AD-A059 010 COLUMBIA UNIV NEW YORK PSYCHOPHYSICS LAB F/G 5/10

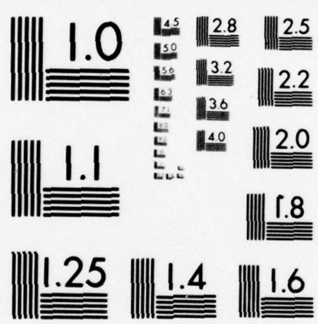
APPLICATIONS OF TWO-PARAMETER DECISION THEORIES IN PSYCHOLOGY.(U)

AUG 78 E GALANTER N00014-67-A-0108

UNCLASSIFIED PLR-39 NL

1 OF 2

AD
A059010


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

Psychophysics Laboratory

Columbia University
in the City of New York

This report and the research herein described has been prepared with the partial support of the Office of Naval Research, the U.S. Army Medical Research and Development Command, and other agencies of the United States Government. Inquiries concerning the contents of this report should be made to Professor Eugene Galanter, Department of Psychology, Columbia University, New York, New York 10027.

Technical Report PLR-39

APPLICATIONS OF TWO-PARAMETER DECISION THEORIES IN PSYCHOLOGY

Eugene Galanter

1 August 1978

Contract N00014-67-A-0108-0031

NR 197-016

Research for this report was supported by the Engineering Psychology Programs, Office of Naval Research

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (14) PLR-39	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) APPLICATIONS OF TWO-PARAMETER DECISION THEORIES IN PSYCHOLOGY.		5. TYPE OF REPORT & PERIOD COVERED: (9) Technical Report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Eugene Galanter		8. CONTRACT OR GRANT NUMBER(s): (15) N00014-67-A-0108-0031
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Eugene Galanter, Psychophysics Laboratory, Columbia University, New York, New York 10027		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 197-016
11. CONTROLLING OFFICE NAME AND ADDRESS: Engineering Psychology Programs, Code 455, Office of Naval Research		12. REPORT DATE: (11) 1 August 1978
		13. NUMBER OF PAGES: 112
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

403 688

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(12) 117p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

decision theory
signal detection
psychophysics
experimental psychology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a general two-parameter decision theory as developed in experimental psychology as the theory of signal detectability. The report abstracts published research in seven areas in which the theory has been applied.

The general theory is explicated in a technically precise, but non-quantitative form. Each of the substantive areas that contain abstracts from the Over

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

403 688

unclassified

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

literature are prefaced by introductory and explanatory remarks. Experimental and theoretical work that is critical of the decision theoretic approach within the substantive areas are included among the abstracts.

Sufficient technical information and tabular material is contained to make it possible for the non-specialist to calculate the decision theoretic statistics from appropriately collected data.

APPLICATIONS OF TWO-PARAMETER DECISION THEORIES IN PSYCHOLOGY

Eugene Galanter

Psychophysics Laboratory, Columbia University

Introduction

One of the more pervasive and subtle problems of experimental psychology is how to interpret the verbal responses of people who make judgments in psychophysical experiments. We presume that they tell us something about the impact of environmental stimuli. Since the time of Fechner, and for seventy-five years after, such responses were construed as directly representative of the observer's state of mind. In these early cases the interpretation seemed plausible, insofar as the respondent was asked merely to report the presence or absence of some event, or whether one event was greater or less than another. These phenomenal reports were occasionally challenged by the experimental introduction of false or misleading stimuli designed to trip-up the observer if one failed to understand the instructions or was actually dissembling. But these catch-trial procedures were primarily defensive: they helped the experimenter select data worth further analysis.

The use of introspective reports expanded dramatically in psychophysics with the experimental introduction of the magnitude estimation methods for psychophysical scaling (Stevens and Galanter, 1957). Here, justification based on a "simplicity of judgment" argument was no longer applicable. Indeed, experimental observers occasionally required a fair amount of instruction and training before they could perform adequately the tasks set them by the experimental design. But the overwhelming concern was how to interpret the numerical judgment. Was it really an estimator of some quantitative feature of the observers' experience? This interrogatory objection was presented most diligently by Graham and Ratoosh (1962) and Torgerson (1961) but these criticisms did not impede the massive application of magnitude estimation techniques to a variety of scaling problems.

The fact is that a useful method for systematically accumulating information will always overpower theoretical arguments that prove the method illegitimate. It was true for Fechner, it remained true for Stevens. For, as the philosopher, Nelson Goodman has remarked, "The case against the measurability of almost any property is overwhelming--until the property is measured. Consistency and objectivity are the products of measurement, not prerequisites for it." (Morganbesser, 1967).

The primary justification for the use of these techniques of phenom--enal report is that the data are systematic, reproducible, and can be plausibly interpreted. Thus, a determination of the absolute threshold of visual sensitivity based upon judgments of the presence or absence of an increment of light against a background (Hood, 1978) continues to be the accepted and routine technique for the study of the psychophysics of vision. Qualms about judgmental bias, even when the experimenter serves as the observer, hardly exist. The data from experiments of this kind confirm too many well founded beliefs to be rejected because of methodological objections to the natural interpretation of the observer's report.

And yet doubt prevailed among the experimentalists. The early experiments of Irwin and Preston (1937), and later the research of Verplanck, Cotton, and Collier (1953) showed response dependent effects in psychophysical judgments. The results were interpreted in a variety of ways, but the primary notion was that subjective judgment is only loosely coupled to the stimulus objective of the judgment. The judgment is constrained to a greater or lesser extent by variables that influence the response structure in some unknown way. These variables as a class have all been designated "response bias" variables. They constitute the substance of a variety of psychological disciplines which fall under the rubrics of "personality", "motivation", "attitudes", and so forth. Sometimes these response bias variables are construed as having a feedback effect on the perceptual nature of the stimulus itself (Galanter, 1974). But this view, once called the "new look" in perception, has failed to develop into a viable substantive area of research.

In order to cope with this intrusive issue that relates so forcefully to topics in psychology far beyond the psychophysical laboratory, theoreticians--beginning with Moncrieff Smith (1953) and unfolding fully through the exceptional efforts of Wilson P. Tanner and his associates and students (1954)--implemented a modus vivendi between scientists interested in the performance of the sensory systems, and researchers concerned with the methodological issues. We shall here call the general structure of these abstractions Two-Parameter Decision Theories. This name emphasizes that the observers' responses are to be construed as volitional decisions about the stimulus events arranged by the experimenter. Furthermore, these decisions are not only based upon the experimenter controlled events but also on (independent?) events interpretable as motivational, attitudinal or instructional. These theories therefore serve to decompose the observed response measures into a part attributable to the stimulus variables, and an independent part that represents other psychic factors.

We shall recite first the outlines of the original theoretical structure designed to cope with these problems, the Theory of Signal Detectability, (TSD) and then discuss criticisms of the theory in terms of its applicability both within and outside the area of psychophysics. We will then review briefly alternative theories being explored vigorously in various laboratories. Finally, we will examine ramifications of the study of two-parameter decision theories into areas beyond the classical psychophysical ones. In these extensions we shall, after a short introduction, present abstracts--occasionally critical--of examples of the experimental and theoretical work based on these decision theoretic notions. We offer no over-arching organizational principles for the discussion of these extensions of decision theory, the order in which we consider the research papers and indeed the categories into which they fall are the result of arbitrary decisions by the author.

The Spirit and Substance of a Signal Detection Theory An Example of Two-Parameter Decision Problems

We introduce the theory of signal detectability by considering first a paradigmatic experiment. As we examine the experiment we will need to introduce richness into the description. This will lead naturally to a characterization of models of the experiment that will culminate in a two-parameter decision theory.

An experimental observer is placed in an isolated environment where he or she has two keys available, one labeled "yes," the other labeled "no." He or she is instructed that on a sequence of successive trials, defined by some arbitrary stimulus display, perhaps a clock face with a moving hand, he or she is to decide whether a particular signal, say a weak sound, is present or absent. If he or she decides that it is present, he or she is to press the button marked "yes," whereas if he or she thinks it is absent, he or she is to press "no." If the signal is presented on every trial, as it might be in an audiometric examination, then the percentage of times the observer reports hearing the signal can be determined. If that proportion is less than one, the signal is appropriately weak and may be called "near-threshold."

Notice first that if the observer knows the signal will be presented continuously he or she may say "yes" on every trial whether he or she "hears" the signal or not. We may construe this tendency to reply "yes", as a fact of the observer's personality independent of ones ability to detect the signal. We presume that among the "yes" responses to actual "auditory experience," there may be possible "yes" reports independent of the "auditory experience" and dependent only upon response bias. The observer's report may not report his or her state of mind. Consequently our paradigmatic experiment fails to distinguish between the actual sensory performance of the observer and his or her response bias. It is impossible in this experiment to estimate independently the sensory components and the bias components of the observer's judgments and decisions.

This experimental problem is resolved by arranging that the signal be presented on some fixed proportion of trials in some irregular order. Therefore if, say, 50% of the trials do not contain a signal, then the experimenter is able to calculate two independent measures of "yes" responses. One represents the proportion of times the observer reported the signal present when in fact it was, the other is the proportion of times the observer reported the signal when in fact it was not presented. We call the first of these proportions a "hit" proportion, whereas the second represents what is called a "false alarm." The hit proportion tells us something about how the sensory system is operating, the false alarms inform us of the observer's response bias, that is his or her tendency to say "yes" independent of the presence of the signal.

If in the preceding experiment the false alarm proportion was greater than zero, then the experimenter would be justified in believing that during some of the trials on which the signal was presented and the observer reported "yes," that the observer did not "hear" the signal. What this discussion represents is the failure of the experimenter to be aware of the value, or motives, or attitudes, that the observer exhibits vis-a-vis his or her use of the "yes" button. Although it may seem plausible to assume that he or she has no greater reason for pressing the button saying "yes" than he or she does for pressing the button saying "no," such an assumption leaves uncontrolled the actual performance variables.

One way to gain control over these performance variables is to use methods that have been developed to train animals. Provide appropriate rewards and costs to the observer that are contingent upon the joint probabilities of signal presentation and response. When the observer becomes, or is made aware of, the contingencies between his or her performance and objects of his or her desire or aversion, then we may expand the experiment to determine something about the response structure itself.

An arrangement of benefits and costs contingent upon the experimenter's presentation of the observer's response is called a pay-off function (Galanter and Gerstenhaber, 1956). It often takes the form of a matrix that shows the value to be received and the costs to be leveled contingent upon responses relative to the signal presentation. The entries in the pay-off matrix are often shown in monetary terms, although occasionally the entries represent other objects with positive or negative incremental utility to the observer. Table 1 shows an example of a monetary pay-off matrix. In Table 1 the matrix is called "fully symmetric". That is to say, a hit receives a reward equal and opposite to a "false alarm". Notice that two other stimulus-response contingencies are contained in this simple pay-off matrix, a response of "no" when a stimulus is present (called a "miss"), and "no" when the stimulus is absent (called "correct rejection"). The full symmetry of the matrix is represented by equal and opposite values in these cells also. The "symmetry" referred to here is only an objective description of the matrix. The effects of the pay-offs may or may not be "psychologically" symmetric.

Table 1

	Signal	No-Signal
"yes"	$1	-$1
"no"	-$1	$1

Notice that whereas the pay-off function in Table 1 may represent what is, intuitively, the "appropriate" pay-off for the experiment, it is not unreasonable to believe that an observer could discriminate just as well if the pay-off function were modified into the matrix shown in Table 2.

Table 2

	Signal	No-Signal
"yes"	\$1	-1¢
"no"	-1¢	10¢

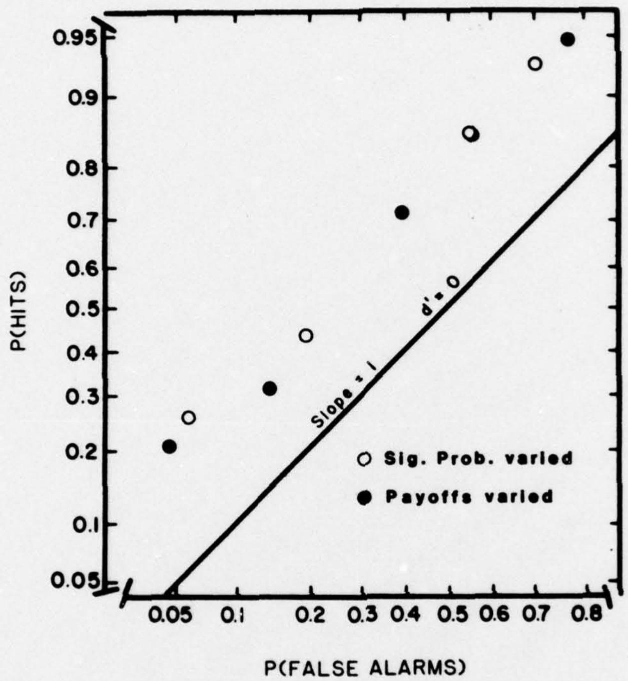
In this matrix the observer is heavily rewarded for "hits" and only very lightly fined for "false alarms". In this case we would expect the proportion of "yes" responses to increase dramatically, which would of course, increase both the "hit" rate and the "false alarm" rate. Now, if the same observer under the same conditions were faced with each of these matrices separately, one would presume that any difference in response proportions would reflect <u>not</u> a difference in sensory capabilities, but rather a change in response bias. Thus, any theory that purports to represent performance in these experiments would have to distinguish between consistent sensory behavior between the experiments and variations in response bias that the pay-off functions would induce. Furthermore we would expect the theory to deal with these two questions independently. That is to say, variations in response bias should not influence the perceptual processes and equivalently changes in the perceptual parameters, for example alterations of auditory threshold, should not modulate response bias.

If we keep the auditory threshold fixed and vary the resonse bias with different pay-off matrices we observe data relating "hits" and "false alarms" as shown in Figure 1. These data points show how changes in the "hits" and "false alarms" may proceed as the observer increases his or her "yes" responses. The data from Galanter and Holman (1967) represent values of different pay-off functions. The pay-off function that generated the low probability of saying "yes" is like the matrix in Table 3. The datum showing a high probability of "yes" are the consequences of a pay-off matrix like the one shown in Table 2.

Table 3

	Signal	No-Signal
"yes"	10¢	-\$1
"no"	-1¢	10¢

Figure 1



All of the data points shown in this figure represent shifts in response proportions induced by the same signal, but with different payoff matrices, and therefore are presumed to represent equal subjective sensitivity. Consequently such data graphs are often called isosensitivity functions. They represent the equivalent of the operating characteristic or OC curve of the statistician, and the receiver operating characteristic or ROC curve of the electrical engineer. Commonly, the initials ROC are used to describe the functions fitted to such data, in which case psychologists interpret these initials as "response operating characteristics."

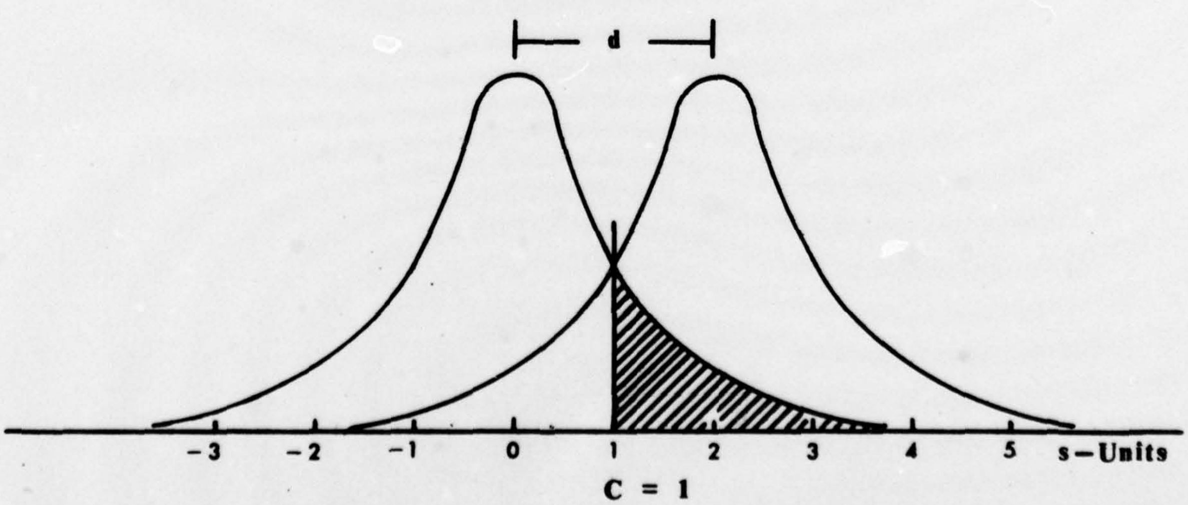
It is known that changes in response bias can be induced by a variety of methods (Galanter and Holman, 1967), and consequently it may be assumed as a first approximation that the various experimental factors that induce bias are all having their effect upon a single parameter. This is not necessarily true in all contexts, but in our experiment here, there is no room for more than a sensitivity parameter, and a parameter to represent bias variables. This implies that although changes in response bias may vary in their deep structure as a result of the experimental factors that influence this bias, it will require more complex experiments to detect such changes. Having issued this warning, we assume henceforth that all experimental effects that induce response bias changes are representable by the same process. For many experiments, including many complex ones we shall review below, this assumption is reasonable.

A Two-Parameter Decision Theory: The Theory of Signal Detectability

In the experiment described above our observer was listening to the sound of a weak signal. However we can, with equivalent justification construe the observer as making decisions among various kinds of abstract events that could be represented in a variety of different ways. We shall adopt this interpretation as the most useful one for the development of a theory, and interpret the events the experimental observer was deciding between as numerical quantities induced by the experimental stimuli. The simplest assumption is that the quantity associated with no-signal is represented by the value "zero," the quantity represented by the presence of a signal is given an arbitrary numerical assignment, say, "two."

Now the important thing to recognize about the nature of empirical events in general and the psychic processing of environmental stimuli in particular, is that although physical events of essentially identical kinds are repeatedly presented, their effects upon the organism are presumed to vary from occasion to occasion. The most common and plausible assumption about the nature of this variation is that the environmental quantity is distributed normally. In the context of signal detection theory we make that assumption about all effects induced by stimulus events. For this example the non-stimulus "0," and the stimulus "2," represent the means of two normally distributed variables. The second parameter of the normal distribution is the standard deviation. In order again to simplify the initial assumptions of the theory, we presume that the standard deviation -s- of both the 0 and 2 distributions are equal to each other and that both are equal to unity. If we then portray these two distributions as in Figure 2, they overlap as shown.

Figure 2



The abscissa in this figure is the magnitude of the psychic effect of the occurrence of one or another of the events. The presence of the overlap of the two distributions is the fundamental theoretical process that gives rise to the "difficulty" inherent in the decision. That is to say, if the two distributions did not overlap in a significant way, then an event drawn from the distribution with 0 mean would be absolutely and consistently distinguishable from an event drawn from the distribution with mean = 2. The significant overlap means that an event drawn from one distribution could have been drawn from the other with only moderately different probability. Therefore it is incumbent upon the observer to estimate not only how likely an event is to arise from one or the other distribution, but also how likely one or the other distribution is to be sampled. What are the a priori probabilities that events will be drawn from each distribution? These presentation probabilities are often selected to be equal as in our example above, but whether they are or not, they must be factored into the decision process. Observers may discover these probabilities themselves. This discovery is commonly attributed to learning processes that go on during the course of an experiment. Alternatively, information about the a priori probabilities of the stimuli can be included in the overt instructions to the observer.

In any case we may begin with the symmetric assumption, i.e., events are drawn from the zero and two distribution with equal likelihood. In order to represent numerical values along the abscissa we may select as a natural metric, units of the standard deviation. These correspond to the widely tabled values of the function Z--values of the unit normal distribution with zero mean. (Appendix 1) In Figure 2 these units have been stepped off along the abscissa.

From this representation it can be seen that if an observer is asked to decide whether a particular event has been drawn from the zero or two distribution, then a reasonable procedure would be to construct a decision point on the abscissa, say at the point shown as "C" in Figure 2, and call all observations greater than C "two" and observations less than C "zero." The location of the criterion point will obviously depend upon features of the experimental conditions that the observer understands or that he or she is exposed to during the course of the experiment: for example the pay-off matrices, the signal presentation probabilities, their attitudes about the use of the words "zero" and "two," and their willingness to take risks.

On the assumption that the value of C is fixed by the observer after some preliminary groping for an appropriate criterion point, then we note that his or her conditional response probabilities P("two"|1) and P("two"|0) or P("zero"|0) and P("zero"|2) can be represented by the integrals or areas of these distributions from the cut point to the right (or left). The relative sizes of these areas will depend on how far apart the means of the two distributions are located. In this example, this distance d, equals 2. If the signal were represented by a distribution with mean = 4, then if s = 1 the two distributions would overlap less, and the hits would be greater relative to the false alarms for any cut point. This mean difference, d, when normalized by the value of s, is represented by the symbol d'. In this example, since s = 1, d = d'. The portion in Figure 2 under the 2 distribution to the right of

C shows the probability of correctly reporting that an event came from the 2 distribution, and represents a hit = P("two"|2). Notice also that, the shaded portion of the zero distribution to the right of C will also be reported as coming from the 2 distribution, and this probability--P("two"|0)--represents a false alarm. The areas to the left of the cut point C under each of the distributions represent the complementary probabilities of a miss and a correct rejection. Observe that the two-parameters, d' and C capture completely the nature of the underlying process.

The following expressions summarize arithmetically the geometric concepts that we have been using. Equation 1 shows that d' is just the difference between the means normalized by the standard deviation.

$$d' = (\mu_s - \mu_n)/s \qquad (1)$$

For our numerical example the value of d' is (2 - 0)/1 = 2. The parameter C is represented by the Z score of the cut point referenced to the noise distribution. Because it is just half way between the two means its value is 1.

In this example, we have been talking about theoretical values of a theoretical structure. There is no empirical content in the material discussed thus far except for the integrals of the distributions of Figure 2 that represent the response probabilities generated by the observer. Consequently although in the example here we talk as though we know the nature and location of the distributions, the problem is quite the reverse in any actual application of the theory. In reality we must use our knowledge of the observer's empirical response probabilities and work backward to construct the underlying structure from which those response probabilities could have arisen.

Insofar as the signals and non-signals in any given experiment come unmarked with arithmetical values, the notion that the abscissa of the underlying perceptual structure is a numerical representation must depend upon the response probabilities themselves. One way to do this is to assume that the observer calculates a likelihood ratio $l(x)$, by taking the ratio of the value of the ordinate $f_s(Z)$ of the signal distribution at the observing point Z, and the value of the no-signal ordinate $f_N(Z)$ at the same point as shown in Equation 2.

$$l(x) = f_s(Z)/f_N(Z) \qquad (2)$$

If we then redefine the cut point C, as a ratio of such ordinates at C = Z, then we can define a new response bias measure β, as Equation 3.

$$\beta = f_S(C)/f_N(C) \qquad (3)$$

In our example above, since the value of C was just at the point that the distributions crossed, the height of the ordinates of each distribution are equal, and $\beta = 1$. The observer's decision rule is then reduced to the principle if $l(x) > \beta$, say "one"

if $l(x) < \beta$, say "zero"

Such a simple and transparent theory seems hardly likely to serve as a candidate for a revolutionary way of thinking about psychological problems concerning human judgment, and yet this is exactly the result of the theory of signal detectability. It has spawned new appreciation of the possibilities of representing human nature as a function of behavioral variables whose interactions and invariances are constrained by a more or less well formed mathematical structure. Obviously many questions arise. We shall see them dealt with in various of the research reports that we abstract, but we mention here three that come to mind most immediately.

First, what happens if the condition that the standard deviations of the signal and the no- signal distribution be equal is relaxed? In principle nothing serious occurs except that an additional parameter must be estimated from the data. What happens to the data points is that the symmetry of the isosensitivity function around the minor axis is distorted, or if the data are plotted in normal probability coordinates rather than linear probability coordinates, the best fitting line to the data points will tilt away from a 45 degree line. The interpretation of such differences in variability between the no-signal and the signal distributions are open to any ripe imagination, the central experimental problem is to design techniques for administering events about which decisions are to be made that give rise to distributions with equal variability. Such experimental methods are coming to be understood. They rest primarily upon observers to make judgments about differences or ratios between pairs of events rather than absolute judgments about the events themselves. Thus instead of asking an observer to judge the presence or absence of some weak signal, we may ask the observer to judge whether the second of two signals presented on each occasion is greater or less than the first.

A second kind of question orthogonal to the first concerns methods for assessing the reliability of the estimated parameters. This statistical issue has been examined from time to time and there are both parametric (Gourevitch and Galanter, 1965) and non-parametric (Pollack, Galanter, & Norman, 1964) methods for comparing data obtained within these experimental contexts.

Once introduced to the theory of signal detectability as a basis for making decisions, a common question arises. Can some procedure be prescribed based on the pay-off matrices and the sensitivity of the observer to the stimulus presentation that will permit him or her to maximize or optimize the pay-offs in a given situation. That is to say, is there some criterion point that is "best" for the particular pay-off matrix and the observer's sensitivity? In addition to being an intriguing theoretical issue for scientists ranging from economists to psychotherapists, the question is of great practical import insofar as decisions for action often depend upon poorly discriminable events and pay-off matrices whose utilities may not be entirely obvious. Thus, for example, it would be helpful to know where to set the cut point for the selection of personnel for programs that require expensive and extensive training when that selection is based upon tests or other measures that yield "signals" that are hard to distinguish among. Solutions to this problem depend, of course, upon the kinds of decision rules that are used. An early discussion of some of these decision rules can be found in Peterson, Birdsall, and Fox (1954), and the extensive analysis of optimum decision procedures contained in the important dissertation by Marill (1956).

