was changed, with the center key being dim during the initial 40 pecks on the key, and then being bright on the next 10 pecks of the key. The alternative noise presentation was also presented, and this was brightness during all fifty pecks. The signal presentation was then changed to having the center key dim during the first 30 pecks but bright during the last 20; then dim during the first 25 but bright during the last 25; then 20-30; then 10-40; and at the present stage the key is dim for only the first 5 pecks but is bright for the remaining 45 pecks. The corresponding noise presentation consists of brightness during all 50 pecks and the pigeon must distinguish the events that happen during the first 5 pecks in either case, since this provides the differentiation between signal and noise.

The experiment has progressed to the stage indicated thus far. Making the noise key left and the signal key right may produce certain effects. It appears that the pigeon may assume a posture during those first few pecks at the center key which indicate that a signal is presented, and may retain that posture during the pecks during brightness. This posture may then serve to "facilitate memory". Accordingly, red and green are now being introduced, with the green key the signal key and the red key the noise key. These are being systematically altered in position in an attempt to eliminate posture effects. The experimental design also calls for alteration of the entries into the matrix from their present symmetrical form. In the present symmetrical form, both the consequences of both types of correct responses are the same as are the consequences of both increased responses. It can be demonstrated that under these conditions the S^{Δ}/S^{D} ratio will produce results which are similar to those produced by a signal detection analysis. However, we intend to vary these entries and make them asymmetrical and it will be interesting to ascertain to what extent the S^{Δ}/S^{D} ratio serves as a useful measure when the limiting conditions of symmetry are removed.

During the signal presentation the number of pecks under dimness and the number of responses under brightness have been varied. This ratio can be considered the signal parameter. This experiment is related to a prior experiment reported by Pliskoff and Goldiamond (in press) to be reported later under this section.

EXPERIMENT TWO: DISCRIMINATION OF ELAPSED TIME

The present experiment is concerned with training in the estimation of elapsed time, or establishment of temporal discrimination and its maintenance, without change of associated stimuli and without requiring explicit responses during the time period.

In this situation, the apparatus is also a match to sample apparatus with three keys, the center one being illuminated and the outer two being dark. One peck on the center key turns it yellow. The yellow key then stays on between one and ten seconds in steps of one second, the number of seconds it is on being random. The yellow key then goes out, and the two side keys go on. One is red and the other one is green. If the number of seconds duration of the yellow period was one to five, the green key is appropriate and if the number of seconds is six to ten seconds, the red key is appropriate. The larger time is conceptualized as signal, with the red key being the signal key. This produces the following decision matrix:

	1-5 sec.	6-10 sec.
Red	Time-out 30 sec.	Feeder Flash CRF FR 5 Food 4 sec.
Green	Feeder Flash CRF FR 5 Food 4 sec.	Time-out 30 sec.

As can be seen this is a symmetrical matrix which is being used in the initial stages; it will be made asymmetrical as the study progresses.

The time-out penalty is 30 seconds. For the correct responses, the feeder light flashes with every correct response but the feeder itself is presented every fifth correct response, providing the pigeon access to the grain for a period of four seconds. Fading has been used to establish control by the appropriate keys. Originally only the correct key of the two matching keys was illuminated with the incorrect key gradually being faded in, a procedure previously utilized with children (Moore and Goldiamond).

Three pigeons have been run thus far.

A second study will investigate the pay-off matrix in this experiment. Reinforcements, conditioned reinforcements, and time-outs will be varied. Besides the obvious relation of this study to signal detection research, the study will relate to research on differential reinforcement of low rate schedules (DRL).

Related is study III. In this study various time durations will be investigated. Discriminations of time intervals around 5-6 sec., 10-11 sec., 20-21 sec. and 40-41 sec. will be investigated. The degree of discriminability of the various durations will be investigated and various pay-off matrices will be set up for studying the birds' discriminations.

Timing behavior consists of a discrimination of stimuli, or of the organisms' own behavior which are correlated with time or both. The present research has had no exteroceptive stimulus change during the timing interval and has left unspecified the behavior of the organisms during the timing interval. Study IV will investigate situations involving stimulus change and a specification of the behavior. In one experiment, during the timing interval, the center key illumination will be turned off briefly every second (clock). In a second experiment the animal will be required to emit responses at a certain rate during the timing interval. It is suspected that such conditions will lead to improved temporal discrimination in the pigeon by bringing mediation behavior under explicit control.