Stated as a rule of thumb, data obtained to determine whether people optimize in the sense of maximizing expected value or percent correct, show that individual performance departs systematically from optimum behavior. Examples from Green (1960) are buttressed by additional abstracts reported here. In general terms people's responses tend to be more conservative than theories of optimization would predict. In dealing with this issue we see the need for auxiliary conceptualizations to enhance the stark simplicity of the original theory of signal detectability. In particular, questions about how response bias is modulated constitute, at the practical level, a most important class of problems. Signal processing by the sensory systems has been almost entirely preempted by the study of the physiological transduction systems. This work is reinforced by psychophysical studies and the methodologies based upon developments of signal detectability theory, but it seems clear that the primary contributions of this theory will come from a deeper understanding of how the response structure itself is organized by the cognitive and affective aspects of a person's nature.

Criticisms of the Theory of Signal Detectability and the Development of Alternative Theories

A paradigm change such as the theory of signal detectability produced gives us a new way to look at experiments and data in an old area. As such, it leads to conflicts, objections, reactions, and new alternatives. This investiture of a new theory declares it open for opposition and marks it of importance in scientific progress. Theories die more from not being attacked than from being the objects of extensive reactions.

Generally, the objections to the theory of signal detectability take two major forms: First, the theoretical structure is often construed as too weak. That is to say the distributions that underlie the response structure are arbitrary, underivable for more fundamental principles, unconnected with known facts about the physiological structure of the organism, and unrejectable by data. This class of objections is a natural reaction to statistical models in general, especially if the distribution functions are not derivable from simple mechanisms intrinsic to the substantive area. Consequently experimentalists and theoreticians have searched for ways to generate signal detection-like distributions from known physiological mechanisms, or from other structures that spread across more than sensory mechanisms.

Examples of such counter-theories are the choice theory of Luce (1963), the neural counting models of McGill (1967), and of Luce and Green (1972), and the enlargement by Durlach and Braida (1969) of signal detectability theory. All of these theories accept unhesitatingly the central tenent of the theory of signal detectability, namely that a two-parameter decision theory is essential. The issues that are raised by these theoreticians concern questions of the origin of the underlying decision distribution, the nature of the mechanisms by which those distributions are modulated, and the plausibility of the neurological source of information internal to the person on which the decisions are made. But none of these proposals to supersede the theory of signal detectability fail to recognize the profound importance that the notion of a two-parameter theory of decision making has produced.

A second source of objection to the theory of signal detectability is that it does not fit the data. This is quite the reverse of the first question where the theory is construed as too weak to be successful, insofar as it fits all data without illuminating any. These objections are based on experiments for which the theory is silent, but yield data one would not expect if a literal interpretation of the theory were forced on the experiment. A classic example of objections of this kind are contained in the experiments reported by Parducci and Sandusky (1970). The references and abstracts that follow represent examples of criticisms and alternatives to the theory of signal detectability that have established a place for themselves in the literature.

In his seminal book, Individual Choice Behavior (1959) Luce proposed one of the first alternatives to the theory of signal detectability. The theory postulates that the conditional probabilities of response in the presence or absence of a signal are dependent on the value of two hypothetical ratio scales, one called α and the other called v. α is construed as a measure of the similarity between the event presented to the person and some standard event (e.g., the mean of an underlying noise distribution) for which a response of a particular kind is appropriate. The v scale is simply a numerical value of the bias parameter and is estimated from the data based upon the formulas of equations:

$$p(\text{hit}) = \alpha/\alpha + v) \qquad (4)$$

$$p(\text{F.A.}) = 1/(1 + v) \qquad (5)$$

In plotting the isosensitivity functions derivable from both the signal detectability and the choice theoretic model, Luce makes the important point, "although the ROC curves from the two models are practically indistinguishable, there is a significant difference of interpretation. In the signal detectability model the subject selects a cutoff point along a decision axis, whereas in the axiom 1 model, he selects a response bias. The latter model and its interpretation seem to be more readily generalized to more complex experiments." (1959, p. 61-62)

A second class of alternative models arises from the belief that known neurophysiological facts should temper the nature of psychological theory. The first abstract, of McGill's now classic paper, is followed by abstracts of extensions of these counting theories by Luce and Green (1972).

McGill, W. Neural counting mechanisms and energy detection in audition. Journal of Mathematical Psychology, 1967, 4, 351-376.

In the present treatment the fluctuation statistics of acoustic noise are superimposed on a (Poisson) mean counting rate in the auditory system and the resulting counting distributions are analyzed. Detection laws derived from the latter are then compared with auditory data on masking and intensity discrimination, as well as with analogous predictions obtained from direct analysis of stimulus energy. The outcome can be characterized as establishing that internal counting states mimic the noise energy fluctuations. Hence, detection laws derived from either domain are found to be essentially equivalent. This result justifies the stimulus-based analysis of detectability now current in auditory psychophysics, but it also suggests that sensory detection models involving decision strategies with substantial information processing may prove to be unnecessarily complicated.

Luce, R. D. & Green, D. M. A neural timing theory for response times and the psychophysics of intensity. Psychological Review, 1972, 79, 14-57.

This psychophysical theory involves the following fundamental assumptions. At a hypothetical neural decision center, signal intensity is represented by several independent, parallel Poisson processes, whose rates are the same power function of physical intensity. All decisons about signal intensity are based on the observed times between successive neural pulses. The total number of these times observed per channel is at the option of the observer, up to the size of a memory store which is emptied when a decision is made. Overall response time is the sum of the decision latency, which depends both on the signal intensity and the decision rule, and a residual latency which is only assumed to be bounded. Decision rules are suggested for discrimination, recognition, magnitude estimation, detection, and simple reaction time designs, and predictions are derived from the theory in these cases and compared with existing data. Various familiar generalizations, such as Weber's and Bloch's laws and the inverse relation between reaction time and intensity, derive naturally from the theory. Crude estimates of all parameters--the exponent of the power function, the number of parallel channels, the size of the buffer store, and the bound on the residual times--are provided for sound intensity; estimates from different experimental designs appear to be reasonably consistent.

The Luce and Green work derives directly from the counting models of McGill. The general notion motivating such theories may be that because the nervous system emits easily recognizable pulses, and because the pulse rate is roughly proportional to the intensity of the applied irritation to the neural tissue, then the pulse rate is the object of the primary decision. It should be noted that McGill's attempt to reduce the role of decision processes does not extend to Luce and Green. Indeed, their strong physiological substrate is not shared by another current theory of intensity discrimination, namely that of Durlach and Braida.

Durlach, N. I. & Braida, L. D. Intensity perception. I. Preliminary theory of intensity resolution. Journal of the Acoustical Society of America, 1969, 46, 372-383.

An attempt is made to develop a quantitative theory of intensity resolution that is applicable to a wide variety of experiments on discrimination, identification, and scaling. The theory is composed of a Thurstonian decision model, which separates sensitivity from response bias, and an internal-noise model, which separates sensory limitations from memory limitations. It is assumed that the observer has two memory operating modes, a sensory-trace mode and a context-coding mode, and that the use of these two modes is determined by the characteristics of the experiment. In one-interval paradigms, it is assumed that the context-coding mode is used, and the theory relates resolution to the total range of intensities in the stimulus set. In two-interval paradigms, it is assumed that the two modes are combined, and the theory relates resolution to both the total intensity range and the duration between the two intervals. The theory provides among other things, a new interpretation of the seven plus or minus two phenomenon.

Notice that in this abstract, the ideas of signal detectability are carried forward to cope with data for which the theory itself was not designed. Theoretical investigations that move in this direction tend to strengthen the fundamental assumptions of two-parameter decision theory. They generate an expansion of the theory into additonal experimental domains within the psychophysical laboratory.

However before we rest complacently on the assumption that, one way or another, two-parameter decision theory is universally accepted, account must be taken of experimental objections to these theories. The following two abstracts give examples of such critiques.

Parducci, A. & Sandusky, A. J. Limits on the applicability of signal detection theories. Perception & Psychophysics, 1970, 7, 63-64.

Two auditory signals were presented in sequence. In the detection task, observers were required to rate the second signal as louder or softer than the first. In the recognition task, the first signal was represented to observers as a warning signal, and as an approximate reference, and their task was to recognize the signal in the second position as the "louder" or "softer" of two signals that could appear in that position. The a priori probability of the more intense signal was varied. The conditional probability of a louder judgment given either the more or the less intense signal (i.e., the proportion of hits and false alarms), decreased with increasing prior probability of the more intense signal. This was the case both for the discrimination and the recognition task. The effects of changes in signal probability were thus in the opposite direction from that predicted by TSD, when response optimization is assumed. A limitation on the generalization of TSD to discrimination and recognition tasks is suggested.

Ryder, P., Pike, R., & Dalghish, L. What is the signal in signal detection? Perception & Psychophysics, 1974, 15, 479-482.

Two interpretations of the sensory decision continuum in an auditory detection task are investigated: a) the distributions represent amplitude or energy; b) the distributions represent a difference in amplitude or energy. Two experiments were designed in which the signal consisted of short intensity increments of a 1 kHz tone embedded in white noise. On occasional trials the intensity of the carrier tone was increased to the signal level. Responses on those trials support the second interpretation and implications of "difference detection" for TSD are discussed.

Both of these experiments constitute examples of attacks upon the fundamental notions of the theories of signal detectability. Notice that the last abstract however concerns not the theory, but rather the interpretation of the events that serve as the underlying basis for the theoretical structure. In some sense this is not really an attack on a theory, it is an attack on a (possibly) naive interpretation of the theory. We must constantly be aware that the establishment of straw men represents an opportunity for experimentalists to conduct studies that may be more enlightening as experimental facts than as theoretical contributions.

Generalizing Two-Parameter Decision Theories to New Domains

The first consequence of two-parameter decision theory in psychology was the recognition that it would now be possible to measure response bias in many contexts. This was a phenomenon that everyone knew existed, but no one knew how to formalize. The existence of two-parameter decision theory made such formalization possible, and led to questioning many old experimental results. Do the data represent something intrinsic to the experimental variations or are they simply the display of response biases by experimental observers? To lead off this area we turn first to work conducted originally by our laboratory. It had been observed both experimentally and clinically, that respondents often appeared to have elevated taste thresholds for sucrose after eating than they did before having eaten. The question of interest was whether these data indicate a real change in threshold, or variations in response bias. Linker, Moore, & Galanter, (1964) showed that two-parameter decision theory could be applied to estimate detection thresholds for sucrose; Moore later showed that the pre- and post-prandial threshold effects were in fact response bias effects.

We present below additional abstracts of other work that show how decision theoretic ideas can enter new domains.

Linker, E., Moore, M. E., & Galanter, E. Taste thresholds, detection models and disparate results. Journal of Experimental Psychology, 1964, 67, 59-66.

Observers were required to discriminate a sucrose solution from distilled water, at various sucrose concentration levels and with different *a priori* probabilities of sucrose and water being presented. When P(S) was equal to P(N) (=.5), each sucrose solution yielded a point on the ROC that fell on an isobias line. The effect of varying the signal probability was to sweep out the entire isosensitivity function. The implications for traditional threshold measurement are discussed, and the results fitted both by TSD and by Luce's two state threshold theory.

Rees, J. N., & Botwinick, J. Detection and decision factors in behavior of the elderly, Journal of Gerontology, 1971, 26, 133-136.

1) Psychological factors affect conventional audiometric measures. People with strict criterion given lower sensitivity index.
2) If the documented conservatism of elderly people is manifested in auditory judgments, then conventional measures of sensitivity should be lower for them than biological factors necessitate.
3) 18 undergraduate men were compared with 15 elderly men (65-77 with median 71 years old)
4) Results:
   Although traditional threshold estimates, using the method of limits, showed significant differences between the two groups, when signal detection analysis was used there was no significant difference in d's. The older people, however, adopted a much higher criterion (beta) for reporting the tone. Thus, much of the literature on hearing loss in later life may be an artifact of the measurement procedure.

DuCharme, W. M. Response bias explanation of conservative human inference. Journal of Experimental Psychology, 1970, 85, 65-74.

Conservative human inference has been attributed to misperception or misaggregation of data, but it may be caused by response biases. In these experiments, observers' revised odds estimates about which one of two normal distribution data generators was being sampled. An analysis of special sequences and a plot of revised odds against theoretical odds in Exp. 1 showed a bias in the observers response functions. A second experiment showed that the biased functions remained invariant over changes in data generator familiarity and diagnosticity. Of the several explanations offered for these response functions, an odds bias seems the most likely. Whatever the cause of the bias, observers neither misaggregated nor misperceived data within their optimal range.

Lusted, L. B. Signal detectability and medical decision-making, Science, 1971, 171, 12-17.

TSD is relevant to two radiological problems:
1) How does radiographic image quality affect diagnosis?
2) How is effectiveness and efficiency of radiologists increased by use of technical personnel?

It is noted that there is a high degree of disagreement between doctors and between successive diagnoses by the same doctor of the presence of disease indicated by x-rays. When hits are plotted against false alarms these differences can be shown to be attributable to differences in response bias. Lusted introduces two parameters, $d'_e = 2$ (normal deviate of ROC at the minor diagonal) and σ_1/σ_2 = slope of ROC in normal-normal coordinates. d'_e is normalized by averaging variances. He then reports three experiments on sensitivity differences between observers.

Experiment 1. Reports that d'_e can be used to test what kind of viewing arrangement maximizes sensitivity. Finding: sensitivity under direct viewing is greater than sensitivity under contrast enhanced TV which is greater than sensitivity under TV.

Experiment 2. d'_e of radiologists is greater than d'_e of technical personnel and secretaries. (The latter mixed group also shows a departure from the equal variance assumption, probably caused by the mixing of data pools.)

Experiment 3. Is sensitivity increased by training?

	d'_e Pre-training	5 months	10 months
Tech. 1	1.12	2.08	2.53
Tech. 2	0.08	1.42	2.63
Residents (5)	---	---	2.74
Staff (3)	---		3.02

So that after 10 months there was no significant difference.

Ulehla, Z. J., Canges, L., & Wackwitz, F. Signal detectability theory applied to conceptual discrimination. Psychonomic Science, 1967, 8, 221.

The authors test discriminability of short sections of English prose from two different sources. 1) A "he-man" magazine and 2) a "true confession" magazine. Results of one analysis of variance were found to support TSD, (i.e. the d' index was shown to be independent of response modes), and the product moment correlation coefficient between z (hit) and z (false alarm) = .99 demonstrating the linearity of the relation between the response parameters in normal coordinates.

Suboski, M. D. The analysis of classical discrimination conditioning experiments. Psychological Bulletin, 1967, 68, 235-242.

The concepts of TSD are applied to classical discrimination conditioning experiments. In particular the conditioned response is viewed as the joint product of sensitivity and response bias. Some published results are reanalyzed. It is shown that changes in instruction affect response bias and not discriminability. Furthermore differences between high and low anxiety observers (measured on the Taylor Manifest Anxiety Scale lie primarily in their choice of response criteria, and finally observers who respond voluntarily with the CR can be understood as having a considerably lower response criterion than others. The author concludes that TSD has the potential of unifying a number of diverse experimental results within a single descriptive framework.

Pastore, R. E. & Scheirer, C. J. Signal detection theory: considerations for general application. Psychological Bulletin, 1974, 81, 945-958.

This article represents a revised and expanded version of a previous paper that considers the possibility of applying TSD to the study of motivation, and to the study of the effects of surgical or pharmacological treatment. Some of the literature that uses a response measure such as latency of response in deriving the ROC is reviewed, and the applications of TSD in evaluating multiple channel models of perception are discussed.

Schoeffler, M. S. Theory of psychophysical learning. Journal of the Acoustical Society of America, 1965, 37, 1124-1133.

A model for psychophysical learning is developed which combines the conditioning concepts of classical learning theory with the TSD conception of the decision task. The model postulates that an observer uses feedback or his or her level of confidence after a response to alter his or her response probabilities. Some predicted theoretical results are that a) performance improves with practice b) feedback can be detrimental to performance in a psychophysical task c) when the a priori probabilities of the stimuli are unequal and feedback is provided, the response criterion moves in the direction of optimality, however, when no feedback is provided, the criterion moves in the opposite direction.

Price, R. H. Signal-detection methods in personality and perception. Psychological Bulletin, 1966, 66, 55-62.

Price criticizes the use of threshold models in studies of personality and perception on four groups: 1) dependence of result on psychophysical method, 2) arbitrariness of threshold definition, 3) threshold estimation unimproved by correction for guessing, 4) confusion of sensory capabilities and response bias. Signal detection theory is described as an alternative and a variety of studies that use its logic and methods are reviewed and discussed.

Decision Theory and the Threshold

We have not yet remarked on the relation between the development of the theory of signal detectability and the concept of the psychophysical threshold. The threshold notion itself dates at least from the late sixteenth century when philosophers puzzled over the question of the identity of indiscernibles. The formalization of the notion of the threshold may have begun with the researches of E. H. Weber (1835) and the consequent demonstration of his empirical law. Details of the theory of the threshold were developed by Fechner in Elemente der Psychophysik, (1860), along with a set of methods to determine the values of absolute and differential thresholds. These classical methods of threshold determination and the concepts and statistics of the psychometric function, are a representation of theory similar to that of Blackwell (1953) which tries to come to grips with questions of false alarms and other so-called "invalid modes of response." For a general overview see Galanter, 1977.

The central idea of the modern threshold theories is to adjust the proportion of "hits" generated by response bias according to the proportion of false alarms. The assumption is that the observer occasionally guesses correctly when he or she is unable to actually detect the presence of a signal. When this correction-for-guessing theory is coupled to the classical threshold model then one accounts for the presence of false alarms by estimating a second parameter that represents the degree of guessing. Whereas the classical theory presumes that there is a physiological limit below which signals will not produce any effect, and above which signals will always produce a mental effect, this revision decouples the threshold-divided consciousness from the verbal behavior of the observer. The theory becomes a two-parameter decision theory.

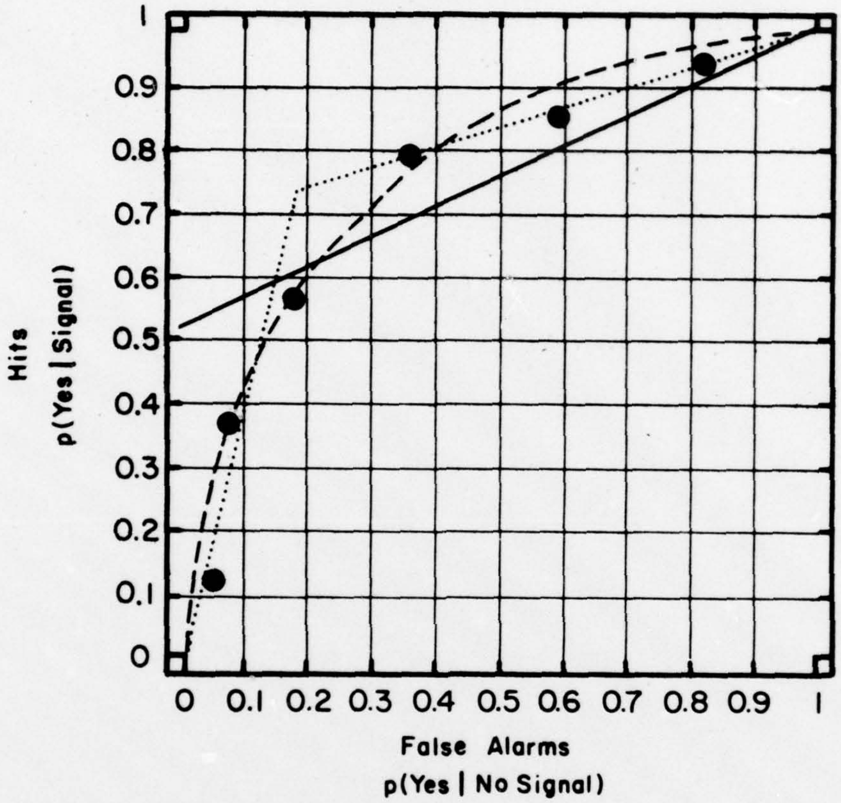
In order to account for response variability, the threshold may drift around its mean value as time passes according to, perhaps, a normal distribution. Consequently, signals weaker than the mean threshold will occasionally be detected whereas signals that are above the mean will be reported much more frequently.

What response biases do within the framework of such a theory is to increase the chance that the experimental observer will report as a signal an event that in fact is not a signal. Consequently his or her bias will increase all of his or her hit percentages by some proportionate amount. This linear increase in hits and false alarms as his or her propensity to say "yes" increases, is represented by a correction-for-guessing formula in which:

$$p(\text{true detections}) = p(\text{hits} - p(\text{false alarms}))/100 - p(\text{false alarms}). \quad (6)$$

A prediction of this theory is that hits and false alarms will trace an isosensitivity function that extends from the upper right-hand corner of Figure 3 to some arbitrary intercept on the ordinate. This intercept is the true probability of detecting a signal and represents the unbiased hit probability for the signal of given strength.

Figure 3



The fact that the data shown in Figure 3 curve down as they approach the ordinate enables us to reject such a theory out-of-hand. But this does not imply that a threshold theory is in principle incapable of characterizing the isosensitivity data. We can easily develop a more sophisticated threshold theory by assuming that in addition to guessing that signals are present when in fact they are not, the observer may also report that signals are absent when in fact they are there. Thus like the observer's mind, the observer's response structure may be in one of two states. He or she may either be in a detection state in which case he or she will report the signal as present when it is or he or she may be in a non-detection reporting state in which case he or she will report the signal as not present when it is. The observer presumably reports the state that he or she is in, which may be induced by the presence or absence of the signal or by other response bias factors. Thus, he or she may falsify a proportion of his or her responses about each of their perceptual states.

This modification of the classical threshold theory produces a two-limbed isosensitivity function as also shown in Figure 3. Notice that it would be extremely difficult to select either decision theory on the basis of observed isosensitivity data. By adding a variety of additional states to the observers mental equipment, it is possible to approximate to any degree of precision, data from a variety of experiments. This has been shown most clearly by Norman (1966); who presents various multi-state threshold models.

Although it is not necessary to reject the concept of the threshold in order to retain the advantages of a two-parameter decision theory, the wide acceptance of the theory of signal detectability has resulted in questions concerning the true existence of the threshold. The theory of signal detectability clearly rejects the notion of a threshold insofar as the events to be classed as one kind either do or do not differ in the statistical sense from the events to be classed as another kind. If the two distributions of the events differ then regardless of the minuteness of the difference, given a sufficiently large sample the observer will be able to make the discrimination. A threshold in such a process does not exist, except insofar as the observer's sample sizes are not sufficient to permit reliable discrimination. In principle, of course, discrimination between distributions with even the most minute differences is always possible.

We move now from considerations of methodological niceties and why the theory of signal detectability is attractive, to questions of whether the theory itself has made any significant contributions to the study of topics having their own intrinsic substantive interest. We begin this examination by turning first to the area of vigilance and reviewing here several abstracts of research on this topic that have resulted from considerations of the theory of signal detectability.

Vigilance and Watch Keeping

Vigilance and watch keeping are concerned with the question of detection and identification under conditions of high uncertainty--temporal or spatial. In the usual vigilance experiment the experimental observer had minimal information concerning the time or visual location of the stimulus on a particular presentation. The consistent experimental finding is that detection and identification performance deteriorates from the beginning to the end of the watch. The rate of deterioration depends on a variety of variables, most importantly the initial detection probability (Teichner, 1974). Other factors such as target stability also influence the watch-keeping, but a common question is whether the deterioration may represent some slow decay of the sensory system in terms of a loss of sensitivity or whether the phenomenon is attributable to biasing factors such as fatigue or boredom. A two-parameter decision theory with experiments designed to distinguish among these alternatives should throw some light on these problems.

Early in the development of the theory of signal detectability experimenters such as Broadbent (1971) and Mackworth (1965, 1970) turned their attention to the application of the theory toward the watch-keeping task. We report below abstracts of some of the classic work as well as collateral reports that show how these topics have influenced experiments on the vigilance process. It should be remarked that some of the later two-parameter decision models such as the counting and timing models of McGill, may provide deeper explanations for the vigilance phenomenon than do simple detection theories. Swets (1977), in his excellent review of recent vigilance experiments, points out most importantly the need to distinguish between the theory of signal detectability as an explanatory model of the watch-keeping task, and as a useful analytical procedure for data reduction. Generally, however, the tenor of research using TSD is to try to "test" the model. This line will appear consistently in the abstracts, and in complete agreement with Swets, we consider this effort a rather empty exercise.

Although time uncertainty has been a central parameter studied by psychophysicists, vigilance experiments, because of the protracted times needed, have minimally exploited these models. The difficulty of coupling decision theory involving discrete responses with a presumably continuous process is the nub of the issue. For example, a current highly intractable problem is the study of skilled motor performance. The experiments are aimed at the measurement of work load decrements in the performance of skilled operators. The problem exhibits itself because of the high quality of motor performance in general. "Crashes", although catastrophic, are extremely rare events and are not heralded by proportionately large departures from routine error rates. But whereas the performance may continue with great precision until a catastrophic event occurs, there is a strong, and probably correct intuition that the catastrophe is preceded by changes in effort--both cognitive and perceptual--required to maintain the requisite precision. Techniques for the study of such work load decrement problems, including secondary task deterioration, etc. may force the expansion of decision theoretic ideas back to the examination of the continuous case. At this time we simply point out the lack of such a rapprochement and suggest the importance of its study.

Finally, we should remark on the connection between practical and theoretical issues that are nicely intertwined in the vigilance situation. Although not as dramatic as some of the possible applications of TSD, we shall note in the medical and pharmacological areas, watch-keeping and the performance that depends upon it are among the most consequential jobs in a high technology environment. The air-traffic control specialist is the prime example of the demands on vigilance made by complex man-machine systems.

Milosevic, S. Effect of time and space uncertainty on a vigilance task. Perception & Psychophysics, 1974, 15, 331-334.

Twelve observers engaged in a vigilance task in which they were instructed to detect increments in light intensity under conditions of spatial and/or temporal uncertainty. Spatial uncertainty had a greater relative effect of d' than did temporal uncertainty, and for all but one condition (spatial and temporal uncertainty) observers became more cautious (increased beta) in the course of the experimental session. The results are interpreted in light of the literature on vigilance behavior.

Broadbent, D. E. Decision and stress. New York: Academic Press, 1971.

Contained in this book are reports of 8 experiments performed between 1963 and 1967 showing that at the end of a vigilance-requiring work-day, when the rate of events is low, d' is the same as it was in the beginning of the day. This substantiates the theory that decrease of detection with time is due to upward criterion shifts.

When event rate is high however, there tend to be decrements in d' which result in less detections unless compensating criterion shifts are made. The appropriate path in these cases, clearly, is to introduce payoff functions that are time-dependent.

Hatfield, J. L. & Soderquist, D. R. Coupling effects and performance in vigilance tasks, Human Factors, 1970, 12, 351-359.

This study reports an extension of the finding that d' is constant in vigilance tasks. Criterion was found to increase and d' to remain constant independent of coupling condition or sensory modality employed. Significant cross-modality correlations were obtained for false alarms, latency, and criterion values.

Mackworth, J. F. Vigilance and attention: A signal detection approach. Baltimore, Md: Penguin Books, 1970.

This book summarizes the findings of the author on a variety of indexed experiments. This finding is, briefly, that the decrease in hit rate in a monotonous decision-making task is explainable by an upward shift of the criterion, and that this upward shift can be seen as evidence of habituation of neural responses to "noise" events, some of which include the neural response to the "wanted" stimuli.

Baekeland, F & Hoy, P. Vigilance before and after sleep, Perceptual and Motor Skills, 1970, 31, 583-586.

Observers performed an auditory vigilance task just before bed and 10 minutes after awakening over five consecutive nights. Averaged over the five nights the proportion of misses was significantly greater in the morning than at night, whereas the proportion of false alarms stayed the same. The lower detection rate after awakening is attributed to physiological changes associated with circadian rhythms.

Cahoon, R. L. Vigilance performance under hypoxia, *Journal of Applied Psychology*, 1970, *54*, 479-483.

Observers were required to detect 36 bright flashes in a series of dimmer flashes over a period of two hours under four different levels of oxygen deprivation (ranging from a sea level oxygen enviornment to an oxygen environment typical of 17,000 ft. (5182 m.) altitude d' was shown to decrease with increasing oxygen deprivation, whereas beta showed little variation across levels of oxygen concentration. Futhermore, scores on the Embedded Figure Test tended to be positively correlated with d' at every level of oxygen concentration.

Guralnick, M.J. & Harvey, K.G. Response requirements and performance in a visual vigilance task. *Psychonomic Science*, 1970, *20*, 215-217.

Three groups of observers performed a visual vigilance task with either one (standard vigilance procedure), two (binary yes-no procedure) or four (rating procedure) keys available as response indicators. Signals were presented once every six sec. d' was found to be independent of response requirement and to be constant over time. Beta was significantly lower for the rating procedure group than for the other two groups. Futher experiments with faster signal presentation rates are suggested.

Davenport, W.G. Vibrotactile vigilance: The effects of cost and values on signals. *Perception & Psychophysics*, 1969, *5*, 25-28.

During a 75-minute watch a vibratory stimulus was applied to participants thirty times. Point pay-off matrices manipulated the losses associated with false alarms and misses. d' and beta were computed, assuming equal variances of noise and signal + noise distributions. d' was invariant both over time and pay-off conditions, whereas beta increased with time and was largest (greater than 9.5) for the group operating under equally high costs for false alarms and misses. This latter finding gives pause to any straightforward TSD interpretation of beta in this context, and suggests that criterion placemant here reflects psychological processes particular to the vigilance situation.

Hatfield, J.L. & Soderquist, D.R. Practice effects and signal detection indices in an auditory vigilance task. *Journal of the Acoustical Society of America* 1969, *46*, 1458-1463.

d' and beta measures were obtained in ten 90-minute vigilance sessions (signal = 1.6 dB increments in pulsed white noise. Averate of 1 signal/min). d' decreased during the first 30 min of each session. Changes in d' over sessions were attributed to practice effects. Changes in d' within sessions were explained by reference to possible distraction or inattention and by the monotonous character of the task. The applicability of TSD to within-session vigilance data is called into question.

We see in this abstract a serious conflict with the interpretation of vigilance decrement as a criterion shift. However this study stands almost alone in questioning what has clearly become the established interpretaion.

Williges, R.C. Within-session criterion changes compared to an ideal observer criterion in a visual monitoring task. Journal of Experimental Psychology, 1969, 81, 61-66.

Observers were required to discriminate between long duration brightness changes (signals) and short duration brightness changes (noise), and then rated their decision on a three point category scale. They were either correctly informed as to the odds of signals vs. noise (1/5 or 5/1) or were incorrectly informed (1/1). Some participants were involved in a second distracting task while monitoring for brightness changes. d' was shown to be stable for the duration of the experimental session, but distracted observers had lower d's than undistracted ones.

Participants were assumed to be maximizing EV. Obtained Beta values were compared to optimal ones (a Symmetrical pay-off matrix was used). Under accurate instructional set, observers began by setting a criterion reflecting equal probability of signal and noise but then quickly adjusted that criterion (up or down) in the direction of the optimal criterion (while still remaining conservative). Under inaccurate instructional set, however, they maintained the criterion reflecting equal probability of signal and noise, and consequently either over or under responded (relative to the optimal beta. The authors argue that the changes in detection probabilities observed in previous vigilance studies represent changes toward more optimal decision behavior.

Sturmer, G. von Time perception, vigilance and decision theory. Perception & Psychophysics, 1968, 3, 197-200.

Three experiments are presented. In the first one, participants were required to tap a Morse key a 8 sec intervals. They performed under each of the two instructional sets, one encouraging them to depress the key as soon as enough time had elapsed ("risky" condition) since the last tap, the other suggesting they depress the key only when positively certain that enough time had elapsed ("cautious" condition). Results indicated that time estimates increased over the duration of the experimental session, and that this effect was considerably greater for those performing under the "cautious" condition. The finding was replicated when two monetary pay-off matrices were introduced. The effect persisted when the participants were permitted to count during the interval. The relevance of these findings to the study of vigilance behavior is discussed.

Lucas, P.A. Human Performance in low-signal probability tasks, Journal of the Acoustical Society of America, 1967, 42, 153-178.

Data show: 1) a conservative fixed response rate 2) a constant hit rate 3) interresponse distributions for false alarms with a general exponential shape showing periodic modes. Detection efficiency in the temporally unstructured task was well below that of alerted-detection efficiency. It is concluded that highly trained observers detecting important signals show constant efficiency over observation periods of 30-45 minutes.

Annett, J. & Paterson, L. Training for auditory detection, Acta Psychologica, 1967, 27, 420-426.

The study investigates different methods of training auditory detection skills such as are found in sonar watchkeeping. Two procedures were compared: 1) providing an observer with knowledge of performance during training, 2) providing an observer with a "cueing signal" 5 sec prior to each stimulus signal during training. The second procedure, in effect, points out instances of signal trials to participants. The major finding in this series of experiments is that procedure 2) leads to an increased number of hits and a decreased number of false alarms, whereas procedure 1) leads to both more hits and false alarms. Although no d' or beta measures were computed, the authors suggest that knowledge of performance results only in a change in response criterion, whereas cueing is effective in actually improving sensitivity.

Loeb, M., Hawkes, G.R. & Alluisi, E.A. The influence of d-amphetamine, benactyzine, and chlorpromazine on performance in an auditory vigilance task. Psychonomic Science, 1965, 3, 29-30

Hits and false alarms were measured in a 1-hour auditory vigilance task where signals consisted of intensity increments of random noise pulses. Four conditions were compared: performance under 1) d-amphetamine, 2) one of two tranquilizers, chlorpromazine and benactyzine, and 3) placebo. Under placebo, changes in detection performance over time revealed a criterion shift toward conservatism with stabel d'; both tranquilizers produced decreases in d' and beta. D-Amphetamine resulted in essentially constant d' and beta for the duration of the vigil.

Mackworth, J.F. The effect of amphetamine on the detectability of signals in a vigilance task. Canad. Journal of Psychology, 1965, 19, 104-110.

This study is a replication of earlier work that suggests amphetamine inhibits the detection decrement symptomatic of a vigilance task. Since the initial data do not include false alarm rates, the question was whether the decrement was a response bias or a sensitivity dependent shift. The replication shows that the ampetamines do indeed correlate with a maintained d' rather than a time shift of response bias in a vigilance situation. (The experimental task was the detection of a brief pause in the sweep of the hand of a clock.)

Colquhoun, W.P. & Baddelye, A.D. Role of pretest expentancy in vigilance decrement. Journal of Experimental Psychology, 1964, 68, 156-160.

Observers were presented with rows of six disks every 2 sec and were required to determine which - if any - of the disks was larger than the others. The larger disk constituted the signal. One group practiced under high signal probability conditions (P(S)=.18), the other under low signal probability conditions (P(S)=.02). The test runs them used one or the other signal probability. Although a TSD analysis was made difficult by the low false alarm rate, the results indicate that a practice session with high signal probability leads to a laxer criterion than the low signal probability practice session, but tha d' does not change with the kind of practice session. The effect of the practice run on the expected signal probability is discussed. It is also shown that the signal expectancy is modified by the temporal placement of the first signal.

Jerison, H.J. & Pickett, R.M. Vigilance: the importance of the elicited observing rate. Science, 1964, 143, 970-971.

This early report suggests a TSD approach to the study of vigilance. Observers attempted to detect twenty visual signals during an 80 minute vigil. Within that period, regularly repeated events occurred at the rate of either 5 per minute or 30 per minute. Participants were induced to attend to these repeated events since the signals were simply modifications of these events. Results showed that the percentage of misses was far higher under the high repetition rate than under the low one. Futhermore, the relative decrement in performance as a function of time commonly observed in vigilance studies was evidenced primarily in the high repetition condition. If the observer is taking the prior probabilities of signal and noise (the repeated events) into account in response decisions, then TSD predicts a higher miss rate in the high repetition condition as compared to the low repetition condition.

Memory

The memorial capacities have been a topic in psychophysics since the initial explorations of Wundt and the Leipzig school. Whenever a judgment of a stimulus just presented required comparison with a stimulus that had gone before, it was clear that the comparison was based, at least in part, upon some representation of the preceding stimulus now long past. Indeed, although the philosophical issues were never quite resolved, the fact is that comparisons in general are routinely between temporally absent events---events in the imagination or the memory. The study of the constant errors, the time error and the space error, were often interpreted as attributable to memorial changes of one kind or another. Therefore, when J. P. Egan (1958) first applied the theory of signal detectability to the analysis of recognition memory, the psychophysical community accepted it as a reasonable interpretation of the memory data, although it did take some time before the techniques and interpretation of two-parameter decision theory filtered down to the students of memory and learning. We should note in passing that the need to include memory functions has come full circle. The abstracts of both Luce and Green (1972), and Durlach and Braida (1969), show how this concept has become a proper part of the decision theory itself.

An example of one of the problems where decision theory makes a substantive contribution to classical topics in memory is in the distinction between recall of individual items and recognition of a previously learned item. It is a common observation that recognition of a previously experienced event from among other events that have not been previously exposed is "easier" than is the identification of a single event as having been experienced before. This fact has been attributed to a variety of psychic mechanisms but nowhere has it been dealt with more expeditiously than within the context of signal detection theory. In the theory the memory task is characterized as represented by either a yes-no detection paradigm or as a forced-choice paradigm. We mean by these two experimental arrangements that, in a yes-no design, the task of the observer is to respond with one of two alternatives upon the presentation of a single signal. In the forced-choice design two signals are presented, one of which must be selected as possessing the requisite characteristic.

If, in these two designs, the signals are events that have occurred previously and the non-signals are events that have not occurred previously, then the yes-no design represents an absolute identification of a past event, and the forced-choice design represents the selection from among two events, the one that occurred previously. The fact that performance is better in the forced-choice task must be explained by the theory of signal detectability.

One rational procedure for analyzing the data from the forced-choice experiment would be to assume that every trial is a yes trial and that correct yeses are hits and incorrect yeses are misses. Data could then be converted to proportions and plotted as an isosensitivity function. The problem with this approach is that the value of d' obtained from the forced-choice experiment when analyzed this way is always larger than the value of d' calculated from the yes-no identification experiment when the signal levels are equal. When different experimental procedures give rise to different sensitivities for the same stimulus, it makes the concept of sensitivity hard to accept. The question is how the data from the two alternative forced-choice experiments can be interpreted so that the results are congruent with the results from other experiments. This is analogous to the problem that the memory theorists face in dealing with the distinctions between recall and recognition.

There is however another way to interpret the data from the forced choice experiment. That is to assume that the observer is really making two yes-no determinations. That is, after each trial he or she has made one of four possible observations:

Observation	Interval 1	Interval 2
1	Signal	No-signal
2	No-signal	Signal
3	No-signal	No-signal
4	Signal	Signal

The first observation would suggest response 1; the second response 2; the last two are hard to decide. But one thing is clear, the observer has two independent "trys" on each trial. We would expect as a result of this that he or she would fare better than the observer with only a single chance. An important fact from statistics is that the product of two equally probable independent events equals either event multiplied by the square root of two. If the interpretation above is correct, we would then expect that:

$$d'(\text{forced-choice}) = \sqrt{2} \times d'(\text{single observation}). \qquad (7)$$

If the d' determined in the forced-choice experiment is divided by the square root of 2, the resulting d' should then be equal to the value determined from the single event yes-no identification experiment. Therefore, one can determine experimentally whether it is reasonable to accept the assumption that the observer is making two independent observations on trials on which two events are present. If so, then the sensitivity is not dependent on the particular experimental technique, but only upon the stimulus effects.

The central characteristic of the research in this area is that the experimental paradigms remain roughly equivalent to what they had been before the introduction of the signal detectability analysis technique. However, what we do observe is that even when the problems addressed by the theory are intrinsic to the experimental designs, the theory provides a more enlightened interpretation of the data. This is seen clearly in Murdock's (1965) early paper, and in the use of the theory to distinguish between varying performances in different contexts as in the research of Norman and Wickelgren (1965). But just as applications of signal detection theory to the classic psychophysical functions may not conform to direct representation by the theory. Klatzky and Loftus, as early as 1969 demonstrated variations in values of d' under conditions in which th sensitivity measure should have remained constant. Similar experimental analyses have continued to the present time.

The question of whether the applicability of signal detectability to any memory experiment is appropriate is not at issue. The real question is whether the parameters of the theory represent important experimental variables and therefore provide metric representations of central cognitive processing. The review by Banks in 1970 demonstrates The critical questions that were being raised about the applicability of signal detection to memory. But this review and criticism did not reduce the importance of the statistics of the thoery from refining and improving technical aspects of the experimentation in this field.

The abstracts that follow are culled from a vast and expanding literature that has been vitalized by decision theoretic ideas. The rote-learning experiments and the paired-associate analogues of association theory have received a boost from these theories that is no less impressive than the impact of Ebbinghaus of the study of memory.

Pollack, I., Norman, D.A. & Galanter, E. An efficient non-parametric analysis of recognition memory. Psychonomic Science, 1964, I, 327-328.

Two category rating experiments are reported in which observers were engaged in recognizing "old" stimulus items among a list of old and new items. Isomnemonic curves relating probability of hits to probability of false alarms are generated. A non-parametric analysis of the data is performed according to which the detectability (recognizability) of a stimulus is represented by the area under the isomnemonic curve. This analysis avoids making assumptions concerning the nature of the distributions of the stimulus events. The area under the isomnemonic curve is shown to increase (recognition is improved) when more time is allotted between initial stimulus presentations in the memorization phase of the experiment (word recognition experiment) and when stimulus presentation period increases (nonsense syllable recognition experiment).

Murdock, B.B., Jr. Signal detection and short-term memory. Journal of Experimental Psychology, 1965, 70, 443-447.

On each trial a list of 6 paired associates (A-B) was presented once, then one of these pairs was tested for recognition. Either A-B (a proper pair) or A-X (an improper pair) was presented (in 6 different positions) and observers were asked to give both a binary (yes-no) decision and a confidence rating. ROC curves $P(R_i | (A - X))$ vs. $P(R_j | (A-X))$ were plotted, one for serial position 1-4, one for serial position 5. Values of d' were 1.36 and 2.0 for serial position 1-4 and serial position 5 respectively. The equal variance assumption held only for serial positions 1-4, (as reflected in the difference in symmetry between the two ROC curves). Curves resembled the curvilinear functions to TSD more than the linear functions required by the high threshold model according to which there is a threshold of associative strength below which no responses occur. The value of a high threshold concept to explain 1-trial learning data is questioned. Short-term memory appears to be a continuous process, with observers capable of varying decision criterion over a wide rangs.

Norman, D.A. & Wickelgren, W.A. Short-term recognition memory for single digits and pairs of digits. Journal of Experimental Psychology, 1965, 70, 479-489.

Norman and Wickelgren develop a model which has direct implications for the distinction between item and order information. In an analysis of short-term recognition memory for single digits and pairs of digits, Norman and Wickelgren observed fundamentally different ROC curves for single digits and digit pairs. The single digit ROC was a smooth, continuous function, as expected, assuming the underlying strength distributions of new and old items to be Gaussian in nature. The ROC curve for digit pairs, however, appeared discontinuous, being best described by two linear components. The a posteriori probability curves actually indicated the lower limb of the ROC to be curvilinear, suggesting that observers were capable of ordering their confidence ratings above a low threshold. The proposed model assumes that observers attend to non-overlapping pairs of digits, the consequence being that only some of the pairs of digits are incremented in strength of the memory trace in a probabilistic fashion upon presentation of an item or pair.

Wickelgren, W.A. Consolidation and retroactive interference in short term recognition memory for pitch. Journal of Experimental Psychology, 1966, 72, 250-259.

Observers listened to a standard tone for 2, 4, or 8 sec followed by an interference tone lasting 2, 4, or 8 sec followed by a comparison tone lasting 2 sec. The were required to decide whether the standard and comparison tones were the same or different in pitch, and to provide a confidence rating. ROCs were approximately straight lines on normal-normal paper, and d' values were computed for each condition, for each observer. d' was interpreted as a measure of the difference in trace strength between the correct (same) and incorrect (different) comparison tones, at the time of the test. According to this measure, trace strength d' increased with longer duration, decreased with longer duration of the interference tone, and generalized to adjacent tones.

Parks, T.E. Signal detectability theory of recognition-memory performance. Psychological Review, 1966, 73, 44-58.

In one of the pioneer articles in the application of TSD to recognition memory, Parks describes a model in which a stimulus item is neither recognized nor not recognized but, rather, the covert events which mediate overt recognition behavior vary in strength along a continuum of familiarity. Observer responds "old" only if the familiarity value of the stimulus exceeds cut-off point, Xc. Observers response criterion is set so that is likely to choose a number of items approximately equal to the number of old items in the test.

Murdock, B.B., Jr. The criterion problem in short-term memory. Journal of Experimental Psychology, 1966, 72, 317-324.

According to TSD the response is a function of both sensitivity and the criterion; this experiment tested for criterion shifts in short-term memory. Each list consisted of fi A-B paired associates followed by a probe (A or B) for one of the pairs. Observers were tested intensively, and recall data were supplemented with latency measures and confidence ratings. Data analysis showed that the strength of the evoked response (as measured by d') was invariant over serial position but that the criterion (as measured by beta) became stricter as retention interval increased.

Aiken, E.G. & Lau, A.W. Memory for the pitch of a tone. Perception & Psychophysics, 1966, 1, 231-233.

Observers attempted to detect the presence of a pitch difference between two successive tones. They gained and lost points equally for correct judgments and errors. Intertone intervals of .95, 4.5, and 8.9 sec occurred with equal frequency and were distributed randomly throughout the trials. Percent of correct judgments was equivalent over different intertone intervals (ITI). Reports of a pitch difference increased with increased ITI; this was interpreted as arising from hypothesized shifts in the neural locus of the first stimulus during the intertone interval. From the TSD viewpoint, observers apparently adopted a conservative criterion for reporting a difference at the .95 sec separation, and then progressively relaxed it as the interval lengthened. Since response bias is traditionally seen to depend on only the probability of the event and the appropriate payoff, and no such variation occurred in the experiment, no explanation in terms of TSD was available.

Winograd, E. & Sall, W.V. Discriminability of association value in recognition memory. Journal of Experimental Psychology, 1966, 72, 328-334.

A traditional recognition memory task was adapted in the present study to investigate the discriminability of CVC trigrams differing in association value relative to two published norms. Observers were presented with a list of trigrams correlated on the two norms and the, in the recognition task, with the orginal items and certain new items. One half of the new items were correlated on the two norms, while the remaining new items were not. Isomenemonic functions showed that the items not correlated on the two norms were discriminable from those that were. The uncorrelated items were then analyzed for characteristic differences.

Suboski, M.D., Pappas, B.A. & Murray, D.J. Confidence ratings in recall paired-associates learning. Psychonomic Science, 1966, 5, 147-148.

Observers were asked to rate their confidence in the correctness of their responses in a paired-associates paradigm by drawing a vertical line across a 5 cm confidence line ranging from "guess" to "sure". Confidence ratings increased under the conditions in which the probability of a correct response increased. An increase in the average response judgment across trials for correct responses following previous correct responses was found. This was taken as evidence against an all-or-none position regarding the nature of the memory trace. A continuum of states of association between stimuli and responses rather than just learned and unlearned is suggested. The confidence rating is seen as a reflection of the strength of the learned association between stimulus and response.

Norman, D.A. Acquisition and retention in short-ter memory. Journal of Experimental Psychology, 1966, 72, 369-381.

Retention in short-term memory was studied by manipulating rates of presentation (1-10 digits/sec), type of item (single digits, paired digits and nonsense syllables) and type of test (probed recall and probed recognition). In the recall tests observers responded with the digit that followed the probe; in the recognition tests, observers decided whether or not the probe had previously occurred in the list and responded "yes" or "no", followed by a judgment of confidence in the response.

Performance in short-term memory experiments is attributed to interactions among three different processes: acquisition, retention and decision. Rate of presentation, length of list, type of item and presentation modality seemed mainly to affect the initial acquisition of items in memory. The rate of forgetting depends mainly on the number of items presented between the critical item and its test. When d' values were plotted against i (number of interfering items), exponentially decreasing curves were obtained. The rate of decrease was the same for all three memory matrices and only the acquisition parameter depended upon the type of material.

Kintsch, W. & Carlson, W.J. Changes in the memory operating characteristic during recognition learning. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 891-896.

Observers learned to recognize 30 lists of paired associates and confidence judgments were obtained for all responses, and were used to construct memory operating characteristics. The learning data were in agreement with a Markov model which reguires a constant error probability in the initial state. The memory operating characteristics based upon all scores of the first test is smooth and symmetric and indicates good discrimination.

Memory operating characteristics were also constructed from scores of the first test trial which were followed by an error on some later trial, and from all scores before the last error. These two memory operating characteristics overlapped and were in between the memory operating charateristics based upon all first trial scores and the chance line. It is concluded that on trials before the last error, observers possess some information about the learning material, but that the amount of information does not increase during those trials.

Suboski, M.D. Signal detection analysis of recall paired-associates learning. Psychonomic Science, 1967, 7, 357-358.

Replicated results of Suboski, Pappas and Murray (1966), who found recognition accuracy to be an increasing function of prior recall confidence. Observers were given a standard Retain, Test, Test (RTT) paired associates paradigm; they were asked to supply the second element of the pair and a confidence rating for each. ROC curves for the 2 test trials were very similar and indicated comparable ability of observers to discriminate between correct and incorrect response on each test. T2 performance was a function of both prior correctness and confidence during T, supporting the hypothesis that a continuum of associative strength results from PA learning and is reflected by the confidence ratings. Explanations involving increased sensitivity during Ts or application of information from T1 to T2 were refused.

Schulman, A.I. Word length and rarity in recognition memory. Psychonomic Science, 1967, 9, 211-212.