EXPERIMENT THREE: STIMULUS CHANGE

Stimulus change refers to a change in ambient conditions which is not related to performance, reinforcement, or discrimination. Examples are the house lights suddenly dimming, a sudden noise, etc. Such novel stimuli often disrupt behavior. On occasion, they also facilitate it. They have considerable theoretical and applied importance, and are involved in generalization, habituation, etc.

Although very little research has been done utilizing stimulus change as a variable, its importance is attested by the effort made in every operant experiment to eliminate its possible effects through stringent control of the conditions. The following experiment is part of a program to investigate this variable systematically; decision theory is used in the analysis.

Two pigeons are being run. The pigeon faces three keys, the outer one being dark and the center one illuminated. The center key contains a column of three vertical dots or a row of three horizontal ones. Pecking the center key keeps it on, but illuminates the outer keys which contain the match -- in this case, the row of column of three. This is a comparatively simple task, and the following decision matrix has been initially attached:

	Horiz.	Vertical
Vertical	Time-out 30 sec.	CRF Feeder Flash FR 25 4 sec. grain.
Horizontal	CRF Feeder Flash FR 25 4 sec. grain.	Time-out 30 sec.

The constant stimulus condition that has been manipulated thus far is that of the illumination of the house light in the experimental chamber. The matching to sample behavior has been shown to be extremely sensitive to the general conditions under which it is established. Although the contingencies for correct and incorrect responses are maintained, a change in the house light stimuli produces marked increases in miss and false alarm rates. This type of change in detection rate appears to be under different control from the detection rate changes produced by systematic manipulation of discriminative stimuli or reinforcing or maintenance stimuli. The present experiments are concerned with the exact relationship between the constant stimulus conditions and detection rate changes as the function relates to the training conditions under which the matching behavior was established. The general phenomenon, although not dealt with directly in signal detection theory, has been explored experimentally in an operant paradigm by Azrin (1958) and discussed in respect to the general similarities among operant conditioning procedures and signal detection theory (Goldiamond, 1962).

EXPERIMENT FOUR: CONCURRENT OPERANTS

The dynamics of the interaction of two or more operants is being investigated in the present experiment. The behaviors in a perceptual or detection experiment may be seen to consist of concurrent operants under the control of multiple and interacting variables. The success in prediction and quantification of behavior in signal detection experiments suggests that the Signal Detection Theory Model and general statistical-decision-theory may be applied directly with equal success to a growing and important area of interest in the experimental analysis of behavior, the dynamics of the interaction of two or more operants. Several experiments are now being carried out in respect to these areas of application.

One of the most important variables known to control the occurrence of one or the other of two concurrent operants is the reinforcement probability associated with each. Several attempts have been made to specify the quantitative relations among current operants as determined by the reinforcement probability (Catania, 1963, 1965; Herrnstein, 1964; Reynolds, 1963). These attempts have all been based on procedures in which there are no programmed consequences for incorrect or irrelevant responses. The results of the attempts to specify the quantitative relations among concurrent operants can be obtained from and be considered as a special case of the signal-detection matrix in which there are no penalties for high false alarm or miss rates when concurrently there are large pay-offs for correct detections and quiets.

In one of the present experiments, pigeons perform on two concurrent VI3 min. schedules on two separate response keys. One key provides the reinforcement. Two variable interval tapes run, and when a reinforcement is scheduled by a given tape, the tape stops, with the reinforcement now available if a response is made. Responding produces reinforcement and the tape starts again. Meanwhile, the other tape is also running, under the same general program (the sets of reinforcements vary according to the pattern on the tape). The pigeon's behavior is related to one tape. A second key is present. Responding on this key switches the reinforcements from that one tape to those on the other tape, on the key providing reinforcement. Switching occurs for the simple reason that while the organism is working on one tape, the other tape is likely to have "locked up" its reinforcement, and reinforcement is available. There is a different key color associated with each tape, and hitting the change-over (CO) key changes this light, as well. This procedure has been shown to be operationally equivalent to a standard two key concurrent design, with the advantage that it makes the change-over or switching behavior explicit and recordable (Findley, 1958; Catania, 1965).