Confidence ratings were obtained for 200 words on a 6-point scale, and operating characteristics were obtained. d' was used a a measure of sensitivity. Words varied in length (poly-vs. monosyllabic) and frequency (common vs. rare). It was found to be much easier for observers to distinguish between old and new rare words than between old and new common words. Rare (but not common) words were easier to recognize when they were polysyllabic than when they were not. The results are attributed to the fact that rare words are more specific, concrete, free from associations, and structurally different. Length is a secondary property used only after some "semantic search" has been initiated; for rare words this search produces only a few possible matches, so that the additional information provided by length may be helpful. For common words, semantic spaces overlap too much for a structural search to be carried out successfully.

Gibson, K.L. Criterion shifts and the determination of the memory operating characteristic. Psychonomic Science, 1967, 9, 207-208.

In a continuous recognition experiment, observers were asked to discriminate whether the stimulus presented for testing had been changed or if it was modified compared to when it was studied. Responses were made on a 6-point rating scale, and a memory operating charateristic curve was constructed. Observers criteria were manipulated by presenting stimuli at three different visual locations on a screen associated with different proportions of modified test stimuli (signals). The memory operating characteristics formed straight lines with slopes close to one. For different signal probabilities memory operating characteristics were found to be shifted but overlapping. Observers seemed thus to be able to maintain several criteria simultaneously.

Lawrence, C. M. & Ross, J. Information available from brief visual presentations using two types of reports. Psychonomic Science, 1968, 13, 199-200.

The effects of the acoustic and structural similarity of letters on the accuracy of report after tachistoscopic presentation were studied using two partial report techniques: 1) content judgment-forced choice recognition (CJ), in which two letters of a cued letter pair were compared and reported to be the same or different; 2) content report-free recall (CR), in which both CJ and report of the letter names were requested. While CR results showed a decline in accuracy of report with increasing cue delay, confirming traditional data (e.g., Sperling, 1960), the CJ results showed a trend in the opposite direction.

Also for the CJ condition, percentage of "different" responses when the letters were the same exceeded the percentage of "identical" responses when the letters were different. The reverse was true for the CR condition. These differences between conditions are attributed to differences in criterion placement in CJ and CR tasks.

Murdock, B. B. Jr. Response latencies in short-term memory. Quart. J. Exp. Psych., 1968, 20, 79-82.

While shortening the interstimulus interval had a statistically significant effect on recall probability, the interaction between recall interval and probe position was neglible. Traditionally response latency is considered a measure of associative strength, but such an interpretation seems inappropriate here. As an alternative hypothesis, latencies may reflect more criterion values more than sensitivity as these measures are interpreted in signal detection theory.

Kintsch, W. An experimental analysis of single stimulus tests and multiple-choice tests of recognition memory. Journal of Experimental Psychology, 1968, 76, 1-6.

Participants were shown five 4-letter combinations and were tested for recognition on one of them after a 20 sec delay. Either single item tests of 2, 4, or 8 alternative forced-choice tests were given. The single item tests revealed strong response biases. Performance on the multiple choice tests decreased as a function of the number of response alternatives. MOCs were constructed from participant's confidence ratings on the single item tests, and TSD was used to predict performance successfully on multiple-choice tests.

Donaldson, W. & Murdock, B. B., Jr. Criterion change in continuous recognition memory. Journal of Experimental Psychology, 1968, 76, 325-330.

TSD was applied to a continuous short-term recognition memory task for 3-digit numbers. Participants made binary (yes-no) decisions as to whether an item had previously appeared in a deck of stimulus items and provided a confidence rating. Sensitivity (d') was estimated from the point of intersection of the ROC curve with the negative diagonal in normal-normal coordinates and was seen to decrease as the number of intervening stimuli increased. An attempt was made to explain the lack of a steady state condition, i.e. the FA rate did not asymptote even after an extensive number of trials. In contrast to previous explanations of such a result, Donaldson and Murdock attribute the increasing FA rate to a criterion shift in the direction of leniency rather than a decrease in d' (increased proactive inhibition).

Levy, B. A. & Murdock, B. B., Jr. The effects of delayed auditory feedback and intralist similarity in short-term memory. Journal of Verbal Learning and Verbal Behavior, 1968, 7, 887-894.

Three studies are reported in which participants heard items under delayed or immediate auditory feedback. (DAF, IAF). In experiment 1, associately similar lists were used in an attempt to limit the use of associative cues, thus forcing the observers to rely on acoustic cues. The hypothesized decrement for recall under DAF as compared to LAF was not found. In Experiment 2, acoustically similar lists of words were used with two presentation rates. Acoustic similarity had an adverse effect on recall in PM. Presentation rate was an important variable. only in SM. Application ot TSD measures to confidence ratings in experiment 2 yielded inconclusive results. Experiment 3 separated visual and acoustic similarity by using letters; again, the acoustic decrement at recall was found. (Visual similarity had no effect). A DAF effect was found in neither Experiment 2 or 3. A TSD analysis of Experiment 3 showed d' to be higher for acoustically similar than for visually similar or neutral material. It is as if observers set a stricter criterion for acceptance of an acoustic item. Thus, the acoustic effect seems to be due to response bias, not lower sensitivity.

Klatzky, R.L. & Loftus, G.R. Recognition memory as influenced by number of reinforcements and type of test. Psychonomic Science, 1969, 16, 302-303.

The authors hypothesize that the sensitivity parameter, d', should be affected only by those experimental variables which increase or decrease an observers familiarity with the studied stimuli (e.g., the number of study presentations of stimuli). d' should, on the other hand, be unaffected by type of recognition test used. CVC lists were presented to observers; members of the list were reinforced 1, 2, or 3 times and 4 types of test were used: Yes-no (1) and forced-choice tests (3) in which the observer was shown 2,4, or 6 words, only one of which was presented in the study list. Hit rate and probability of a correct response increased on all tests with number of study-word presentations and, for forced choice tests, decreased as the number of distractors increased. When probabilities were converted to d' measures it was no longer possible to uphold the hypothesis that d' remains constant as the type of test is varied. It was seen that the TSD model became increasingly inaccurate as the number of reinforcements increased; with three reinforcements, it was not possible to represent sensitivity by a single d' value which held up varying types of test.

Suboski, M.D. & Khosla, S. UCS intensity and instructional set in classical eyelid conditioning: Discrimination conditioning and signal detection analysis. Canadian Journal of Psychology, 1969, 23, 389-401.

The role of motiviation in classical discrimination eyelid conditioning is investigated. UCSs of two intensities and three instructional sets (inhibitory, neutral and facilitory of CR) were used. Although the results were ambiguous, they suggest that instructional set affected a change in response bias but not in discriminability (as measured by TSD). The more intense UCS seemed to produce an increase in d' without effecting response bias.

Banks, W.P. Criterion change and response competition in unlearning. Journal of Experimental Psychology, 1969, 82, 216-223.

The extinction hypothesis is retroactive inhibition (RI) was evaluated in two experiments using the A-B, A-C paired associates paradigm. In Experiment I, modified-modified free recall (MMFR) was augmented with confidence ratings so that original learning (OL) strength or d' could be assessed at two levels of interference (2 or 20 trials of interpolated learning, IL). The OL d' was the same for both interference conditions, but OL response criteria (beta) became more restrictive after 20 trials of IL. Three levels of monetary pay-off were administered at recall and had no effect on emission of correct responses. In Experiment II, observers were forced to respond with at least a guess about every OL and IL response in MMFR and exhibited less RI when so forced. It was concluded, contrary to the extinction hypothesis, that interference changes OL criterion not strength, but that this criterion change is itself a consequence of generalized response competition.

Donaldson, W. & Glathe, H. Recognition memory for item and order information. Journal of Experimental Psychology, 1969, 82, 557-560.

A short-term recognition memory task was designed to provide signal detection measures of the retention of both the items presented and the order in which the items occurred. After being presented with a target series of 5 digits followed by an intervening series of 8 digits, observers were given either a single digit or pair of digits as a probe. Presentation: of a single digit involved a yes-no decision as to whether it had appeared in the target series; presentation of a digit pair involved a decision as to whether they had been presented in the same or reverse order in the target series. Both responses were followed by a confidence rating on a 5-point scale, ROC curves were drawn,with d' calculated from the point of intersection of the ROC with the negative diagonal. Curves for both item and order information were smoothly changing, continuous funtions resulting from underlying overlapping distributions. An adequate description of the retention of order information appears not to require an assuption of probabilistic incrementations based on attention to only part of that information.

Allen, L. R. & Garton, R.F. Detection and criterion change associated with different text contexts in recognition memory. Preception & Psychophysics, 1969, 6, 1-4

Observers made yes-no detection responses for three different recognition series containing equal number of physics words (PW) and common words (CW) imbedded in varing proportions of PW and CW noise items. Both physics and arts observers found PWs (rare words) easier than CWs, although judgements varied according to the properties of the recognition sequences.

From the results on d' and beta the authors conclude that observers adopt a conservative and probabilistic strategy for the recognition task as a whole, rather than utilizing different strategies for PWs and CWs where these would result in superior overall performance.

Wickelgren, W.A. Associative strength theory of recognition memory for pitch. Journal of Mathematical Psychology, 1969, 6, 13-61.

Recognition memory for pitch was studied by means of a delayed comparison task, with the standard and comparison tones separated by a variable delay interval. The obtained ROCs suggest the existence of an unsigned "familiarity" or "similarity" dimension, in addition to the signed pitch difference dimension. Observers relied on familiarity exclusively in the same-different judgements and used both dimensions in the higher-same-lower judgments. The nature of short-term and intermediate-term memory traces is discussed.

Lockhart, R.S. & Murdock, B.B.,Jr. "Memory and the theory of signal detection". Pyschological Bulletin, 1970, 74, 100-109.

A number of issues are raised concerning the identification of the sensory continuum, the decision axis, and the distinction between signal and noise. They suggest that the theory is not a theoretically neutral way of dealing with response bias.

Moss, S.M., Myers, J.L. & Filmore, T. Short-term recognition memory of tones. Perception & Psychophysics, 1970, 7, 369-373.

Latencies and confidence ratings were obtained for each judgment. TSD analysis showed rapid and consistent decreasing d's as a function of interstimulus interval. ROC functions generated by the latencies and the ratings produced comparable results. Response bias produced no consistent trends.

Light, L.L. & Carter-Sobell, L. Effects of changed sematic context on noun recognition memory. J. Verbal Learning and Verbal Behaviour, 1970, 9, 1-11

The effects of semantic context on noun recognition were investigated in three experiments. Changing the semantic reading of nouns at recognition depressed performance in all three experiments. The need for a model of recognition including both retrieval and decision processes was discussed.

Banks, W.P. Signal detection theory and human memory. Psychological Bulletin, 1970, 74, 81-99.

Some applications of signal detection theory in the study of memorial processes are critically reviewed in four categories: a) uses of TSD to scale memory strength, b) use of TSD in criterion interpretations of data that seem to indicate forgetting, c) attempts at using TSD to determine the form of trace storage and to settle the question of all-or-none learning, and d) extensions of TSD to scale memory based discriminability in a finer analysis of retention.

Martin, E. & Melton, A.W. Meaningfulness and trigram recognition. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 126-135.

Continuous recognition after 1, 2, 6, 15, and 30 intervening events, for CCC and CVC trigrams of low, medium and high meaningfulness (M) was studied in the Shepard-Teghtsoonian (1961) paradigm. Correct recognition varied directly with M and inversely with number of intervening events. False recognition varied inversely with M and increased with total number of presentations. In order to measure confidence in correct recognitions, six response buttons were supplied; confidence in "old" items varied directly with M and inversely with the number of intervening events, but remained stable over the experimental session. Confidence in "new" judgments of new trigrams declined sharply over the experimental session. Evidence is presented to the effect that false recognition is largely item specific and not a matter of general decision criterion.

Allen, L.R. & Garton, R.F. Manipulation of study trials in recognition memory. Perception & Psychophysics, 1970, 7, 215-217.

Two experiments on recognition memory are reported in which the total stimulus duration was held constant while the number of presentations making up the total duration time was varied. The task was a word recognition task. Isomenmonics were constructed and revealed that although increasing total stimulus duration time improved recognition d_s a little, mutiple presentations yielded significantly higher d_s values than single or less frequent stimulus presentations (with total stimulus presentation time held constant). This finding is attributed to the influence of more frequent experimenter feedback in the multiple presentation conditions. Experimenter feedback in the multiple presentation conditions. Experimenter feedback was thus more effective than observers own rehearsal strategies in improving recognition memory. Theoretical explanations are considered in the light of models proposed by Norman and by Miller, Galanter, and Pribram.

Moss, S.M., Myers, J.L. & Filmore, T. Short-term recognition memory of tones. Perception & Psychophysics, 1970, 7, 369-373.

Observers judged whether two temporally sequenced tones (ISI= 0.5, 2.0, or 8.0 sec) were "same" or "different". Latencies and confidence ratios were obtained for each judgment. TSD analysis indicated consistent and rapidly decreasing d's (measures of memory strength) as a function of ISI. ROC curves generated from latencies and ratings produced comparable results. Response bias, as indicated by the differences in the latencies between "same" and "different" judgments, did not produce consistent trends.

Brown, J. & Routh D.A. Recognition assessed by d' and by a nonparametric alternative (the A-index) as a function of the number of choices. Quarterly Journal of Experimantal Psychology, 1970, 22, 707-719.

In order to approximate freedom from restrictive assumptions and facilitate psychological interpretation, the A-index (based on the proportion of wrong choices rejected in a multichoice test, as revealed by the number of choices required to select correct choice) was used as a measure of recognition performance. Two experiments on the recognition of words-in-noise were conducted. The first had 3, 5, 8, or 16 alternatives typed on a card which was displayed to the listener during the presentation of a word. On measures of both d' and the A-indes, 5, 8, and 16 choice recognition did not differ significantly, while 3 choice recognition was slightly, but significantly superior. The second experiment concerned the effect of delaying the display of the card until 2 sec after presentation; no evidence for any effect was found. In both experiments, there was suggestive but not conclusive evidence that the d' measure tended to overestimate recognition accuracy.

White, M.J. Signal detection analysis of laterality differences: Some preliminary data, free of recall and report-sequence characteristics. Journal of Experimental Psychology, 1970, 83, 174-176.

Observers were shown half-field visual displays of letters at 50 msec, and were required a) to decide whether or not a probe letter was in each trial display and b) to rate the decision on a 5-point confidence scale from "sure guess" to "positive". No appreciable differences in sensitivity, d_s were observed between the left and right hemishpere information displays. Misses, however, were related to element position. Fewer misses of the signal letter occurred as the distance from central fixation decreased. Results suggest that laterality differences observed with multiple-element displays at superthreshold exposures are more memory/learning dependent than perception dependent.

Hochouse, L. Correct response discrimination as a function of multiple recognition choices: Effect of guessing on Type II d'. Journal of Experimental Psychology, 1970, 84, 458-461.

A "probe" paired associates was used to provide a basis for applying the Type II index measures the ability to indentify correct responses.

Observers were presented with six stimulus pairs, 2, 4, or 6 response alternatives (one of which was from the original list) and were asked to choose the previously presented alternative (forced choice), along with R or W, a two point confidence rating on a "right-wrong" dimension. Type II d' and beta (bias) values were computed, based on hit and FA rates. d' showed typical variability. Unlike the usual results for recall memory, variations in d' matched changes in probability correct. Frequent correct guesses were seen to lower response discrimination capability. For choice conditions, d' increased as incorrect recognition alternatives were added. Under other conditions, (serial position, meaningfulness) values of d' showed the expected direct relationship with P(C).

Schulman, A.I. & Lovelace, E.A. Recognition memory for words presented at a slow or rapid rate. Psychonomic Science, 1970, 21, 99-100.

The authors criticize previous recognition studies for having overlooked the possible effect of study presentation rate. Frequent and infrequent English words were presented at two rates, slow and fast. During the recognition task, observers responded by using six point rating scale. d_s, the index of discriminability, was about 30% less after fast presentations than after slow, for both common and rare words. Recognition was better for rare words than for common words. The fast presentation rate also reduced individual differences, in sum, the fast rate seemed to curtail elaborate and idiosyncratic information processing.

Massaro, D.W. Forgetting: Interference of decay? Journal of Experimental Psychology, 1970, 83, 238-243.

Observers were asked to judge a comparison tone as "same" or "different" in pitch relative to a standard. The time between comparison and standard stimulus was varied, as well as the number of "interfering" tones between standard and comparison stimulus. ROCs were constructed which showed that both the duration of the interval between standard and comparison tones as well as the number of interfering tones affected recognition d'.

Raser, G.A. Meaningfulness and signal detection theory in immediate paired-associate recognition. Journal of Experimental Psychology 1970, 84, 173-175.

Observers were shown lists of six paired associates made up of the four combinations of high- and low- meaningfulness (m) CVC-trigrams. Immediately after each list, one of the six pairs was probed for recognition. Two measures of performance were used: 1) a yes-no response weighted for confidence (99 = definitely old); 2) the d' (sensitivity) measure of TSD. Standardized normal deviate scores were used. Observers responses from the 99 point scale were first transformed to normal deviate scores and then each observer's scores were combined and analyzed separately for m effects and serial positive effects. Normality and equal variance in the underlying distributions existed. Performance was superior for high-high m pairs, using both measures. Response bias shifts toward laxness were also found for high-m pairs. Serial position effects were obtained with a pronounced recency effect using both measures; response bias changes correlated with serial position were also found.

Bernbach, H. A. & Bower, G. H. Confidence ratings in continuous paired-associate learning. Psychonomic Science, 1970, 21, 252-253.

The purpose of the experiment was to investigate the relationship between confidence judgments and recall probability in the continuous PA learning task. Confidence ratings ranging from 1-4 (least to highest confidence) were collected for consonant bigram-consonant items presented three times each. As expected, both response probability and the mean confidence ratings increased with presentations; the latter result was attributed to a criterion shift. Analysis of Type II operating characteristics showed no difference in the discriminability of correct responses from errors after 1 vs. 2 reinforcements. No effect of meaningfulness of the S-R pair on recall probability was found.

Clark, W. C. & Greenberg, D. B. Effects of stress, knowledge of results, and proactive inhibition on verbal recognition memory (d') and response criterion (Lx). Journal of Personality & Social Psychology, 1971, 17, 42-47.

Four groups of participants were run: stressed/unstressed, with (KR) or without (NK) knowledge of results. Stress was induced by instructing the participants that the number of correct identification in the CVC trigram recognition task was related to intelligence. Three recognition test sequences were run, each with a different set of "new" trigrams. For the participants without knowledge of results, stress produced a decrement in d' over trials. The non-stressed group, however, incremented their d' over trials. Similarly, Lx decreased over trials for the stressed group, but increased for the non-stressed group.

The trial by stress interactions are discussed in terms of the effects of drive level on proactive inhibition. On the other hand, knowledge of results produced lower d's over all trials compared to the no knowledge condition, but d' increased over trials. For the KR groups there was little effect of stress. The lower d's of this group are attributed to criterion variability induced by the experimenter feedback. Finally, both stress and KR produced anxiety (as measured on the Zuckerman test), and groups in those conditions set the lowest criterion levels. Thus anxiety seemed to promote risk-taking behavior.

Barr-Brown, M. & White, M. J. Sex differences in recognition memory. Psychonomic Science, 1971, 25, 75-76.

The authors tested 16 year old males and females on a recognition memory task by showing participants a list of 50 "old" stimulus words, followed by a list of 100 randomly-mixed "old" and "new" stimuli. Participants indicated decision confidence on a 6-point rating scale from "old-positive" to "new-positive". The index of discriminability, d_s, was calculated for each participant from the cumulative probability distributions extracted from the confidence rating data. No difference in discriminability between males and females was found. The authors suggest that previous work showing sex differences (in contradictory directions) in recognition memory should be better interpreted as showing uncontrolled response criteria differences.

Zerdy, G. A. Incidental retention of recurring words presented during auditory monitoring tasks. Journal of Experimental Psychology, 1971, 88, 82-89.

This experiment makes use of the area under memory operating characteristics obtained under different experimental conditions in a 5 point category rating procedure to examine incidental retention. The major finding is that listening for semantically (categorically) defined target words leads to greater incidental retention than does listening for a single target word.

Reaction Time

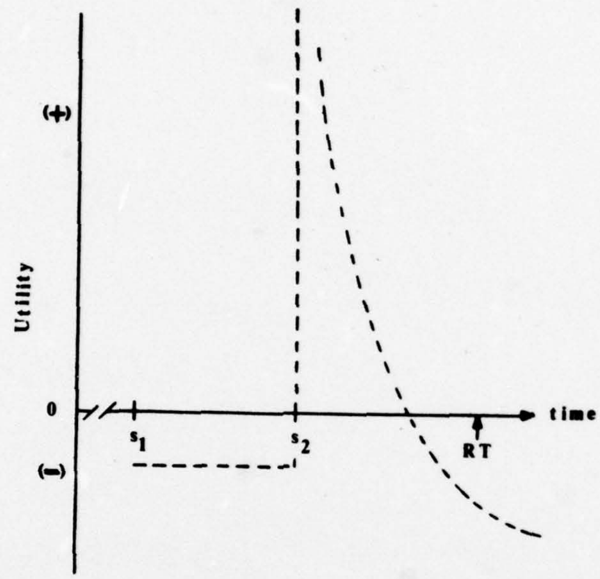
Close to the classical psychophysics is the topic of reaction time. As we remarked previously, the analysis of detection and discrimination data has always been closely associated with temporal effects. The interpretation of the reaction time as an indicator of response strength is the complement of the notion of temporal passage as the primitive source of memorial and perceptual deterioration. The interpretation of discrimination and identification data as based upon some timing mechanism in the neural system is fairly straight forward and transparent. But the interpretation of response latencies as a transform of the decision process (while obvious on its face) represents a puzzle in theoretical analysis. The abstracts that follow provide the flavor of interpretations by decision theoretic mechanisms. Also we intend them to represent the potentiality for theoretical analysis by decisional concepts.

The central difficulty in the applicability of decision theory to reaction time is the plausible notion that the reaction time itself is not a "voluntary" act, but represents the involuntary playing out of neural pre-programming. Consequently it is not intrinsically analyzable as a decision process. However, evidence in support of a decision theoretic analysis of reaction time can be found as early as 1922 in an experiment by Johanson, who showed that the simple RT was affected by the consequences of the reaction. When a participant was informed of his or her previous reaction, the distribution of reaction times was significantly shorter than that produced by normal instructions. Furthermore when a slow reaction was punished by an electric shock, the distribution of reaction time was again shifted significantly in the direction of shorter times. This result suggests that the reaction time is indeed volitional in the sense that it is controlled by the consequences of the event, but as many since Exner (1873) have argued, "everyone who performs this RT experiment, ...is struck by the little control he has of his movements when the task is to execute them as quickly as possible. ......the reaction is involuntary, i.e., no new will impulse is needed after the entrance of the stimulus in order that the reaction shall follow."

For an appropriate decision theoretic analysis of the reaction time experiment we must represent the experiment in a way rather unique in comparison to the classical presentation. Every reaction time experiment in which only a single stimulus is to be responded to, a so-called _simple reaction time_, as distinct from a discrimination reaction time in which more than a single stimulus may be presented from trial to trial, contains two stimuli and a response on each trial. Most often the first stimulus is explicit and is usually called the _warning signal_. Sometimes, of course, simple reaction time experiments are performed in which the warning signal is implicit, i.e., it may be merely the termination of a previous trial. But implicit or explicit, a warning signal of some kind is always present. To simplify discussion, we shall call this stimulus s_1. After s_1 occurs, an interval of time elapses that was classically named the _foreperiod_. This interval is terminated by the occurrence of a second stimulus (usually called the _stimulus_, or signal). We shall call the second stimulus on each trial s_2.

In the classical reaction time experiment the instructions tell the participant what the experimenter expects them to do. Normally this consists of assigning differential values to the participant's temporal behavior by the experimenter and communicating what these values are to the participant via some implicit pay-off function. By interpreting the reaction time experiment as a decision theoretic process we can make this pay-off function explicit by plotting the value of a response for a given time as a function of time since the onset of s_2. Figure 4 shows an example of such a pay-off that conforms to the classical instruction that the participant is to respond as rapidly as possible in order to obtain a positive pay-off. Notice that in this figure long reactions are fined more heavily than anticipatory responses. Insofar as this pay-off represents constraints on the participant's performance we expect the participant would show more anticipatory responses than long ones. Unpublished experiments from our laboratory support this observation.

Figure 4



The first abstract in this section describes an early experiment from our laboratory in which the analysis described above was applied to the reaction time experiment. Indeed, this experiment uses the analysis not only for the reaction time experiment itself, but also to help to conceptualize the time estimation experiment. At that time we believed time estimation to be intrinsic to the reaction time problem. The reason for this is that if a pay-off function defined an appropriate reaction at a time longer than the average simple reaction time with implicit pay-offs, then it must be the case that the observer had to time estimate in order to "wait-out" the period during which the pay-off is low. Whether this interpretation can be supported given some of our more recent data (cf Columbia University, Psychophysics Laboratory Report PLR-35) is open to question. We should also note that among the authors represented in the abstracts that follow are those exemplified by Katz (1970) who believe that the reaction time is in some sense a more "behavioristic" response than, say, a verbal justment. Consequently, searching for connections between the numerical values of verbal judgments and reaction times through some theoretical structure such as TSD represents an inviting research enterprise. Finally, we remark on the relevance of the decision theoretic analysis of reaction time to deal with the classical question of the speed-accuracy trade-off. This is an issue that is central to topics in psychometrics, and in human engineering and performance measurement. We represent it here by Henderson's (1970) paper which attempts to come to grips with some of these questions. Naturally, the author does not press the theory, and consequently is able to demonstrate that the statistics of the theory are adequate for the description of the phenomenon. Further applications of the model in this context will be seen in subsequent sections.

Snodgrass, J. G., Luce, R. D., & Galanter, E. Some experiments on simple and choice reaction time. Journal Experimental Psychology, 1967, 75, 1-17.

4 experiments in simple and choice reaction time are reported. Experiment I examines the effect of monetary pay-offs on the accuracy and variability of time estimation. Experiment II examines the effect of mvoing the position of a narrow pay-off band along the time axis on the variability of observed RTs. This appears to alter the proportion of bona fide reactions (of low variability) and of more variable time estimates of the fore-period duration. Experiment III assesses the factors responsible for the increased mean and variability of choice compared with the simple RT distributions. It is concluded that information processing rather than motor factors is the main source of the difference between simple and choice RT. Experiment IV studies the relation between correct and error RTs as a function of variations in stimulus probability in a 2-choice RT paradigm. Finally, several theoretical distributions are evaluated by the empirical distributions obtained in Experiment II, III, and IV; none seem wholly satisfactory, but those with rounded modes and an exponential tail (e.g., the gamma) are clearly not adequate.

Sekuler, R. W. Choice times and detection with visual backward masking. Canadian Journal of Psychology, 1966, 20, 34-42.

Participants were required to make yes-no judgments as to whether a test stripe had appeared in the first falsh of a two flash masking sequence. The test stripe was present only on half the trials. Participants performed under four different pay-off matrices, and two different signal durations were used. Choice response times were measured and revealed that for "yes" judgments, choice times for incorrect responses (FAs) exceeded those of correct responses (hits), whereas for "no" judgments, there was no difference between correct and incorrect responses. Pay-off matrices also affected choice response times. ROCs revealed both an increase in detectability with increased signal duration as well as criterion shifts reflecting the different pay-off matrices. These choice response times and detection data are considered in a discussion of the observer's decision strategy in this experiment.

John, I. D. A statistical decision theory of simple reaction time. Australian Journal of Psychology, 1967, 19, 27-34.

The theory is based on the view that simple reactions are prepared responses elicited by the triggering of a response release mechanism which can be preset by the observer, and treats the observer's setting of his mechanism as a statistical decision process. The theory is applied with some success to findings concerning the stimulus intensity-RT relationship, motor and sensory preparation, the distribution of RTs, the effect of forewarning signals, the Donder's a- and c-type reactions and so-called psychological refractoriness. It is suggested that the theory may provide a basis for a more adequate conceptual treatment of choice RT. Notice that this study accepts Exner's notion that RT is involuntary, and assigns the decision mechanism (the voluntary component) to the pre-reaction period.

Gescheider, G. A., Wright, J. H., & Evans, M. B. Reaction time in the detection of vibrotactile signals. Journal Experimental Psychology, 1968, 77, 501-504.

A family of ROC curves describing the effects of signal probability on response probability for each signal intensity was interpreted as support of the applicability of signal detection theory to the judgment of cutaneous stimuli. Manipulation of signal intensity and signal probability also led to changes in reaction time for saying "yes" and for saying "no" when the signal was present and when the signal was absent, supporting the conclusion that observer's decision time was longer the closer on the sensation continuum a particular sensory observation was to his or her criterion.

This is a direct implication of the notion that decision time represents "confusibility" or other sensory-perceptual effects.

Katz, L. A comparison of type II operating characteristics derived from confidence ratings and from latencies. Perception & Psychophysics, 1970, 8, 65-68.

Participants were asked to make same-different judgments of visual stimuli and to assign one of three confidence ratings to their responses. Reaction time was measured from stimulus onset to the occurrence of the same-different judgment. Operating characteristics plotted the probability of category i given a correct response vs. the probability of category i given an incorrect response. The response latencies were divided into four categories, and the proportions of correct and incorrect response latencies were computed, yielding a second 3-point operating characteristic.

Both kinds of operating characteristics appropriately reflected differences in task difficulty (in the differences between the isosensitivity functions). There also appeared to be a reasonable correspondance between the two OCs. The authors suggest the use of latency data in place of confidence ratings.

This experiment demonstrates the use of latency data as a metric of difficulty, that is obtainable without subject awareness. As such, it presumes the involuntary nature of the RT.

Henderson, L. Simple reaction time, statistical decision theory and the speed-slowness tradeoff. Psychonomic Science, 1970, 21, 323-324.

The decision processes in a simple reaction time task were investigated by presenting a signal at one of three intensities with probability 0.75. Participants were instructed to react as quickly as possible ("risky" condition), or as quickly as was compatible with the avoidance of all responses on catch trials ("cautious" condition). Three predictions of statistical decision theory were born out: 1) reaction time varied inversely with signal intensity, 2) instructions leading to different criterion placements produced differences in reaction time, 3) a high criterion placement (as in the "cautious" condition) resulted in a proportionally greater lengthening of the reaction time to weak signal intensities than a low criterion placement. The "risky" criterion position did not, however, lead to many false positive or anticipatory responses, so speed was not gained at the cost of errors. This is a clear demonstration that RT may be compounded of both bias and sensitivity effects.

Perception and Psychophysics

Topics in perception were always thought to be illuminated if not explained by psychophysical data. In addition psychophysical experiments have often asked the basic perceptual questions about the limits and constraints on the sensory side of the perception process. Thus the growth of decision theory in the study of psychophysical functions constitutes a natural development, its applications in areas more "perceptual," depend upon the philosophical stance of the investigator. Topics in perception have consistently divided theorists into two major opposing camps: the nativists, gestalt psychologists, holists, or organization theorists on the one side; and empiricists, learning theorists, choice theorists, and associationists on the other. The central issue on which the two points of view divide is whether perceptual events as a basis for cognition are intrinsic to the structural constraints of the organism and the the physical constraints of the world--the gestalt position--or are the result of accidental contingencies and highly probable consequences that arise in a relatively universal way among all members of a given population in their commerce with the physical world based on the associative structures of their neural tissue--the associationist position. The argument consequently is a genetic argument. How do the observable perceptual organizations develop?

The advent of two-parameter decision theory in no way resolves the primary nativist-empiricist controversy. Indeed it does not speak to the question, although we have suggested elsewhere that the associationists' doctrine may in fact be representable as a pure decision theoretic problem. This view, which has never been considered seriously, is most forcefully enunciated in the following quotation:

> "But in choice theory, stimuli are simply discriminable events. Any organization that the stimuli possess must be based upon connections of discrimination, or orderings over manipulable variables of the stimuli. The kind of rebuttal that choice theory gives to these ideas is the proposal that, for the human adult, the organiza-

tions may exist, but such organizations are simply an elaborate construction out of basic stimulus elements that results from having learned certain things. We now merely project this acquired knowledge upon the environment. Thus, the choice theorist believes that the perceptual world, the world that we see, is composed of two parts. First, the discriminative elements that we have called stimuli, and second a mental operation imposed on stimuli as a result of prior knowledge. The prior knowledge that the choice theorist uses to get some organization onto the stimuli was called, classically the apperceptive mass. Although it was thought of by the classical psychologist as an image of one kind or another, many modern choice theorists presume that the apperceptive mass is some form of bias on previously learned responses. These responses and their biases, when made in the presence of certain stimuli, are the only evidence of an organization of the stimuli. In essence, the choice theorist argues that the visual world is constructed from discriminative components held together, or organized, as a result of our having learned certain responses. These responses, when they were made to these particular discriminative stimuli in the past, yielded outcomes of value which led to biases that now suggest an organization of the stimuli. But the stimuli are as disconnected as ever. It is only what is said or done about them that leads us to assume they are organized" (Galanter, 1966).

Such a strung-out view of perceptual processes as merely response bias is hard to swallow. On the other hand, it is not inconceivable that many of the perceptual puzzles--the illusions for example-may represent the effects of biasing variables in the perceptual system. Such biases may function to provide compensation for the flexible and deformable energy ensembles at our receptors. Thus can the perceptual world be formed into coherent and continuous stretches and expanses as the disjunct glimpses and overheard phrases become assembled into the nicely filled up and infinitely extendable world of sight and sound.

In the abstracts that follow we begin by reviewing reports in which two-parameter decision theories constitute the basis for new psychophysical experimental designs, and for the generation of data not previously encompassed by classical psychophysical theories. From this section we move on to a consideration of problems that have most usually been construed as perceptual. These perceptual problems are seen as containing in part issues that relate to decision theory. The final two abstracts consider the application of decision theory to classical problems in learning, slightly differently than they are applied by the theorists and experimentalists in the field of memory.

Carterette, E. C. & Cole, M. Comparison of the receiver operating characteristics for messages received by ear and by eye. Journal of the Acoustical Society of America, 1962, 34, 172-178.

Participants were asked to learn a list of words and were then tested for recognition. On the test trials, the words were presented either visually (by a tachistoscope) or auditorily (embedded in white noise). Participants responded by recording the word and providing a confidence rating of their response. For three different levels of task difficulty (as measured by the mean proportion of correct responding), the results indicate:

1) similar distributions of response categories were obtained for the two modalities.

2) probabilities of a correct recognition within a response category were similar for visual and auditory presentations.

3) when the cumulative probability of a jth category response given correct recognition was plotted against the cumulative probability of the jth category response given incorrect recognition, the ROCs for the two modalities appeared very similar.

The results support and extend the generality of the statistical decision making theory of the observer.

Lee, W. Choosing among confusably distributed stimuli with specified likelihood ratios. Perceptual & Motor Skills, 1963, 16, 445-467.

Choice behavior is investigated with the use of specified distributions, distribution locations, separations, dispersions, and likelihood ratios. A distributed stimulus consists of a set of dots sampled from a bivariate normal distribution and placed on separate cards. Cards with dots from two or three distributions are mixed together and shown one by one to observers who had to choose the distribution each dot derived from and give a confidence rating. Two theoretical choice models were evaluated:

1) statistical decision theory

2) a probability micromatching model according to which observer made his or her choices in the proportion defined by the likelihood ratio. (The second model suggests performance at a level below that of maximizing percept correct.)

Related findings: Confidence was not always monotonic with likelihood. The perceived distance between distributions was about twice the true distance.

Emmerich, D. S. ROCs obtained with two signal intensities presented in random order, and a comparison between yes/no and rating ROCs. Perception & Psychophysics, 1968, 3, 35-40.

Two experiments are reported. In the first one, the effect upon ROCs of mixing auditory signals of two different intensities within the same block of trials is investigated. Detection data were obtained by means of a twenty-point rating scale. The ROCs obtained when the signals of differing intensity were mixed in blocks of trails were found to be similar to those obtained when only one signal intensity was presented in a block of trials. In the second experiment, instructions to the observer maintained criteria of "strick", "medium" or "lax", and a simple yes-no procedure was employed. The data points in this experiment approximated the ROCs obtained from the same observers with the rating procedure.

Shipley, E. G. A signal detection theory analysis of a category judgment experiment. Perception & Psychophysics, 1970, 7, 38-42.

Observers rated the loudness of above threshold stimuli on either a three, five, or nine point category scale. Five or eight stimulus intensity levels were used, and biased (toward low stimulus levels) and unbiased presentation frequencies were employed ROC curves were constructed by plotting, for a given pair of stimulus intensities, the probability of a response category given the stronger of two signal intensities as hit rate, against the probability of that response category given the weaker of the two signal intensities as false alarm rate. The linearity of the rating data in normal-normal coordinates supported the application of TSD. It is shown that an increase in the number of possible response categories led to a decrease in discriminability (d'_e). This decrement in discriminability seemed due to an increase in criterion variance following an increase in the number of response categories. Also the slopes of the ROCs were consistently different from different stimulus pairs; stimulus variance was not constant nor did it increase with stimulus intensity. Both results call certain assumptions of TSD into question. The author suggests that stimulus variance is less for stimulus distributions on that part of the sensory continuum where internal observations are most frequent. Particularly the results from the biased presentation frequency condition support this suggestion.

Viehmeister, N. F. Intensity discrimination: Performance in three paradigms. Perception & Psychophysics, 1970, 8, 417-419.

Pure tone intensity discrimination is investigated in three experimental paradigms analyzable by TSD: a) Two alternative forced choice, b) Single interval rating with an intensity cue preceding each observation interval, and c) Single interval rating procedure without cue. No large difference was observed between performance in the cue and the non-cue condition (b & c). Sensitivity measures for the two alternative forced choice and the single interval tasks were related by a model which assumes that a listener uses the difference between the observed input and a stored referent as his or her decision variable; the stored referent can arise from a previous interval or from previous trials.

Eijkman, E. & Vendrik, J. H. Can a sensory system be specified by its internal noise? Journal of the Acoustical Society of America, 1965, 37, 1102-1109.

TSD is used to investigate the nature of the auditory and visual channels. From data on the detection of noiseless signals (auditory and visual) presented separately and simultaneously, a measure of the correlation between the internal noise present in auditory detection and the internal noise present in visual detection can be derived. If the internal noise of the two channels is correlated, these channels can be said to have something in common. Particular conclusions:

1) discrimination of intensity increments is specific to modality (internal noise not correlated for the two channels)

2) since discrimination of duration increments produced complete correlation between the internal noise of the two channels, a "duration center" is said to exist that serves to estimate the duration of both visual and auditory signals.

Brown, A. E. & Hopkins, H. K. Interaction of the auditory and visual sensory modalities. Journal of the Acoustical Society of America, 1967, 41, 1-6.

The authors define P'(D) as the optimal probability of (correct) detection given equal a priori probabilities of signal and noise, and equal costs for hits and misses.

$$P'(D) = 2 \int_{0}^{d'/2} f_n(x)\, dx.$$

The experimental results show that if participants are required to detect the presence of an auditory signal or the presence of a visual signal, then auditory and visual signals are chosen that yield identical P'(D) and participants were then required to detect either when both were presented. Proportions of correct detections in the bisensory stimulation condition were in close agreement with theoretical predictions derived from a model of response probability summation between the two modalities. There was no apparent interaction between the visual and auditory sensory information processing systems.

Thijssen, J. M. & Vendrik, , A. J. H. Internal noise and transducer function in sensory detection experiments: Evaluation of psychometric curves and of ROC curves. Perception & Psychophysics, 1968, 3, 387-400.

TSD is used to investigate the discrimination of stimuli without external noise. Two models are developed to assess the character of the "sensory transducer" (which translates the stimulus into neural activity) and the nature of the internal (neural) noise. ROC curves and psychometric functions are interpreted in the light of these two models, and visual as well as auditory experiments are presented. Results support one of the two models and indicate that the noise which limits auditory discrimination at low and moderate intensities is of an additive nature and has a Gaussian distribution. Visual discrimation is subject to additive noise at low intensity levels.

Murphy, E. H. & Venables, P. H. Ear asymmetry in the threshold of fusion of two clicks: A signal detection analysis. Quarterly Journal Experimental Psychology, 1970, 22, 288-300.

TSD reveals a significant ear asymmetric effect, which is accentuated when a burst of white noise is presented contralaterally with the clicks. Results are discussed with reference to differentiation of function of the cerebral hemispheres.

Efner, L. F. & Delaune, W. R. Detection of shift in biaural images: A rating method approach. Perception & Psychophysics, 1970, 8, 158-160.

TSD is applied to the study of auditory lateralization. Sensitivity to interaural intensity imbalances at three auditory frequencies is measured using right and left from center lateralizations, as well as practiced and unpracticed observers. The primary conclusion is that the rating procedure with TSD analysis is a promising approach to the study of auditory lateralization.

The sensitivity measure used was d_s. The following notational equivalence (according to Green & Swets) seems to hold $d_e' = (d'_e)^{1/2} = d_s$. All these determine sensitivity at the point of intersection of the ROC with the negative diagonal in normal-normal coordinates.

The authors also report the slopes of the ROCs from (from 0.6 to 1.2 predominantly). They say that "d_s is determined relatively independently of criterion and a measure can be obtained that may at least partially indicate changes in criterion (slope of the best fit line)". What they mean by this is not at all clear.

Yost, W. A., Turner, R. & Bergeot, B. Comparison among four psychophysical procedure used in lateralization. Perception & Psychophysics, 1974, 15, 483-487.

Four psychophysical procedures (two 1- and two 2-observation interval tasks) were used to measure the detectability of interaural temporal differences in the presentation of a 250 Hz tone. Although TSD predicts the same d' for each kind of task, different measures were obtained. However, the data show that performance in the two 1-observation interval tasks is similar, as is performance in the two 2-observation interval tasks. Based on observers' reports, the single observation interval condition is interpreted as requiring detection of lateral position whereas the two interval observation task is interpreted as requiring detection of lateral movement.

Soderquist, D. R. Frequency analysis and the critical band. Psychonomic Science, 1970, 21, 117-119.

Musicians and non-musicians were presented with two complex auditory (12 components) stimuli and on each trial with two pure tone comparisons. A forced choice procedure required an observer to choose which of two comparison signals coincided in frequency with one of the components of the complex stimulus. The independent variable was the component number, the dependent variable was P(C). Results indicate that non-musicians are inferior to musicians in their ability to analyze complex wave forms. It is suggested that musicians possess critical bands which are rectangular in shape and approximately 20% narrower in width than published values.

Creelman, C.D. Human discrimination of auditory duration. Journal of the Acoustical Society of America, 1962, 34, 582-593.

A 2 AFC procedure was used to determine how human observers discriminate between durations of a 1000 Hz tone embedded in white noise. d' was plotted as a function of signal voltage, as a function of base duration T, and as a function of duration increment, T. A decision theoretic model is developed, based on a counting mechanism which operates on impulses generated over the relevant durations. The decision processes underlying the model are presented as a general theory of duration discrimination.

Gross, H. A., Boyer, W. N., & Guyot, G. W. Determination of a DL using two point tactual stimuli: A signal detection approach. Psychonomic Science, 1970, 21, 198-199.

The theory of signal detection was used to determine a difference limen for two point tactile stimuli to the dorsal forearm. Participants made same-different judgments of stimulus pairs that consisted of a standard stimulus paired with itself or with one of three other stimuli each differing in length from the standard. A "hit" was a report of "different" when the stimuli were indeed different, a "false alarm" was a report of "different" when the stimuli were the same. There were considerable individual differences, but overall a stimulus of 6 mm in excess of the standard was required to produce performance reliably different from chance. (A subsequent study by Boyer, et al., Psychonomic Science, 1970, 21, 195-196 showed that the DL for two point tactile stimuli was larger on the back than on the dorsal forearm. Again, theory of signal detection methods were used.)

Swets, J. A., Markowitz, J., & Franzen, O. Vibrotactile signal detection. Perception & Psychophysics, 1969, 6, 83-88.

TSD is applied to the determination of vibrotactile sensitivity, using sinusoidal vibration of a disc applied to the fingertip. ROC curves of the familiar form were obtained for both yes/no and rating response methods. Fairly consistent estimates of sensitivity were obtained in a second experiment using yes-no, rating, and forced choice procedures. The sensitivity indices examined were d' and d_e', based on Gaussian density functions; A, based on Rayleigh density functions; and the distribution-free indices P(A) and P(C). For each type of index, a tendency was observed for the forced-choice value to be lower than the yes-no and rating values. The authors conclude that TSD can reasonably be applied to the study of vibrotactile signal detection.

Although the values of A (assuming Rayleigh density functions) are not reported; the authors say "they are almost precisely the same picture given, by d' and d_c'". They also do not evaluate the merits of d' vs d_e', but lump them together in their discussion.

Gescheider, G. A., Barton, W. G., Cruce, M. R., Goldberg, J. H., & Greenspan, M. J. Effects of simultaneous auditory stimulation on the detection of tactile stimuli. Journal of Experimental Psychology, 1969, 81, 120-125.

The masking effects of auditory stimulation on the detection of tactile stimuli applied to the fingertip were investigated within the context of TSD. A 2 AFC procedure was employed and the results indicate that d' for the detection of brief tactile stimuli of four intensities decreased as the intensity of a simultaneous auditory click increased. In a second experiment, observers were run in a binary decision task, with p(S) = p(N) = .5. As in the first experiment, d' decreased as a function of the intensity of the auditory click. Additionally, observers' criterion increased as a function of click intensity. The authors urge the further application of TSD to the study of intermodality masking and discuss various physiological explanations of the present findings.

Semb, G. The detectability of the odor of butonol. Perception & Psychophysics, 1968, 4, 335-340.

Three experiments were conducted to measure human sensitivity to the odor of butonol. The application of TSD was supported in various ways. First, observers were able to adjust their response criterion in a modified method of constant stimuli procedure so as to meet a number of arbitrarily chosen experimentally imposed "thresholds". Furthermore, in a six point category rating procedure, various butonol concentrations each produced an isosensitivity function that plotted as a straight line with unit slope in normal-normal coordinates. The assumptions of normality and equal variance of the underlying distributions were thus supported. d' is shown to be related to signal strength by a power function with a slope of about .30, which suggests that the olfactory transducer compresses sensory input produced by weak concentrations of butonol.

Westendorf, D. H. & Fox, R. Binocular detection of positive and negative flashes. Perception & Psychophysics, 1974, 15, 61-65.

In a three-interval forced choice procedure, detection rates were measured under conditions where both eyes received positive flashes, both eyes received negative flashes, and one eye received a positive flash while the other received a negative flash. Predictions were derived from two models, one based on probability summation, the other on Green and Swets (1966) integration model (in this context:

$$(d' \text{ binocular} = (d'^2 \text{ left eye} + d'^2 \text{ right eye})^{1/2}).$$

When both eyes received the same kind of flash, detection rates were above those predicted by probability summation, with detection of positive flashes being approximately identical to that of negative flashes. On the other hand, the results of the detection of negative-positive pair flashes are in accord with the predictions based on probability summation models. It is suggested that positive and negative flashes are detected as though they were separate, independent events.

Lowe, G. Interval of time uncertainty in visual detection. Perception & Psychophysics, 1967, 2, 278-280.

Observers in a binary visual detection task were uncertain as to when a signal might occur within a given observation interval the duration of which was varied. Results indicate that longer observation intervals lead to larger false alarm rates and decrements in d'. However, the shortest interval duration (.375 sec) surprisingly did not produce the highest d'; rather that of .75 sec did.

Rollman, G. B. Detection models: Experimental tests with electrocutaneous stimuli. Perception & Psychophysics, 1969, 5, 377-380.

A rating scale procedure produced data on the detection of rectangular electrical pulses delivered to the skin. When hit rates were plotted against false alarm rates, the form of the obtained functions conformed to the predictions of TSD rather than to those of high threshold theory. A second experiment utilizing the four alternative forced choice paradigm determined the proportion of correct second guesses after an initial incorrect response. High threshold theory predicts that performance on second guesses cannot be better than chance, whereas TSD predicts better than chance performance (because an observer is supposedly able to rank his or her internal states in order of signal likelihood). The results support TSD. It is further determined that the variance of the noise distribution exceeded the variance of the signal + noise distribution.

Dorosh, M. E., Tong, J. E., & Boissoneault, D. R. White noise, instructions, and two-flash fusion with two signal detection procedures. Psychonomic Science, 1970, 20, 98-99.

This experiment compares a TSD analysis with a model based on the method of constant stimuli. Sensitivity and bias measures were computed according to each for an experiment on the detection of two flash fusion. Both sensitivity measures were unchanged by the introduction of white noise into the experiment and by changes in instruction. Instructions, on the other hand, produced differences in the bias measures of both models. TSD analysis was considered the more "sensitive" of the two models.

Doehrman, S. The effect of visual orientation undertainty in a simultaneous detection-recognition task. Perception & Psychophysics, 1974, 15, 519-523.

TSD is applied to the study of how the output of orientation-sensitive mechanisms in the visual system is processed by higher order mechanisms. Observers engaged in detecting and recognizing angular deviations of a line from a standard d'_e (see Green & Swets, 1966) was shown to increase with angular deviation. Data were collected for different amounts of stimulus uncertainty (1, 2, 8 possible orientations) and it was shown that d'_e did not decrease appreciably with uncertainty. It is suggested that observers are continuously examining the output of all orientation sensitive mechanisms, regardless of the number of potential stimuli.

Swets, J. A. & Birdsall, T. G. Deferred decision in human signal detection: A preliminary experiment. Perception & Psychophysics, 1967, 2, 15-28.

This study investigates decision dependent on successive observations. In the "deferred decision" condition, the observer in an auditory detection task is allowed to determine how many observations he or she will make before deciding whether or not a signal is present. A cost is established for each observation. The human observer appears capable of using the optimal process of cumulating sensory information over successive observations (through multiplication of likelihood ratios), but certain initial training procedures lead to less than optimal cumulation of sensory information. In particular, the training procedure requiring only binary choice (yes-no) was inferior in this respect to a training procedure that utilized the rate method. d' did not change with the number of intervals observed, but a certain decision bias was observed: for example a no-decision required, on the average, more observation intervals than a yes-decision, at two different signal probabilities.

Earle, D. C. & Lowe, G. Channel, temporal, and composite uncertainty in the detection and recognition of auditory and visual signals. Perception & Psychophysics, 1971, 9, 177-181.