While the subject is responding on one of the VI schedules (VI-A), one of two states may be in existence. A reinforcement may be "locked up" and thus available at the next response. If the subject responds on the VI-A key, he will have correctly detected the presence of a reinforcing stimulus (signal). In the other state, a reinforcement is not available on the VI_A schedule and responses on the VI_A key would constitute false alarms. False alarm responding makes up the majority of behavior on VI schedules when there is no programmed consequence for them. A high false alarm rate means by definition a high detection rate. The subject may, at any point in time, respond on the change-over key and switch from VI_A to VI_B. If the subject responds on the CO key when there is a reinforcement present on the VI_A schedule, the subject's response is recorded as a Miss. A response on the CO key when there is no reinforcement available on the VI_A schedule is recorded as a Quiet. Correct detections and false alarms may also be recorded on the VI_B schedule, as well as misses and quiets. Specification of the consequences of the above eight responses in respect to the probabilities of reinforcement occurrence may account for the behavior and interactions of concurrent operants.

The matching of relative response rates to relative reinforcement frequency in concurrent operants (Catania, 1965) occurs only when there is a specified COD programmed on the switching key. The matching function can be viewed as a special case of a wide variety of functions that could be produced. The matching function is produced by placing a very mild punishment consequence on miss and quiet responses on both VI schedules. Catania (1965) has demonstrated the shift in responding from one schedule to the other as a function of COD duration. The increase in detection and false alarm responses on one VI schedule when punishment is attached to misses and quiets on that schedule follows from a consideration of the general signal-detection model.

The decision matrices are as follows:

VI$_A$

Reinforcement is

	Not Ready Next Response	Ready Next Response
Stays at Key		
Switches		

VI$_B$

Reinforcement is

	Not Ready Next Response	Ready Next Response
Stays at Key		
Switches		

INITIAL ENTRIES

No conseq.	Continuous reinforcement
Produce Stimulus	No conseq.

PRESENT ENTRIES

Fixed ratio 25 produces 30 sec. time-out	Continuous reinforcement
Produces Stimulus	No conseq.

One of the aims of the present research in this area is to specify the interactions between the two 4-fold tables in terms of their relationship to particular behavioral phenomenon. Attachment of penalties for false alarms on the VI_A schedule should not only decrease false alarm rate as well as detection rate (generally considered as a decrease in response rate on the VI_A schedule), but should also increase the rate of misses (if there is no programmed negative consequence) and quiets. By definition this means more switches to and more time spent in the other schedule, the VI_B schedule. At the same time, Miss or Quiet responses on the VI_B schedule will produce the VI_A schedule with its penalties for false alarm responding, which in some sense might function as a punishment for switching from the VI_B schedule. The single manipulation of placing a penalty on false alarm responses on one schedule may increase the false alarm rate (as well, perhaps, as the detection rate) on the other schedule through the two above sources of control. This type of interaction may account for such behavioral phenomenon as "contrast" of concurrent operants and suggests the significance of the application of the signal-detection model to this area.

The actual schedule values of the VI schedule may be considered as the manipulation of the a priori probabilities. One may specify the overall average probability for one or the other schedule. One may also specify the probability density function for reinforcement occurrence as a function of time. The inverse of their function specifies the probability of noise. Thus, at any given time value, t, from the preceding reinforcement occurrence, there can be specified a likelihood ratio in respect to the presence or absence of a reinforcement on the VI schedule. Considering the penalties and reinforcements for any one schedule, there can be specified an ideal response in terms of what

IRT value at which to set a criteria. Actual behavior in the concurrent schedules may be compared to their ideal standard, which gives the current approach a mathematical prediction and behavioral quantification that is independent of the particular schedules employed.

The present experiments deal primarily with the manipulation of the pay-off matrix for one or both of the two concurrent schedules. For consideration of these experiments, the signal-noise ratio has been considered to be zero. Investigation of this variable is seen to be particularly important in a general statement of the analysis of concurrent operants. Experiments are now being set up which involve manipulation along the dimension of signal-noise ratios as they interact with the other controlling variables in concurrent situations. Previous work concerned with the independence of concurrent responding has involved the manipulation of the discriminability of reinforcement presence (Catania, 1963) and has been in accord with the general predictions to be made from detection theory.

EXPERIMENT FOUR: DISCRIMINATION OF OWN RATIO BEHAVIOR

Our own behaviors often supply stimuli to us (for example, speech), and the task in many skilled behaviors, such as target practice, is to alter our own behavior in accord with the feedback it presents us, in terms of consequences contingent upon the behavior.

In the present experiment, which is in press (Pliskoff and Goldiamond), the discriminative stimuli were the pigeon's own behavior. The pigeon faced two keys, one being red. Its position varied. Responding to the red key turned it off and substituted for it the two keys, now equally illuminated and white.

The red key went off after a number of responses. Initially, if the fixed ratio was 5, the Left key produced reinforcement and if 95, the Right key.

These ratios were then changed from 5-95 to 10-90, 20-80, 30-70, 40-60. The signal-noise ratio was clearly the ratio between these fixed ratios, and decision theory is clearly applicable. The decision matrix used was of the symmetrical type previously presented. Consequently the S^{Δ}/S^{D} ratio served as a useful measure, and this ratio declined as the ratios between the fixed ratio performances by the pigeons changed from 5-95 to 40-60. Further research will deal with the more general case, where all four entries will differ.

The results obtained indicate the possibility of establishing and maintaining discrimination in animals (including people), where the discriminative stimuli are the different behaviors of the organism itself.

A publication describing the procedures in detail is in press, and copies will be transmitted when it appears.

FUTURE RESEARCH

Future research in this area is concerned with the systematic application of decision theory and TSD to the design of operant experiments.

The experiments reported in this section will be continued. These include delayed responding, discrimination of elapsed time, the use of TSD-operant research as a base for assessing stimulus change, concurrent operants and related research on operant behavior.

In addition, it is proposed to initiate a series of experiments in generalization. The generalization gradient and psychophysical curve share commonalities, and the proposed research would seek to apply TSD to generalization research. Analysis of the literature in these terms suggests that TSD may be especially relevant to understanding contrast effects, the peak shift gradient, the steepness of the gradient, and other generalization phenomena. An extension of TSD has been developed which would account for some of these in terms of criterion change. The extension involves consideration of at least two matrices, and their interrelations, an example of which was presented in the discussion of concurrent responding.

OTHER RESEARCH

This section reports perceptual research and instrumentation in which the research interest is specific to the substantive phenomena themselves. Three areas are reported: subjective phenomena, eye-movements, and conditioned reinforcement.

SERIES ONE: PURKINJE AFTER-IMAGES IN ANIMALS

There are certain perceptual phenomena which are considered to be subjective by their very nature. These include after-images and subjective color. In after-images, the subject stares at a presentation, then looks away and reports what he sees. In subjective color, black and white are flashed and the subject may report seeing different colors.

These phenomena have been considered elusive, subjective, and evanescent. They have often been considered approachable only through introspective report, and therefore not capable of demonstration in animals.

Despite the methodological difficulties, the phenomena are extremely important. For example, after-images enter into the phi phenomenon and motion pictures, and it has been argued that ordinary vision of motion is governed by similar after-images, as is our vision of a constant world despite saccadic eye movements.

At present, 3 pigeons are being trained to respond in terms of negative after-images. The experimental situation consists of a key, illuminated from a projector, into which a color is presented. A response turns this light out, simultaneously illuminating a row of 12 colored keys, ranging spectrally from violet through red. Hitting the appropriate key provides reinforcement; with the others, time-out. The pigeons have thus far learned seven colors.

When they learn 12, a Bidwell disc will be installed. This is a black and white disc with a sector opening which, when it interrupts the light while rotating in one direction, turns the presentation into the negative of the color interrupted. Turning in the other direction produces an enhanced positive. The effects are not ephemeral, but last as long as rotation occurs. The matching response of the pigeon will tell us what after-images, if any, he sees.

The device can also be used for subjective color, or other effects.

Should the procedures prove effective, it may be worthwhile to run comparative studies, using squirrel monkeys and other animals.

SERIES TWO: EYE MOVEMENTS

A Mackworth Eye Camera for two eyes has been installed, and is currently being instrumented and being adapted for research. The observer fixates on a point on a target. A television camera monitors the target. A beam is shined into the left eye as the observer is asked to fixate on the center of the target. A television camera picks up the reflection of that beam, and is adjusted so that the spot appears on the center of the television screen. The same procedures are used for the right eye. Thereafter, when the observer moves his eyes, the screen depicts not only the target, but two spots representing what part of the target he is looking at.