In a 2 AFC detection task, an increase in temporal uncertainty produced a decrement in d'. This was the case in the detection of visual and auditory signals separately, as well as in the case of visual/auditory uncertainty. Visual/auditory uncertainty, in the absence of temporal uncertainty, produced an overall decrement in d' (auditory and visual) for one observer, and a decrement in the more detectable auditory signals with no change in visual sensitivity for other observers. It is suggested that observers employ a "compensation strategy" by which performance on less detectable signals is maintained at the expense of performance on te more detectable ones. Some recognition measures support this suggestion.

Erdelyi, M. H. REcovery of unavailable perceptual input. Canadian Journal Psychology, 1970, 1, 99-113.

Two experiments on the "recovery effect" are reported. In experiment 1, observers recall of a briefly flashed stimulus was tested before and after fantasy generation. Past fantasy recall was greater than prefantasy recall. It is suggested however that fantasy augments response rates rather than sensitivity to the stimulus trace. This was confirmed by a secondary experiment in which a recognition indicator with confidence ratings was employed. ROC functions were extracted allowing direct measure of pre and post fantasy sensitivity. No sensitivity increments were found, though fantasy affected confidence ratins and therefore, hit and false alarm rats.

Munsinger, H. & Gummerman, K. Simultaneous visual detection and recognition. Perception & Psychophysics, 1968, 3, 383-386.

A prediction is derived from Luce's two state threshold model which asserts that the probability of recognition in a simultaneous detection and recognition task decreases as the observer's false alram rate increases. The experiment required the visual detection and recognition of a vertical or horizontal bar. Criterion placement was manipulated by varying point pay-offs under one recognition pay-off matrix and eight detection pay-off matrices. ROCs plotted in double probability coordinates revealed linear relations between P(Hits) and P(False Alarms), although the slopes were below unity. In linear coordinates, the ROC curves were fitted by two straight line segments; the prediction from Luce's model was confirmed.

Parks, T.E. & Kellicutt, M. H. The probability-matching decision rule in the visual discrimination of order. Perception & Psychophysics, 1968, 3, 356-358.

This experiment investigates the underlying nature of the detection and discrimination process. In three experiments, observers were required to decide, on each trial, which of two spatially proximate, nearly simultaneous lights (S_1 and S_2) was illuminated first. When observers were repeatedly informed of the prior odds of S_1 (or S_2) being first, the probability of the response "S_1" ("S_2") matched the a priori probability. This was not the case when observers were infrequently reminded ofthe a priori probabilities. This effect is interpreted in the light of Atkinson's three state threshold theory, according to which the third "uncertain" state leads to matching of responses with a priori probabilities.

Creelman, C. D. & Donaldson, W. ROC curves for discrimination of linear extent. Journal of Experimental Psychology, 1968, 77, 514-516.

ROCs were obtained for the identification of one of two possible lines as the longer of the pair, for two different pairs. Two different monetary pay-offs were used, and the a priori signal probabilities ranged from .05 to .95. A priori probability did not effect discriminability, but only the response criterion. Similarly, different monetary awards affected criterion levels rather than discriminability. Although the results were compared to that of an ideal observer maximizing expected value, the authors suggest that the data are better fit (especially in the case of high signal probabilities) by a model which assumes that decision criteria are set to match response proportions to a priori stimulus probability.

Kinchla, R. A. & Allan, L. G. Visual movement perception: A comparison of sensitivity to vertical and horizontal movement. Perception & Psychophysics, 1970, 8, 399-405.

Observers were required to discriminate between four stimulus patterns: 1) a stimulus light S_o followed by a stimulus light in the position (stationary pattern) 2) S_o followed by a light .01 rad to the right of S_o 3) S_o followed by a light displaced downward .01 rad and 4) S_o followed by a light displaced .01 rad to the right and .01 downward. Interlight times ranged from .5 to 2 sec. The following conditional response proportions were computed: proportion of hits = the relative frequency of horizontal (vertical) movement reports given horizontal (vertical movement, and proportion of false = the relative frequency of horizontal (vertical) movement reports given no horizontal (vertical) movement. The authors develop a signal detection type model by which they estimate sensitivity to horizontal and vertical movement. No differential sensitivity for the two kinds of movement was observed. There were, however, idiosyncratic differences between observers' willingness to report one or the other kind of movement. Previous findings that differences between horizontal and vertical movement perception exist are attributed to response bias effects rather than to differential sensitivity.

Halpern, J. & Ulehla, S. Z. The effect of multiple responses and certainty estimates on the integration of visual information. Perception & Psychophysics, 1970, 7, 129-132.

This paper reports the results of two experiments on the discrimination of left vs. right tilt. A trial in the first experiment consisted of five stimulus presentations, in the second experiment a trial was a presentation of from one to five stimuli. Observers were required to respond with a binary lef/right decision, with or without certainty estimates, either after each stimulus presentation or at the end of a trial. The integration model of information within the TSD context predicts an improved d' for the later responses on multiple observation interval case than in the single interval case. The question is whether this improvement is predicted also for the n-th response, where in addition to multiple observation intervals one response occurs after each trial? Results showed theoretical predictions to be in excess of the actual improvements in d' observed as a function of response number. Although the presence of additional observation intervals *per se* facilitated performance in comparison to the single observation interval condition, the inclusion of certainty estimates and/or multiple responses actually produced lower d's than the single response conditions. These tilt discrimination results differ from other information integration results obtained in the areas of audition and conceptual discrimination. Certain *post hoc* explanations are considered, such as the complex nature of the response required on the part of observers.

Dodwell, P. C., STanding, L. G., & Thio, H. Are thresholds reduced by illusion? An attempt at replication. Quarterly Journal of Experimental Psychology, 1969, 21, 127-133.

Three experiments are reported in which attempts are made to replicate the finding that sensitivity for weight differences can be improved by altering the apparent weight of an object by means of the size-weight illusion. This finding had been established by the method of constant stimuli. The present authors present a TSD analysis of a discrimination experiment in which observers had to make "same" or "heavier"/ "lighter" judgments of comparison stimuli relative to a standard. On 50% of the trials the comparison stimulus equaled the standard. Proportion correct and numbers of hits and false alarms were virtually identical for large and small objects. The authors also failed to replicate the earlier finding using the classical method of constant stumuli.

McNicol, D. & Willson, R.J. The application of signal detection theory to letter recognition. Australian Journal of Psychology, 1971, 23, 311-315.

Signal detection measures were used to assess tachistoscopic recognition of single target letters or pairs of targets embedded in strings of non-targets whose shapes were either similar or dissimilar to the targets. A yes-no rating procedure was used with confidence judgments from category 1 (high confidence that the signal occurred) to category 5 (high confidence that the signal did not occur). The measure of sensitivity used as P(A), the proportion of the area below Ss ROC curve. Response bias was measured by determining the point, B, on each observers rating scale, at which was equally disposed to making S and N responses; if this point did not fall exactly at any one category, bias was obtained by linear interpolation between categories. Sensitivity was worse and there was a stronger response bias toward reporting targets (i.e., an increase in FA's) when similar non-targets were used. This change in the number of FA's could be due either to observers adopting a laxer criterion in the similar non-target condition or to failure to adjust the criterion to take account of a higher level of noise arising from increased confusability between targets and non-targets. Observers who were informed about the nature of the non-targets showed little change in sensitivity, but a marked reduction of FAs with similar non targets.

Clement, D.E. & Hosking, K.E. Scanning strategies and differential sensitivity in a visual signal detection task: Intrasubject reliability. Psychonomic Science, 1971, 22, 323-324.

A 16 alternative forced choice visual signal detection task is reported, in which a target signal appeared in one out of 16 locations on each trial. An examination of d' revealed differential sensitivity to target location. However, the ordinal stability of the differential sensitivities across locations was high for a given observer. The results implied extremely strong scanning biases which existed prior to the experimental task.

Shiffrin, R.M. & Grantham, D.W. Can attention be allocated to sensory modalities? Perception & Psychophysics, 1974, 15, 460-474.

Observers were asked to report on the presence (or absence) of a signal in one of three sense modalities: visual, auditory, and tactual. Observers either attended to all three sense modalities simultaneously or to one modality at a time in successive observation intervals. The authors develop two d'-like measures to assess changes in visual, auditory and tactile sensitivity between the two conditions. No reduction in sensitivity was observed when simultaneous monitoring was required. It is suggested that attention does not operate on a level prior to short-term memory. A further experiment investigates this hypothesis.

Lieblich, A. & Lieblich, I Arithmetical estimation under conditions of different pay-off matrices. Psychonomic Science, 1969, 14, 87-88.

Observers were presented with six three-digit numbers and a sum which was correctly computed 50% of the time. Presentation time was 5 sec and observers were required to make correct/incorrect discriminations. Three pay-off matrices were used, two symmetrical ones and one with high penalties for false alarms. The different pay-off matrices produced no significant changes in the numbers of hits, false alarms, misses and correct rejections. This is interpreted as observers "lack of rationality" relative to the goal of maximizing expected gains. Observers in fact showed perfect probability matching in the distributions of their responses.

Wickelgren, W.A. & Becker, G.M. Decisions based on conflicting and inaccurate observations. Journal of Mathematical Psychology, 1965, 2, 180-189.

Observers were asked to guess which of two symbols would be drawn from a population of two symbols. After a made choice, was shown the "reports" (cues) of two or more "observers". The accuracies of these reports varied from 0 to 100%. In a series of preliminary training runs, observers had estimated the accuracies of the cues, and these estimates were solicited again on the test trials (if observer misremembered, was corrected). Observer then made a second judgment as to which symbol had been chosen. The number of correct second guesses determined the receipt of a bonus. The authors concluded 1) estimates of cues with very high or very low accuracies were better than estimates of cues of intermediate accuracies. 2) people tend to maximize expected payoff when faced with conflicting information in binary choice problems 3) conformity pressures exist and can interfere with the maximization response, if there is uncertainty about the maximizing response.

Kopp, I. & Livermore, I. Differential discriminability or response bias? A signal detection analysis of categorical perception. Journal of Experimental Psychology, 1973, 101, 179-182.

Categorical perception occurs when the discriminability (along some dimension) between stimuli depends on the way the observer has labelled the stimuli. Stimuli with identical labels are supposedly less discriminable than stimuli with different labels. A three phase experiment is reported here. First, observers are provided with two response categories and are reinforced for discriminating between a 500 Hz and a 532 Hz tone, They are then presented with tones varying from 500 to 532 Hz in 4 Hz steps (total of 9 stimuli) and are again required to make dichotomous discriminations. Results show that stimuli from the middle of the frequency range were placed in each of the two response categories about equally often. Finally, observers were presented with all possible pairs of those nine stimuli (including stimuli paired with themselves) and were asked to make same-different discriminations between the tones of a pair. The proportion of correct "different" judgments (hits) was greatest for tones in about the middle of the frequency range. This fact appears consistent with categorical perception since the middle of the frequency range. This fact appears consistent with categorical perception since the middle of the frequency range represents the category boundary region. However, estimations of eta and beta* show that the increase in hits in the middle of the frequency range is entirely owing to a change in bias rather than due to a change in sensitivity. This result is left unexplained, but implications are drawn for other work in categorical perception, expecially in the area of speech perception. It is suggested that

$$*\text{eta} = \frac{\text{misses x false alarms}}{\text{hits x correct rejections}}$$

$$\text{beta} = \frac{\text{misses x correct rejections}}{\text{hits x false alarms}}$$

Segal, S.J. & Fusella, V. Influence of imagined pictures and sounds on detection of visual and auditory signals. Journal of Experimental Psychology, 1970, 83, 458-464.

This study tries to determine the nature of the interference posed by imagery during a detection task. Observers were required to report the presence of either a visual signal, an auditory signal, or neither, both before, during and after an attempt to hold visual or auditory images in mind. TSD statistics were computed and showed that

1) d' was reduced during imagery as compared to the other conditions. Within the imagining condition, d' was smaller when image and signal were of the same modality than when they were from different modalities. Also d' was smaller for unfamiliar images than for familiar ones.

2) Likelihood ratios were reduced when image and signal were of the same modality.

It appears that during imagining, observers tended to confuse auditory images with auditory signals and visual images with visual signals. The authors argue that imagery does not simply act as a "general distractor"; rather, signals and images have similar, modality specific, internal representations, and observers make their sensory decisions on the basis of those representations.

Schuck, J.R., Cross, H.A. & Mills, D.H. Asignal detection analysis of the rod and frame test. Perception and Psychophysics, 1970, 7, 276-280.

This experiment applied TSD to Witkin's rod and frame test measure of field dependence and independence. A rod is presented within a tilted frame at various angles of tilt. A hit is the report of "vertical" when the rod is in fact vertical, a false alarm is the report of "vertical" when the rod is in fact tilted. Two hypotheses are examined:

1) Field dependent observers, although they have the same perception of verticality as field independent observers, deliberately misreport their perception on a certain proportion of trials in order not to appear too extreme in weighting or failing to weight the tilt of the frame. This predicts that areas under the ROCs for field dependent will be less than those of field independent, but that their ROC functions will nonetheless overlap or lie above the chance diagonal.
2) Field dependent observers actually perceive the rod as vertical when it is tilted frame. This predicts that ROC functions for field dependents will lie below the chance diagonal.

A four point category scale was used to obtain observers judgments of verticality. ROC curves supported the second hypothesis. The results were taken to suggest that field dependence is not a response bias effect, and the following decision rule accounted for the behavior of field dependence is not a response bias effec, and the following decision rule accounted for the behavior of field dependents: "when the rod and frame are about equally tilted, call the rod vertical, for all other conditions, call the rod not vertical". The intercorrelations of ROC area with Witkin's measures of field dependence were high.

Friedman, M.P., Carterette, E.C., Nakatani, L. & Ahumada, A. Comparisons of some learning models for response bias in signal detection. Perception & Psychophysics, 1968, 3, 5-11.

The authors develop a three state threshold model from which they derive a linear function relating P(Hits) to P (False Alarms) with two free parmeters. Data obtained in an auditory detection task were consistent with the derivation and a particular choice of values for the parameters. This allowed for the calculation of a bias parameter P, the probality of saying "Yes" given a sensory state of uncertainty. Bias P was seen to be an increasing function of signal probability but did not depend on the correctness of feedback among signal and noise trials). Some sequential statistics were computed and various learning models proposed. A model which assumes that bias changes if there is disagreement between feedback and sensory state was found to fit the data rather well.

Tanner, T.A., Rank J.A., & Atkinson, R.C. Signal recognition as influenced by information feedback. Journal of Mathematical Psychology, 1970, 7, 259-274.

Observers were run in a signal recognition task involving two tones of different amplitudes. Three binomial schedules for presenting the two signals were used, and four conditions varied the information given to an observer about the presentation schedules and the performance on each trial. The information that an observer was given about the presentation schedules markedly influenced hit and false alarm rates. The influence of the preceding trial's signal and response on hits and false alarms also varied as a function of both the presentation schedule and the information given about the schedules. A mathematical model of signal recognition, involving the comparison of present sensory input with the memory of the input from the previous trial, is shown to account for the results rather well.

Animal Psychology

Studies of animal behavior vary from field observations by ethologists to laboratory experiments that utilize the stimulus control and experimental finesse of the most resolute psychophysicist. Animal studies are designed from two points of view. On the one hand animals may serve as behavioral models for certain mental processes that are more easily comprehended in reduced behavioral form. On the other hand there are many psychologists who are interested in the actual mental equipment possessed by the animal under observation. These scientists often believe that many of the processes one observes in animal behavior may represent evolutionary antecedents to analogous behavior observed in man. Consequently, an understanding of these more primitive psychological functions may help to illuminate similar observations in human beings.

The following review of the limited literature in animal behavior that connects to decision theoretic concepts starts with an examination of experiments in which psychophysical questions about animal behavior are paramount. The techniques of two-parameter decision theory are applied to partition the animal behavior into a bias variable and a sensitivity effect. The central interest often focuses on estimates of the sensitivity of the animal to the particular stimulus variable being studied.

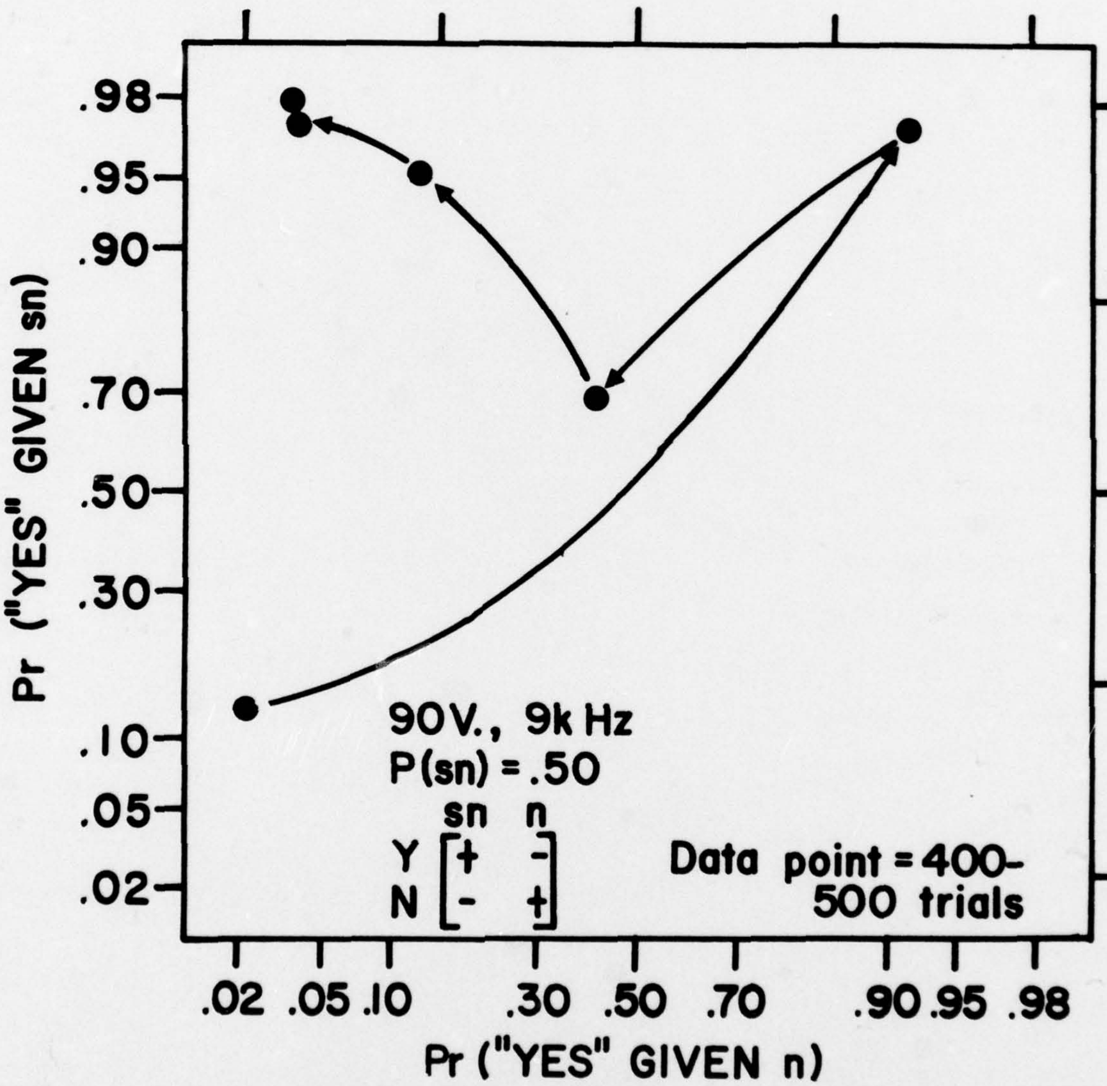
As a prototype of psychophysical experiments in animals we consider first experiments conducted by Galanter and Huckle in 1965, and further refined by Huckle to constitute his Ph.D. dissertation (Huckle, 1972). In this experiment albino rats were trained individually to make an auditory discrimination by turning in one or another direction in a choice depending upon the presence or absence of a 9 kHz tone. Turns in the correct direction were reinforced by varying amounts of food, turns in the incorrect direction were punished by the onset of a high wattage light bulb close to the animal's face. All of the components of a psychophysical and learning experiment were present in this design. The first question: whether animals learn to make the discrimination, is answered by Figure 5 where averages over four or five hundred trials constitute each point. These data are generated by an animal learning to make a fairly easy discrimination in which the positive pay-offs were equal. The first five hundred trials are represented by the data point with a hit probability of approximately 0.15 and a false alarm rate of about 0.02. This position habit (a tendency to say "no" regardless of the presence or absence of the signal) was shortly replaced by the opposite habit, to generate data with a high probability of 0.98, and a false alarm probability of 0.95. After abandoning this second position habit the animal moved to the third data point showing some slight discriminative capability with a hit rate of 0.65 and a false alarm rate of 0.33. During successive trials the animal continued to move up along the minor diagonal until it was correct 98% of the time and made only 3% false alarms.

After the animal has mastered the acquisition of the discrimination, we demonstrate the variations in the signal strength can be represented behaviorally by variations in the magnitude of d' as estimated by the location of the data point for different values of signal strength. This is shown clearly in Figure 6 where the increasing voltage level for varying values of the 9 kHz tone generate progressively larger values of d'. Finally, the animals are shown to be sensitive to the bias inducing effects of the pay-off matrices in Figure 7. Here, for one of the weaker tone levels, (d' = 1.3) variations in the ratio of positive reinforcements for hits and correct rejections are shown to produce shifts on an isosensitivity function as the theory predicts. Notice that the dynamic range of the reinforcement ratio is of the order of three log units at the maximum.

This experimental analogue of a human decision problem using animal subjects demonstrates without question that within a paradigm in which the response structure is conveniently represented by decision theoretic models, the statistics of these models are as useful for parameterizing the animal behavior as they are when they represent human behavior. As we have remarked in other contexts based on a decision theory model the analytical techniques applied to animal behavior imply nothing about decision making in the rat, any more than a dog catching a thrown stick implies about its differential equation solving power.

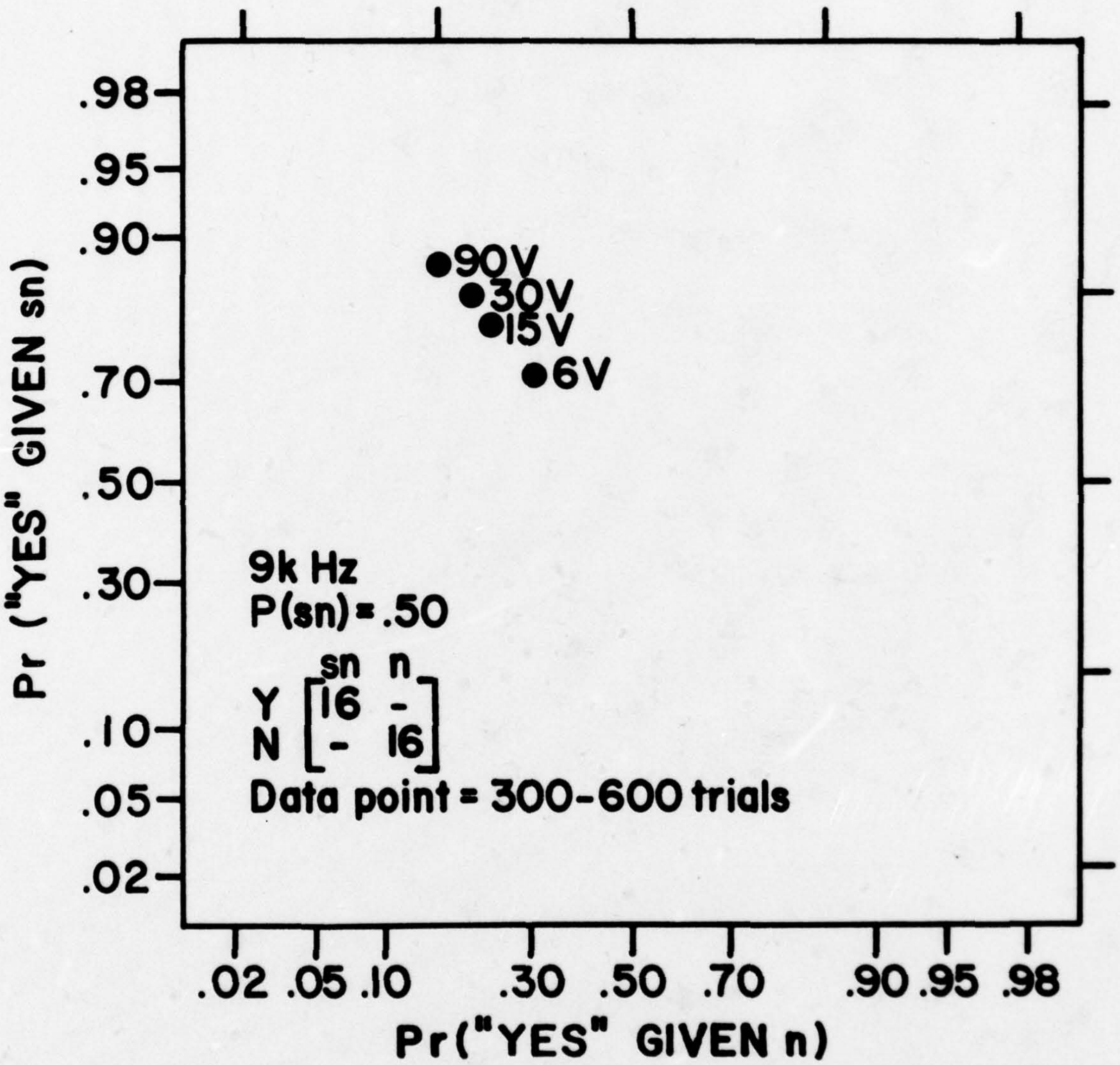
In the summaries of research that follow we should note that the decision theoretic ideas serve both a methodological and a theoretical role. On the one hand they enable experiments to be performed that

Figure 5



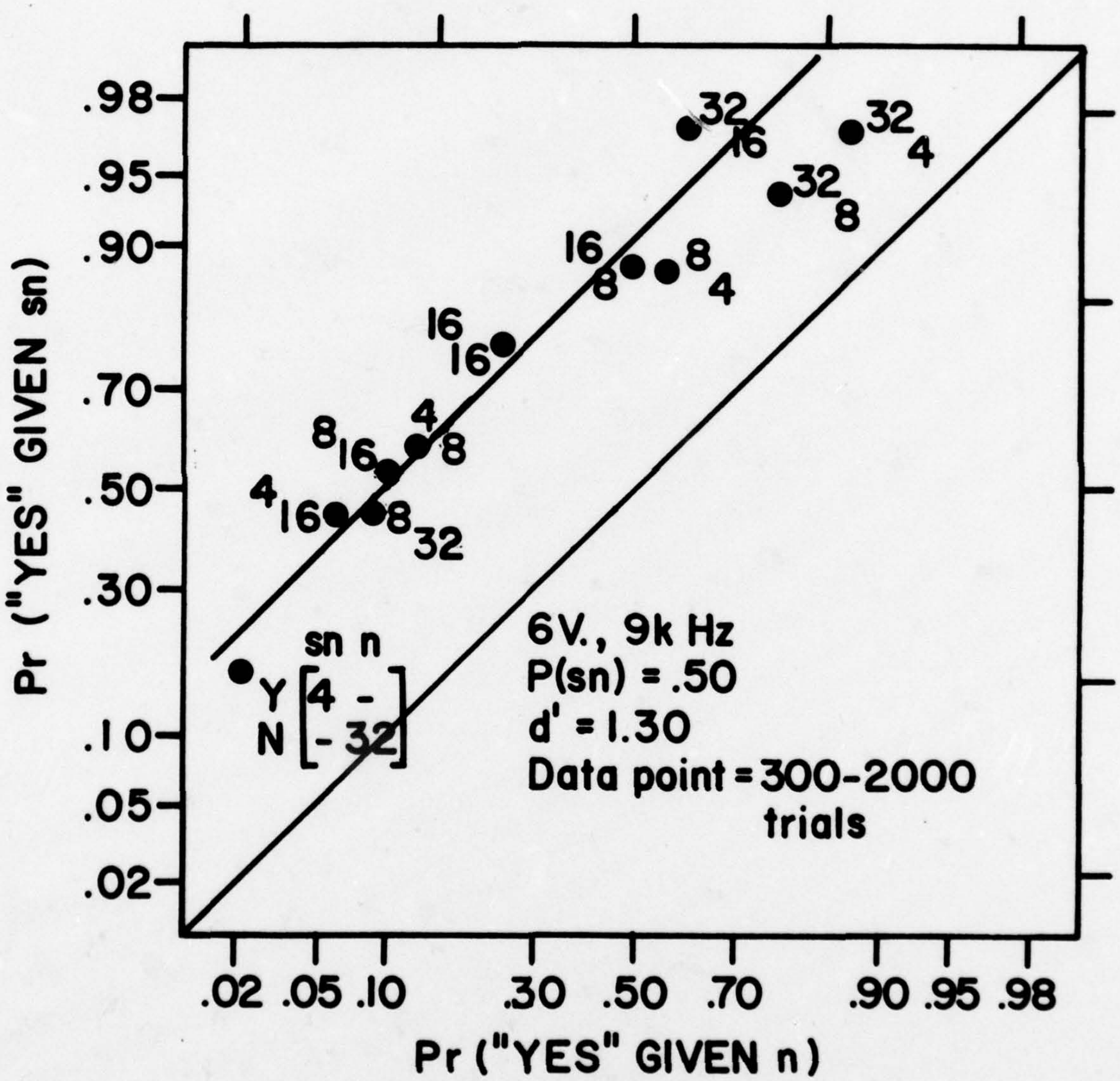
Identification training, S-1

Figure 6



Isobias curve, S-4

Figure 7



The isosensitivity curve, varied payoffs—S-4 would otherwise not be interpretable, on the other hand the notions of decision theory are thought to underlie a major revision of classical stimulus-response psychology as it has developed from five decades of animal experimentation.

The first abstract shows how psychophysical studies provide methodological inroads into problems that would be difficult if not impossible to perform with human beings. The concern here is with the neurochemical effect of drugs on stimulus sensitivity. This study is illustrative of the way in which decision theoretic notions can be used to analyze complex animal behavior without reference to any "conscious" function on the part of the organism. The analysis of this experiment by the theory of signal detectability is neutral with respect to questions of consciousness or other higher cognitive processes. All that is at issue is a characterization of the response structure in such a way that the responses may be fairly attributable to stimulus effects and to inter-response variables respectively.

The final abstracts in this section are directed toward purely psychological questions in animal psychology. The review by Boneau and Cole interprets the components of a decision theoretic model as representing equivalent psychological structures in the animal. It is presumed that the animal is in fact making decisions equivalent to the decisions made by a person in that situation, the animal here represents a formal analogue for human performance in similar situations. The last two abstracts by Nevin and his student use decision theoretic ideas to study features of animal behavior that are not sensory, but are in fact motivational. In this sense the aspects of the pay-off matrices as interpreted in animal psychology by reinforcement schedules are the objects of inquiry. Just how these schedules of reinforcement influence the behavior is analyzed with the help of decision theory.

The extensions of decision theory to animal behavior represents a broadening of the two-parameter models that were developed originally to analyze problems of stimulus sensitivity. In the animal work we see emerging a clear and coherent study of the the theoretical structures themselves which serve as representations of the response interlocks. These aspects of the behavior and not the sensory functions, become the objects of concern. It is not merely how well the animal can discriminate or identify stimuli, but how the stimulus values can be used as objective representations of the response interlocks. Consequently, it is not how well the animal can discriminate or identify various environmental events, but how the response structure of the animal is constrained by some internal representation signed by the stimulus, which may be formally equivalent to what we think of as a decision process in the human being.

Brown, K. & Warburton, D.M. Attenuation of stimulus sensitivity by scopolamine. Psychonomic Science, 1971, 22, 297-298.

TSD is applied to the question of whether scopolamine produces response disinhibition (response criterion shift) or a change in sensitivity to an incoming stimulus. Rats were trained on a differential reinforcement at low rate (DLR) schecule, which required them to space their responses at intervals exceeding 15 seconds. After stable performance was achieved, they were injected with various doses of scopalamine hydrobromide. The mean probability of a response over the five 3 sec intervals between 16 and 30 sec provided the hit rate, the mean probability of a response over the second to fourth 3 sec interval the false alarm rate. d' was computed for each rat and was shown to decrease with increasing dosage level. (d'_e was in fact very sensitive to extremely small dosages). No bias change is reported. The authors conclude that scopolamine hydrobromide modifies sensitivity rather than response criterion. Impairment of the ascending cholinergic reticular pathways is suggested as a possible explanation for the decrement in sensitivity.

Yager, D. & Duncan, I. Signal-detection analysis of luminance generalization in goldfish using latency as a graded response measure". Perception & Psychophysics, 1971, 9, 353-355.

ROC curves were determined from response latencies of goldfish in a single-stimulis generalization task. The resulting functions were similar to ROC curves obtained by rating methods with human observers.

Shusterman, R.J. "Low false alarm rates in signal detection by marine animals. Journal of the Acoustical Society of America, 55,(4) 1974, 845-848.

This study summarizes a series of experiments on the visual and auditory sensitivity of several species of marine mammals. He criticizes the experimental prodedure; and the data analysis on the grounds that they result in arbitrarily low estimates of sensitivity. The animals were conditioned to vocalize when the signal was present and to remain silent in it's absence. The basic conditioning paradigm was negative reinforcement in an avoidance task for departures from a Neyman-Pearson criterion. False alarm rates were held below 10%. The obtained psychometric functions give unnecessarily low sensitivity estimates because they fail to take into account the depressive effect of response bias on the hit rates in situations which reinforce type-II errors.

Muntz, W.R. An experiment on shape discrimination and signal detection in octupus. Quarterly Journal of Experimental Psychology, 1970 22, 82-90.

Ten octopi were trained to perform a successive discrimination between two shapes. Attacks on the positive shape plotted against attacks on the negative shape constitute an ROC curve from which a value of d', independent of the general attack level can be obtained.

Irwin, R.J. & Terman, M. Detection of brief tones in noise by rats. Journal of the Experimental Analysis of Behavior, 1970, 13, 135-143.

These reasearchers trained two rats to detect brief 8 kHz tones centered in a 1/3 octave band of noise. The procedure was analogous to the yes-no method of human psychophysics in that the second response was defined as correct and reinforced if the tone was absent. Biases in responding were sometimes observed.

Hack, M.H. Signal detection in the rat. Science, 1963, 139, 758-760.

An auditory detection experiment was performed with rats. Prior probabilities were varied, as was signal intensity. An application of TSD produced linear isosensitivity functions in normal-normal coordinates for each rat, and $d_e^{1/2}$ was shown to increase with SPL of the signal.

Kinchla, J. Discrimination of two auditory durations by pigeons. Perception and Psychophysics, 1970, 8, 299-307.

Pigeons discriminated between two auditory durations in a task analogous to the yes/no detection task in human psychophysics. ROCs were constructed showing shifts in performance towards the positive diagonal with increasing task difficulty. Reduction in the probability of reinforcement produced changes in performance analogous to those observed in humans under changes in pay-offs. The independence of experimental trials was supported in an investigation of possible sequential response dependencies.

Hume, A.L. Auditory detection and optimal response biases. Perception & Psychophysics, 1974, 15, 425-433.

Two rats detected increments in the intensity of random noise under different conditions of signal strength, signal probability and probability of reinforcement. Each point obtained on an ROC curve was based on 2000 trials. The major findings were:

1) d' was independent of variations in signal probability and ratio of brain stimulations for correct responses; d' increased with signal strength.
2) As signal probability varied, response biases changed and remained close to the optimal betas for maximum number of brain stimulations. When the ratio of brain stimulations for correct responses varied, response biases varied, but the changes reflected a compromise strategy between optimizing the number of brain stimulations and the number of correct trials.
3) Finally, the data showed that changes in signal probability as small as .10 & .05 resulted in distinct and systematic differences in the response biases.

Boneau, C.A. & Cole, J.L. Decision theory, the pigeon and the psychophysical function. *Psychology Review*, 1967, *74*, 123-135.

A decision-theory model for the behavior of lower organism is described. This model bases predictions of behavior upon the principle of maximization of payoff under conditions of stimulus uncertainty. The model is first developed for a simple, 2-stimulus color discrimination task for pigeons and then generalized to multiple-stimulus tasks. From this generalized model are derived the "psychophysical function" and alterations in this function produced by changes in motivation and stimulus probability. Some relevant data are described.

Wright, A.A. & Nevin, J.A. Signal detection methods for measurement of utility in animals. *Journal of the Experimental Analysis of Behavior*, 1974, *21*, 373-380.

Pigeons were first trained to detect the presence or absence of a stimulus given a symmetrical pay-off matrix and 100% reward and punishment probabilities. Subsequently, false alarms were punished with various levels of shock 50% of the time, and the sum of the positive reinforcement probabilities was held constant a .5. Bias was manipulated by changing the positive reinforcement probability of hits. The value

$$B' = \frac{\text{hits x misses -false alarms x correct rejections}}{\text{hits x misses + false alarms x correct rejections}}$$

was computed and plotted against relative hit reinforcement (= probability of reinforcement for a hit/probability of reinforcement for hit + probability of reinforcement for false alarm). It is shown that for five levels of shock, bias toward choosing "yes" increased fairly linearly with relative reinforcement. The five functions have similar slopes and differ primarily by an additive constant. From these plots the authors derive "utility functions" relating shock level to the amount of relative reinforcement required for equal bias. These functions are increasing with shock intensity level.

Nevin, J.A. On the form of the relation between response rates in a multiple shedule. *Journal of the Experimental Analysis of Behavior*, 1974, *21*, 237-248

Nevin suggests that besides studies of input-output relations of operant behavior such as those commonly found in S-R theorizing the study of R-R relations a la' TSD would be potentially illuminating to the investigation of the structure of responses.

Running pigeons on a concurrent multiple VI-VI and FI schedule, the author plots log R_1 vs. log R_2 where these denote the relative response rates of the two responses. The resulting linear relation and the extraction of the slope parameter are discussed 1) as an analogue of TSD-type analysis, 2) as a means of extracting input-output relations analogous to the extraction of the pyschophysical relation from TSD data. He suggest a form for this I-O relation similar to Heirnsteins's law. The point of differentiation is the plotting of rates of response rather than the effectiveness of reinforcement.

Utility and Motivation

The initial impetus for the development of decision theoretic models for use in psychophysics resided in the observation that judgments made by people were as often influenced by their own desires and interests as they were by the stimuli presented to them by the experimentalists. Once a theory was developed that allowed the subtraction of these extraneous motivating and attitudinal variables, the psychophysicist was satisfied that he or she had found ways to assess the purely stimulus effects. Indeed, the motivational and attitudinal effects represented a constellation of problems that were (hopefully) going to dissolve under careful and more rigorous analysis of the stimulus parameters themselves. This is most evident in the work of McGill, (p. 12) who overtly eschews the importance of motivational effects, and attempts to replace these variables with a more detailed and fine grained analysis of the stimulus. On the other hand, as we have seen in the section on animal behavior, some psychologists see these models as most valuable in the analysis of response organization, which is dominated by motivational or reinforcement variables.

This aspect of the theory of signal detection, i.e., its potential to unravel motivational factors in behavior, has made decision theory an object of interest among experimental psychologists of human behavior. As a result of this interest a body of literature has developed in which two-parameter decision theory is used not so much for an analysis of stimulus effects, as for an analysis of response bias, motivational effedts, attitudinal structures, and generally what has come to be called "utility theory." Thus, the theories of signal detectability have been used less for their relevance to signals and more for their relevance to pay-offs. Recall that the payoff matrix, as well as the signal structure, was one of the central components controlled by the experimentalist. It can be seen that whereas one gets a pure estimate of sensitivity when the variations in bias that do not induce changes in sensitivity are understood, it is also the case that by varying sensitivity and observing what factors leave bias invariant, one can interpret those variables as "motivational."

The abstracts in this section deal with several aspects of this problem. They are primarily directed toward illuminating the role of valuation in judgment, and how a person's evaluations of alternative consequences influence that judgment. The fundamental principle underlying the theoretical structures is that a representation of valuation as "utility" will be the ultimate analytical tool. Whereas the classical views of utility as a one-dimensional parameter that represents the combined evaluation of a particular experimental design is still a forceful contender for the motivational variable, other concepts, in particular multi-attribute concepts of utility have also been explored. We start with the multi-attribute theory in the abstract because it represents an attempt to capture all of the motivational variables in a single net, and so aims to provide a general theory of desire and aversion.

Before proceeding with summaries of the research conducted on this topic, it will be worthwhile to outline the underlying ideas that have connected concepts in the field of perception with those of motivation. The primitive notion in perception is the idea of discrimination. That is to say behavior can be supported by variations in the physical characteristics of environmental energy configerations. Furthermore, the behavior displayed under different energy configerations can be modulated by sentient organisms so that slight differences in the energy bath give rise to clearly observable differences in the overt behavior. It is this capability to magnify behaviorally minimal environmental changes that makes possible the performance of complex motor tasks that depend for their successive components on cues arising from changes in the environmental flux.

The introduction of decision theoretic ideas into the study of perception coupled the notion of discrimination to that of preference. This connection made it clear that the existence of differential preferences could enhance or conceal the existence of differential discrimination. But coexistant with this idea the notion of an important asymmetry remained: Namely, that on the one hand the existence of a preference necessarily implied the existence of a discrimination, whereas on the other, the existence of a disecrimination did not seem to demand the existence of a preference. This distinction seems true a priori, in the sense that for an organism to prefer one or another outcome the ability to discriminate among the outcomes is a prerequisite. But it also seems plausible that organisms can discriminate among various stimulus arrays without having any preferences vis-a-vis the arrays. However the fact that the objects of discrimination may not be differentially preferred does not mean that discrimination can occur without any differential preference. Indeed, decision theory presumes the existence of some preference for the display of discrimination. That is to say, the behavioral manifestation of a discrimination requires the existence of preferences for some set of outcomes. The outcomes will normally not be identical to or even isomorphic with the objects of discrimination.

Once the symmetry and independence of discrimination and preference is established, then metrics for the sensory system can be assigned to discriminative capacities separately from metrics assigned to the preferential behaviors. It is these preference metrics which comprise the set of utility measures, that constitute the objects of great interest in the study of motivation. Thus, the intrinsic interlock between perception and motivation becomes overt when it is recognized that the existence of preferential behavior is just as necessary for the existence of a discrimination as is the existence of discriminative behavior for the establishment of preference. This underlying theme pervades the utility literature and it is this decision theoretic idea that has induced a change in the study of motivation from questions of organismic need and tissue deprivation to a concern with psychic states as representative of the ways in which such organic needs display themselves as variations in taste, style, attitudes, desire, and so forth.

Winterfeldt, D. & Fischer, G.W. Multi-attribute utility theory: Models and assessment procedures Tech. Rep. Engineering Psychology Laboratory, Ann Arbor, MI: U. of Michigan, Nov. 1973.

Since alternatives can be varied on the dimensions of 1) multi-attributedness, 2) uncertainty, 3) and time variance, with each variable possessing a discretely realizable null state there are $2^3 = 8$ cases available for the model builder. The number of available models/cases ranges from 0-4. This paper examines the $2^2 = 4$ cases in which the alternatives are multi-attributed and asks the question, "What measurement theoretic assumptions underly a given model? Handy flow diagrams and summary of necessary conditions for models ranging from simple order to additive expected utility are provided. In general, though it is a summary, not an innovative thesis.

Sample MAUT Equations

$$U(\underline{X}_1, \underline{X}_2, \ldots\ldots, \underline{X}_i \ldots \underline{X}_n) = \sum_{j=i}^{m} P_j \sum_{i=1}^{n} u_i \;(Xij)$$

$\underline{X} = (\underline{X}_1, \ldots, \underline{X}_n)$ = risky alternative for which $w \rightarrow X$; if F_j occurs.

P(Ej)=pj. Xij is the state of the i-th attribute and the j-th alternative.

u_i is utility function over states and u = utility function for $\underline{X}$ defined by above rule.

Lee, W. Preference strength, expected value difference and expected regret ratio. Psych. Bull., 1971, 75, 186-191.

This paper discusses the mathematical relationships between expected value differences and the regret ratio (the cost of a win not obtained relative to the loss) and gives a method of constructing sets of gamble pairs orthogonal in value and regret.

Swets, J.A. & Sewall, S.T. Invariance of signal detectability over stages of practice and levels of motivation. Journal of Experimental Psychology, 1963, 66, 120-126.

2 AFC and rating procedures were used to assess the effects of practice and levels of motivation on performance in an auditory detection task. Motivational levels I and II (low and medium) were induced by instruction, motivational level III (high) was induced with monetary rewards for improved performance. The effect of practice on d' extended over no more than three sessions and was equivalent to no more than a 2 dB change in signal power: the effect of motivational level on d' was equivalent to less than a 1 db change in the rating task and less than a .5 dB change in the 2 AFC task. The authors suggest that the assumption made by some learning theorists that detection performance will vary as a result of motivation from chance to near perfect is not justified.

Galanter, E. & Holman, G.L. Some invariances of the isosensitivity function and their implications for the utility function of money. Journal of Experimental Psychology, 1967, 73, 333-339.

Experiments were performed in which human observers reported whether or not they could detect the difference in amplitude between a pair of acoustic stimuli. Probability that the stimulis pair differed, pay-off matrices, and instructions were varied. An extreme condition called for the multiplication of all monetary values in one pay-off matrix by a factor of five. ROCs were constructed, plotting the proportion of correctly reported stimulus differences against the proportion of incorrectly reported ones. The normality and equal variance assumptions of TSD were supported. The isosensitivity curve was unchanged under all conditions, including the extreme pay-off matrix. In fact, the five-fold change in the monetary values left the absolute response probabilities of hits and false alarms unchanged. This last result provided additional empirical support for the claim that the utility function of money is a power function.

Carterette, E.G., Friedman, M.P., & Wyman, M.J. Feedback and psychophysical variables in signal detection. Journal of the Acoustical Society of America, 1966, 39, 1051-1055.

A two alternative, forced choice, auditory signal detection experiment was conducted with eight conditions: 2 signal intensities with each of four kinds of information feedback (no feedback (NF), correct feedback 100% of the time (F100), correct feedback 75% and incorrect feedback 25% of the time (F75), and correct feedback 50% of the time and incorrect feedback 50% of the time (F50)). Correct feedback consisted in information as to which interval had been the signal interval. A priori probabilities of signal occurrence were equal for each interval. Percent correct (P(C)) was higher for NF and F100 than for F75 and F50 for both signal intensities. For the high signal intensity, P(C) was higher for NF than for F100, but the reverse was true for the low signal intensity. A sequential analysis of the data revealed that on trials following agreement between observers response and feedback hits were higher and false alarms lower than on trials following disagreement. (These differences disappear in the F50 condition). The authors contend that disagreement leads to a variability in the criterion that has the effect of depressing the sensitivity index.

Valenti, M. & Galanter, E. The SEU function determines the isosensitivity curve. (Rep. 38). New York: Columbia University, Psychophysics Lab. 1975.

SEU is examined in a simple auditory TSD context. The dependence of utility and subjective probability on pay-off amount and a priori event probabilities was investigated. Matrices were used where value can be presented by a single number-relative expected net outcome (RENO). On the assumption that observers maximizes utility, equations are presented which relate RENO and the a priori odds to the slope of the isosensitivity function at observers operating point for that matrix. It is shown that 1) utility is a power function of RENO with a slope of .44; 2) subjective probability grows as the .75 power of probability; 3) a nonzero intercept of the bias vs. the outcome implies that the subjective probability function is the a priori probability, not the odds. These experiments confirm the form and parameters of the utility functions of money constructed by magnitude estimation experiments, and also validate earlier indirect estimates of that function by signal detection experiments.

Hammerton, M. An investigation into changes in decision criteria and other details of a decision making task. Psychonomic Science, 1970, 21, 203-204.

Observers were required to decide from which of two distributions of two digit numbers (normal, equal variance) a given number had been drawn. One experiment involved a binary decision, the other a category rating procedure. Observers were informed prior to the experiments what the means of the distributions were. The obtained d' was below the objective d', a finding which is attributed to a variable cut off point. It is suggested that observers behavior constitutes a deviation from perfect Baysesian behavior.

Jacobs, D.E. & Galanter, E. Estimates of utility function parameters from signal detection experiments. (Rep. 32). New York: Columbia University, Psychophysics Laboratory, 1974.

A theory is developed to make it possible to estimate the slope parameter of a presumed power law utility function from an analysis of data obtained in a psychophysical signal detection experiment. The theory can be applied to data that is analyzed either by the classical theory of signal detectability (TSD) or by a choice theory of detection. An experiment is described that tests the consequences of the theory. The estimated parameter of the utility function is similar to the parameter obtained by magnitude techniques.

Clinical Psychology and Personality Theory

If they have done nothing else, the preceding sections demonstrate the vitality of the theory of signal detectability, and two-parameter decision theories in general, as a conceptual scheme to embrace a large class of problems in the central areas of experimental psychology. In this final section we demonstrate that the application of two-parameter decision theory can breech the usual gap between the clinical and social psychologists and the experimentalists, and so provide a common ground for theory and interpretation that may serve to strengthen scientific work in all these areas. The studies in this section consider topics that range from whether it is possible to analyze the wave forms of neural signals with a decision theoretic model, to the question of the influence of various drugs on pathological groups, to considerations of the analgesic effects of drugs and placebos, and finally we even include a reference that, although not explicit in its application of the theory of signal detectability, construes the criminal justice system as a decision theoretic structure.

This mixed bag of abstracts demonstrates at the very least the breadth of impact that two-parameter decision theory has had upon psychology outside the narrow confines of the experimental laboratory. Although some of the work is poorly conceptualized, as for example in the analysis of evoked potentials, the researchers have grasped the essential nub of the concepts and have recognized its potential for explanation and understanding. On the whole, the application of decision theoretic ideas does not remove the difficulty of working with patient populations or the difficulty of having to analyze the noisy data intrinsic to the substantive problems under consideration. The theory of signal detectability does not replace the psychological and psychophysical measurement instruments, rather it provides a technique for estimating statistics from such instruments that lead to a relatively coherent interpretation of the data. The need for additional psychophysical scaling methods is clearly demonstrated in some of the abstracts that follow.