The experimental problem is an analysis of ongoing eye-movements to attempt to bring them under experimenter control. If this can be done, relevant variables are being manipulated, and the procedures may not only prove useful in the control of visual anomalies and eye movements in observing, but also in understanding the variables governing monitoring and observing behaviors.

SERIES THREE: CONDITIONED REINFORCEMENT

Much of our current research in perceptual behaviors, detection behaviors, or application of the detection model to new behavioral areas involves the maintenance of complex and highly developed baselines which have been demonstrated to be highly sensitive to manipulation of those variables in which we are interested. Many of these repertoires consist of long and extended sequences of behavior which are not or cannot, due to experimental demands, be maintained directly with primary or terminal reinforcements. Many of the complex behaviors are under the control of visual stimuli that function as conditioned reinforcers as a technical tool in the maintenance of the complex behavior under study, several experiments have been directly involved with several basic concerns in the use of conditioned reinforcement. The results of some of these experiments have been directly applied to the maintenance of sensitive detection behaviors over long experimnntal periods discussed elsewhere in the present report. The experiments concerned with conditioned reinforcement have been performed in the general framework of extended chain schedules with several different schedules of reinforcement. The present experiments have allowed the specification of what aspects of a conditioned reinforcing stimulus function to maintain behavior and what conditioning histories are necessary to produce control by those aspects.

Two articles based upon this research have been submitted for publication.

References cited

Azrin, N. H. Some effects of noise on human behavior. J. exp. Anal. Behav., 1958, 1, 183-200.

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. J. exp. Anal. Behav., 1963, 6, 253-263.

Catania, A. C. Concurrent operants. In W. K. Honig (Ed.) Operant behavior: Areas of research and applications. New York: Appleton-Century-Crofts, 1965.

Findley, J. D. An experimental outline for building and exploring multi-operant repertoires. J. exp. Anal. Behav., 1962, 5, 113-166.

Goldiamond, I. Indicators of perception: I. Subliminal perception, subception, unconscious perception: an analysis in terms of psychophysical indicator methodology. Psychol. Bull., 1958, 55, 373-411.

Goldiamond, I. Perception. In Bachrach, A. J. (Ed.) The experimental foundations of clinical psychology. New York: Basic Books, 1962.

Gollub, L. R. The relations among measures of performance on fixed-interval schedules. J. exp. Anal. Behav., 1964, 7, 337-344.

Green, D. Consistency of auditory detection judgments. Psych. Rev., 1964, 71, 392-407.

Herrnstein, R. J. Secondary reinforcement and rate of primary reinforcement. J. exp. Anal. Behav., 1964a, 7, 27-36.

Luce, R. D. Detection and recognition. Handbook of Mathematical Psychology, Vol. 2. New York: Wiley, 1963.

Moore, R. and Goldiamond, I. Errorless establishment of visual discrimination using fading procedures. _J. exp. Anal. Behav._, 1964, _7_, 269-272.

Morgan, C. T. _Physiological psychology_. New York: McGraw-Hill, 1943.

Pavlov, I. P. _Experimental psychology_. New York: Philosophical Library, 1957.

*Pliskoff, S. and Goldiamond, I. Ratio behavior as discriminative stimuli. _J. exp. Anal. Behav._ (in press).

Reynolds, G. S. Some determinants of choice in pigeons. _J. exp. Anal. Behav._, 1963, _6_, 53-59.

*Thomas, J. R. Avoidance of an initial chain component. Submitted to _J. exp. Anal. Behav._

*Thomas, J. R. Time out from a fixed ratio schedule. Submitted to _Psychon. Sci._

Ulrich, R. E., Holz, W. C. and Azrin, N. H. Stimulus control of avoidance behavior. _J. exp. Anal. Behav._, 1964, _7_, 129-134.

*Research publications under current grant. Also:

Doctoral dissertations in progress under grant

Miller, Albert, Dept. of Psychology, Arizona State University, Tempe.

Quagliano, John, Dept. of Psychology, Florida State University.

Stubbs, Alan, Dept. of Psychology, George Washington University.