In part, the advancement of the use of decision theoretic ideas within the clinical areas waits on the development of a closer connection between scaling models designed to tap the dynamic range of human potential, and the analytical techniques of decision theory which are based upon an analysis of relative frequencies interpreted as probabilities. Whereas, for example, a person is capable of appreciating a dynamic range of auditory stimulation of better than a trillion to one, the dynamic range within which sensitivity estimates are obtained in a signal detection task bearly span half a log unit.

The establishement of a connection between such "microscaling" and "macroscaling" was, of course, the goal of Fechner. The current counterpart of these attempts as seen in Luce's book on choice theory (1959), and the recent models of Luce and Green (1972). However none of these ventures into the connection between the resolving power of the sensory systems and the perceptual range of these systems has been satisfying in a theoretical sense. Consequently we continue to work around Fechner's problem in the hope of a decisive insight. It may well be the case that contributions in the far flung areas of psychology such as clinical psychology, social survey research and so on, may yet make major contributions to the deep understanding of some of the central problems of the experimentalists. It is on this note that we present the abstracts that follow in the hope that they will stimulate consideration of this important connection between system resolution and system dynamics that will leapfrog our understanding of human nature in much the way that the decision theory models have done.

Paul & Sutton, Evoked potential correlates of response criterion in auditory signal detection, Science, 1972, 177, 362-364.

In a Yes-No design observers reported presence or absence of signal, criterion was varied by both a priori probability changes and payoff shifts. Intensity was set so d' corresponding to P ("hit") = .75 for each observer. Evoked potentials were averaged in four slots each one corresponding to one of the p(fc/S). They found that on hit trials P3 amplitude increased monotonically with bias towards the No response. (i.e., monotonically increasing against criterion level where higher criterion is a relative bias towards No.) They tentatively postulate that P3 increases with the "salience" of the stimulus; where salience is defined as the relatively greater impace of a hit under cautions vs. liberal criteria.

Hillyard, S.A. Squires, K.C., Bauer, J.W. & Lindsay, P.H. Evoked potential correlates of auditory signal detection, Science, 1971, 172, 1357-1360.

The use of TSD in the analysis of P3 waveforms allows for the independent analysis of such factors as attention to which the waveforms are apparently very sensitive. When this separate analysis is done, P3 shows itself to have close correspondence to behavioral measures of the perception of weak (what they term near-threshold) stimuli. Their data show 1) increase magnitude of P3 with increased $_p$ (Y/S) for a constant d' in all four response conditions with the largest increase being on hit trials by approximately 2:1 over any other trial. This is then, again a case of P3 increasing with the increase of the criterion at constant d'. (i.e., it is monotonic with the sweeping out of a single ROC-curve.) 2) An inverted U-shaped function for the relation between P3 amplitude and d'. In this condition (varying d') there are essentially two groups of points a) the large amplitude hit condition set and b) the small amplitude set consisting of all other three conditions falling essentially on top of one another.

One major problem occurs. There are large portions of the hit curve (d' = 0.0-d' approsimately equals 3.0) that is approximateldy linear. Together with Paul and Sutton's results this implies a monotonically increasing relation between d' and the criterion.

Paul, D. & Sutton S. Evoked potential correlates of psychophysical judgments: The threshold problem. A new reply to Clark, Butler and Rosner. Behavioral Biology, 1973, 9, 421-433.

This paper has the clearest though unintentional statement of the evoked potential mixup re TSD. It reports a linear relation between both d' and P3 and C and P3 thus if

1) d'=aP3 + e and
2) c =fP3 + g then
3) c =f/a (d' -e) +g and such a relation is absurd in the context of TSD where C as a function of d' is constant.

Ulehla, Z., Little, K.B. & Weyl, T.C. Operating characteristics and realism of certainty estimates. Pyschonomic Science, 1967, 9, 77-78.

Observers estimated the probability that each of a series of conceptual discriminations would be correct. These certainty estimates were compared with the actual percentage correct at each level of certainty. Certainty estimates were found to be fairly accurate for most people, although consistent individual differences were found. Operating characteristics were consonant with signal detection theory.

Kuechler, H.A. & Dodwell, P.C. Auditory signal detectability as a function of pre-experimental shock. Quarterly Journal of Experimental Psychology 1968, 20.

Neurotic, schizophrenic and normal subjects were run in two conditions of a Yes-No auditory signal detection experiment. 1) Standard design followed by 2) session preceded by three 200 ma electric shocks at the just tolerable voltage level. The shocks were administered in 30 sec, and were followed immediately by session. They report no change in β across conditions for any group except schizophrenic. An increase in d' was reported for normals, while both the neurotics and schizophrenics showed a decrease in d^1. Although they reported only means and individual parameter values the following table can be reconstructed from their data.

	$\bar{X}$	σ^2	σ	$\bar{X}$	σ^2	σ	$\bar{X}$	σ^2	σ	$\bar{X}$	σ^2	σ
Normal	1.066	.266	.52	1.001	.041	.202	1.495	.197	.44	.982	.093	.305
Neurotic	1.169	.183	.43	1.105	.091	.303	.789	.301	.549	.986	.029	.172
Schizo.	.87	.297	.55	1.711	.853	.92	.56	.257	.507	1.34	.27	.523

n - 8/group 150 trials/n

Since the chocks were non-contingent, and affected d' not β for normals and neurotics (which is the expected result) the ability of these schocks to affect β in schizophrenics is in order.

Clark, W.C. The psyche in psychophisics: A sensory-decision theory analysis of the effect of instructions on flicker sensitivity and response bias. Psychological Bulletin, 1966, 65, 358-366.

Psychiatric patients were run in an experiment on the detection of flicker. Two sets of instructions were used, one encouraging "yes" responses, the other inhibiting such responses. First, psychometric functions were computed on the basis of all "yes" responses. Results indicated a difference in sensory threshold between the two conditions. However, a TSD analysis revealed that only a change in response bias, not in sensitivity (as measured by d'), had occurred as a consequence of the change in instructions. The influence of attitudes on performance is discussed.

Clark, W.C., Brown, J.C., & Rutschmann, J. Flicker sensitivity and response bias in psychiatric patients and normal subjects. Journal of Abnormal Psychology, 1967, 72, 35-42.

Some researchers, finding flicker threshold higher in psycho-neurotic and anxious patients than in normal have hypothesized a physiological dificiency in the patients. Others have hypothesized a more cautious attitude in responsible for the difference.

This paper seeks to a) resolve this questions and b) compare "traditional" psychophysical procedures (i.e. method of limits and constant stimuli with the forced choice procedure.

Their conclusions were: 1) the differences obtained using traditional psychophysical procedures can be attributed to response bias. It is the patient's attitude toward the outcomes of decisions that alters report probabilities. 2) Forced choice is seen to have a greater "inferred validity" with psychiatric patients; even more so than with normals. It is suggested that procedures which are adequate when people scale stimuli (method of limits, and constant stimuli) are inadequate when the stimuli are used, in turn, to scale people.

Rappaport, M. & Hopkins, H.K. Signal detection and chlorpromazine. Human Factors, 1971, 13, 387-390.

Nine normal observers were tested at six different S/N ratios and four different drug dosage levels of chlorpromazine (including both a placebo and a no drug administration). The difference in d' were accounted for by the subject X drug dosage interaction. All observers adopted increasingly stringent criteria as drug dosage increased. It is suggested that chlorpromazine would cause greater detection deficits in a continous vigilance task than in a cued, brief detection situation.

Rappaport, M., Silverman, J., Hopkins, H.K. & Hall, K. Phenothiazine effects on auditory signal detection in paranoid and non-paranoid schizophrenics, Science, 1971, 12, 723-725.

With increasing phenothiazine dosage a decrease in signal detection performance occurred among non-paranoid schizophrenics while an increase in performance occurred in paranoid schizophrenics.

The results seems to be related to differences in information processing deficiencies between the two types of schizophrenics. The neurophysiological basis of these differences seems to be affected differentially by phenothiazine. In particular, phenothiazine seems to decrease the hypersensitivity to sensory stimuli of non-paranoid schizophrenics, while increasing the attention-paying capabilities of the paranoids.

(Apparently, these people are unaware of the work being done by Broen and Nakamura (1972), and vice, versa).

Gruzelar, J.H. & Corballis, M.C. Effects of instruction and drug administration on temporal resolution of paired flashes. Journal of Experimental Psychology, 1970, 22, 115-124.

TSD analysis shows that promazine hydrochloride affected d', but not in sixteen male alcoholics. Parallel experiment showed instructions capable of affecting bias.

Evans, T.R. differential effect of dexamphetamine and phenidylate on auditory detection. Psychonomic Science, 1969, 17, 139-140.

The experiment investigates the effects of two phrenotropic drugs (dexamphetamine and phenidylate) on the detection of single and multiple frequency auditory signals. An improvement in the detection of multiple frequency signals (as indexed by a decrease in the signal level required for a d' of 1.5) was observed following the administration of dexamphetamine, whereas pheyidylate had no such effect. Single frequencies were equally detectable before and after the administration of either dexamphetamine or phenidylate. The results were interpreted in light of the possible increase in the "focus of attention" due to amphetamine.

Kopell, B.S. & Wittner, W.K. The effects of chlorpromazine and Methamphetamine on visual signal-from-noise detection. Journal of Nervous and Mental Disease, 1968, 147, 418-424.

Using traditional threshold measures, they found 1) no significant methamphetamine effect and 2) dosage related deficit due to chlorpromazine. Although they did not use TSD, these characteriazations of the stimuli in terms of S/N ratios, makes such an analysis of this kind of work possible.

Zeidenberg, P., Clark, W.C., Jaffe, J., Anderson, S.W., Chin,S. & Malitz. S. Effect of oral administration of delta-9 tetrahydrocannibinol on memory, speech, and the perception of thermal pain. Comprehensive Psychiatry, 1973, 14.

TSD analysis of thermal pain perception showed that d' decreased across under the influence of THC. L (liklihood ratios criterion) varied unsystematically across but varied in three of four withot other manipulation.

Schneider, E.W. & Carpenter, J.A. The influence of ethanol on auditory signal detection. Journal of Studies on Alchohol, 1969, 30, 357-370.

This reports a very well-done set of experiments. Alcohol was found to have, in general, no significant effect on d^1. It was the response criteria that suffered effects as, under a variety of financial payoff matrices, on alcohol were unable to adopt the appropriate criterion. Thus alcohol would seem to affect earning-power more than sensitivity.

Price, R.H. & Eriksen, C.W. Size constancy in schizophrenia A reanalysis. Journal of Abnormal Psychology, 1966, 71, 155-150.

Theories that assert differences in size constancy between normal and schizophrenics have failed to show any consistent direction to the proposed effect. However, these experiments have all used traditional threshold measures of sensitivity which may obscure the inter-group difference. In this experiment they compared normals, paranoid schizophrenics and non-paranoid schizophrenics for size-constancy using method of constant stimuli. The results were analyzed for both PSE and Egan's d_s. No difference was found using PSE; but the d_s measure showed non-paranoid schizophrenics to be significantly lower in sensitivity to changes than the other two groups.

Whalen, Richard E. Sexual motivation. Psych. Review 1966, 73, 151-163.

The distinctions usually made between human and animal sexuality is a result of differing metatheoretical positions on what are the data of sexology between human and animal researchers. He suggests that the tendency to engage in sexual relations of either group can be conceived of as having two components: 1)Arousability which is the bias toward sexual response mediated by such things as experience, hormonal balance, etc., and 2) Arousal which is the sensitivity of the organism to relevant stimuli.

Milner, A.P., Beech, H.R., & Walker, V.J. Decision processes and obsessional behavior. Brit. Journal Soc. Clin. Psychol., 1971, 10, 88-89.

The complex pattern of doubt, ritualistic behavior and repeated checking symptomatic of the obsessive patient is not amenable to explanation solely in terms of learning theory. The presence of some decision-making abnormality among obsessional patients should be demonstrable in the laboratory.

Fourteen observers, six of them obsessive, were given a Yes-No signal detection task. Under one condition, they had to respond after the presentation. d^1 and β was not found to differ between the two groups. However, when in the second condition they were allowed as many repeats as possible; obsessives asked for .227 repeat/trial vs. .065 repeat/trial for the normals. This difference was significant at the .05 level. It is hypothesized that the subjective "cost" of further observations relative to the value of correct responses is low for the obsessive. Thus the obsessive may be deferring decisions, in order to gather more information, to an abnormal extent.

Kleinmutz, B. The processing of clinical information by man and machine. In B. Kleinmutz, Formal Representation of Human Judgment. Wiley, New York: 1968.

ROC analysis is applied to the question: Would computerizing clinical evaluations improve the accuracy of diagnosis?

Four ROC curves can be plotted (almost) to form the data in this article.

1)Given the MMPI profiles of 126 students, who were themselves classified as either adjusted or maladjusted re their z-score on the normal distribution of MMPI scores, a clinician's report of decision rules for making evaluations of the profiles were programmed into a computer. This program was then used to evaluate the students. The computer's output was compared to the evaluation of the students based on their z-scores. The results were:

		Response	
		YES	NO
STATE	Maladj.	.63	.27
	Adjus.	.14	.86

2)The decision-making program was then revised by making the final evaluation depend entirely on the majority of the simple decision rulse outputs re a student. The output of this revised program was then compared in the same way as above. The results were:

		Response	
		YES	NO
STATE	Maladj.	.91	.09
	Adjus.	.12	.84

3)These new decision rules were then cross-validated on four new samples. The results were:

		Response		
		YES	NO	
STATE	Maladj.	.80	.20	p(Maladj) = 1/2
	Adjus.	.36	.64	
	Maladj.	.72	.28	p(Maladj) = .31
	Adjus.	.94	.06	
	Maladj.	.72	.28	p(Maladj.)= .31
	Adjus.	.76	.24	
	Maladj.	.43	.57	p(Maladj.) = .28
	Adjus.	.52	.48	

The most reasonable conjecture as to why there is a shift in the hit rate is that they changing probability of maladjustment with a constant decision rule represents a case in which the operator bias is not affected by changes of the world which should affect the bias. Hence the points representing these matrices on a ROC curve should be spread across different curves, rather than moved along one of the curves. This has been plotted in the figure and the conjecture (which the author failed to make) is verified. This result suggests that a mechanized decision maker must be given some idea of the prior odds in order to maintain it's senstivity.

4)Finally these computerized rules were compared with the evaluations of both "expert" and "average" clinicians using the MMPI. Unfortunetly, the author did not report either the false alarm on the correct rejection rates; even though he did report both the hit and the miss rates, so no analysis of this most important part of the experiment was possible.

Broen, W.E., Jr. & Nakamura, C.Y. Reduced range of sensory sensitivity in chronic non-paranoid schizophrenics. Journal of Abnormal Psychology, 1972, 79, 106-11.

Chronic non-paranoid schizophrenics were compared to acute paranoids in an auditory forced-choice detection task while they were simultaneously tracking a visual stimulus. Either the auditory or the visual task was set as the "important" one. The percentage of accurate reports was plotted against the two conditions. Acute paranoids were seen to remain fairly constant across tasks at approximately 75% while chronic non-paranoids showed a drop from approximately 77% to 62%. Measured in d^1; the chronic non-paranoids showed a change in d^1 of -.75 when shifting from auditory stimulus dominant to auditory stimulus secondary. On the other hand the acute paranoids showed only a drop of -.13 in d^1.

(Thus chronic non-paranoid schizophrenics are relatively unable to successfully divide their attention. It is interesting that overload cuts deeper than in the case of paranoids.) In any case, they go on to discuss the possible reason for this difference, suggesting either attention setting or channel shutdown as the answer.

Clark, W.C. Sensory decision theory analysis of the palcebo effect on the criterion for pain and thermal sensitivity (d'). Journal of Abnormal Psychology, 1969, 74, 363-371.

This study uses twelve rating scale items (labelled "nothing", "maybe something", "faint warmth" up to "very painful" and "extremely painful") to categorize thermal stimuli of four intensities. Normal observers provided these ratings of thermal stimuli applied to the forearm. Control and placebo conditions were run; the placebo was described as an extremely effective pain killer.

Proportions of hits and false alarms were computed as follows: for each response category, the conditional prabability of that response at each signal strength was obtained. These probabilities were summed in such a way that the probability of a particular response category (or a higher one) occurring was known, conditional upon a signal strength. Given any pair of adjacent stimulus intensities and a response category c, the cumulative probability of a response being c or above c for the stronger intensity level was considered analogous to the proportion of hits, whereas the cumulative probability of a response being c or above c for the weaker signal intensity was considered analogous to the proportion of false alarms. ROC's were plotted and the data supported the assumption of normality and equal variance for the underlying distributions.

Because slightly different stimulus intensities were used for each observer, a common measure of discriminability was required before data could be pooled. For each observer. differences in intensity between two adjacent stimulus intensity levels were divided by d', and the average of these values compared. No differences in this discriminability index was observed between the control and placebo conditions. Cut-off points on the decision axis were computed for a given stimulus intensity pair and a response category. The placebo condition lead to the use of a <u>more</u> <u>severe</u> criterion, therefore effecting only observers willingness to report pain. It is suggested that studies in pain have not always distinguished between physiological and psychological (response bias) factors.

Clark, W.C. Acupunctural analgesia? Evaluation by signal detection theory. <u>Science</u>, 1974, <u>184</u>, 1096-1098.

A 12-category rating procedure was used to determine the effects of acupuncture (of the arm) on the perception of thermal pain. Before, during and after acupuncture conditions were run, and the pain intensity ratings for the acupuncture arm were compared with those of the non-acupunctured one. An analysis of variance on the obtained d's failed to reveal significant differences between acupunctured and control arm and between treatment periods. The criterion point, on the other hand, was significantly higher for the acupunctured arm during acupunctural stimulation than for the control arm. The failure to obtain a decrement in d' suggests that acupuncture does not produce a decrease in the sensitivity to pain. However, during acupunctural stimulations, observers are less likely to report sensations of pain., as is evidenced by the choice of the stricter criterion in that condition. As in this author's earlier work, there are clear implications for the measurement of the "psychic" affects of pain relievers.

Stanford, R.G. Response bias and the correctness of ESP test responses. <u>Journal</u> <u>of</u> <u>Parapsychology</u>, 1967, <u>31</u>, 280-289.

This article uses some of the language of TSD to discuss an issue in parapsychology. The notion is that a person is more likely to consider a thought or intuition as ESP Mediated if its day by day probability of occurrence is low. A severe response criterion is supposed to reflect this tendency to take signal probabilities into account. The claim is then made (and experimental evidence provided) that this severe response bias leads to more "accurate" responding than a laxer response bias. It is difficult to disentangle the conceptual confusions as regards TSD, but it appears that a clear understanding of TSD and a well constructed application of the model would have allowed the author to sharpen his argument considerably.

Ryder, P. & Pike, R. Criteria placement in detection: Implication for Kogan and Wallach's theory of risk-taking. Australian Journal of Psychology, 1973, 25, 211-216.

Kogan and Wallach's theory predicts that observers who score low in test anxiety and defensiveness (as measured on certain personality scales) will tend to behave optimally in risk taking situations, whereas those who score high will be consistently either conservative or risky in their decisions. A signal detection experiment was conducted with a symmetrical, "yes"-biased and a "no" biased pay-off matrix. Low scores tended to move their criterion in the direction suggested by the pay-off matrix, but did not behave optimally. High scores tended to perform conservatively under all pay-off matrices. Kogan and Wallach's theory is therefore called into question. The experiment constitutes and application of TSD to the study of individual differences.

Hardy, G.R. & Legge, D. Cross modal induction of changes in sensory thresholds. Quarterly Journal of Experimental Psychology, 1968, 20, 20-29.

Two experiments are reported in which subliminal stimulation of one modality with emotional material impaired detection performance in another modality. TSD was applied to the second experiment in which emotional or neutral words were presented visually (below any level of "consciousness") concurrently with the auditory presentation of a 1000 Hz tone embedded in white noise. Observers were instructed to report on the detectability of the tone according to the rating procedure. Overall d's were shown to differ significantly depending on whether concurrent visual stimulation was neutral or emotional (emotional d' was lower). Difference in criterion placement were also observed between the two conditions, but were attributed to the effect of changes in the separation of the underlying distributions under conditions of a fixed cut-off point. The authors argue that the decrease in d' during cross modal emotional stimulation implies that perceptual defense to emotional stimuli is a central rather than a peripheral effect. A hypothesis is discussed which attributes "perceptual defense" to decreased cortical arousal caused by depressed reticular activity following discrimination of the emotional stimulus.

Lieblich, I. Kugelmass, S. & Ben-Shakkar, G. Efficiency of GSR detection of information as a function of stimuluz set size. Psychophysiology, 1970, 6, 601-609.

No significant reduction in absolute detection scores was found as the number of stimulus cards was increased and an analysis based on the theory of signal detection also suggested better autonomic discrimination as the stimulus set size increased. Results suggest that the observer responds to the stimuli by dividing them into a single relevant stimulus and a reject category containing all other.

Neal, J. M., McIntyre, C. W., Fox, R., & Cromwell, R. L. Span of apprehension in acute schizoprenia. J. Abnormal Psych., 1968, 74, 593-596.

The span of apprehension in two groups (good premorbid paranoid and poor morbid nonparanoid) of schizophrenics was compared with the span for a normal control group (hospital aides) by a forced choice letter recognition analogous to TSD methodology. This procedure, in conjunction with a quantitative model of the span, provides an indirect but relevant measure insensitive to variance imposed by nonperceptual systems. The span size was the same for all three groups in the absence of visual "noise." With visual noise the span drops about 50% for the schizophrenic groups. It is argued that the reduction in span represents a true deficit in attention, uncontaminated by extraneous variables.

Ogasawara, I. Relation between detectability and personality traits: An application of signal detection theory. Japanese Journal of Educational Psychology, 1968, 16, 80-86.

The author attempted to determine how well Japanese students could evaluate the intelligibility of their own English hearing reception, applying the detectability measure of detection theory. Correlation coefficients indicate that depressive, neurotic, introversive scores of personality tests had negative correlations with the detectability measure.

Rappaport, M., Hopkins, H. K., Silverman, J., & Hall, K. Auditory signal detection in schizophrenics. Psychopharmacologia, 1972, 24, 6-28.

Signal detection performance of paranoids increased while that of non-paranoids decreased, with increasing dosage of phenothiazine. Paranoids were also found to adopt more conservative criteria throughout all conditions. Normals and non-paranoid schizophrenics adopted close to optimum (?) criteria. It is suggested that d' represents more than just the sensitivity of the auditory mechanism itself, and contains influences of para-auditory problems of the syndrome. (The authors don't say this well, and they seem to be strawgrasping at that point. However the summary sentence is a not unreasonable facsimile of the deep structure of their thought.)

Smith, E. E. Short-term memory impairment in chronic schizophrenic. Canadian J. of Psych., 1969, 23, 114-126.

The information to be remembered was presented both visually and verbally and was later probed for--after a variable interval--by either visual or verbal cues. The schizophrenics and controls did not differ with respect to which type of cue retrived more of the information, suggesting that the modality in which the information was stored was the same for both groups. However, the schizophrenics was markedly inferior to the controls with regard to both the initial acquisition of information and the maintenance of it in storage. The important conclusion is that in comparison with controls, schizophrenics show a poorer initial acquisition and a faster loss of information even when memory is indexed by d', a measure which is independent of the response bias.

Strickland, B. R. & Bodwan, A. S. Relation of certain personality variables to decision making in perception. Perceptual & Motor Skills, 1964, 18, 353-359.

Observers were given the Marlowe-Crowne Social Desirability Scale to measure need for approval and then given a binary guessing task to obtain an estimate of the criterion measured as the ratio of the hit to false-alarm rate. Observers who showed a strong need for approval showed a greater willingness to say yes, producing more false alarms compared to hits than the people needing less approval.

Gordon, S. K. & Clark, W. C. Application of signal detection theory to prose recall and recognition in elderly and young adults. J. of Gerontology, 1974, 29, 64-72.

There were age differences in recall at both retention intervals. The difference between the two age groups on delayed recall was greater than that observed for immediate recall. As response bias remained constant while d' shifted there is evidence that there is deterioration of recent memory in the elderly.

Dorfman, D. D., Keeve, S. & Saslow, C. Ethnic identification: A signal detection analysis. Journal of Personality & Social Psychology, in press.

Indices of sensitivity and response bias were obtained from receiver operating characteristics in a task requiring the identification of Jews and non-Jews from facial photos. With constant sensitivity, high prejudiced observers showed greater confidence (presumably reflected in lower variance of bias param.) in their judgments than low prejudiced observers.

Clement, D. E. & Sullivan, D. W. No risky shift effect with real groups and real risks. Psychonomic Science, 1970, 18, 243-244.

Five discussion sections of an introductory psychology course were asked to select an examination schedule from a set of eight alternatives. The choices had been scaled by students in a previous course on a risk-safety continuum. Four of the five groups shifted in a conservative direction from the average of initial individual choices. The results suggest that the "risky-shift" effect is an artifact of the laboratory conditions.

Clark, W. C. & Mehl, L. Signal detection theory procedures are not equivalent when thermal stimuli are judged. Journal of Experimental Psychology, 1973, 97, 148-153.

A total of 34 intensity pairs, differing by 25 $mcal/sec/cm^2$ were used as objects of discrimination. Yes-No and 2AFC procedures were seen to yield a higher d' than either confidence rating or magnitude rating procedures. It is suggested that a variable criterion, rather than a noisy memory is responsible for the shift. (This hypothesis seems nonsensical given the assumed independence of d' and the criterion, but it is representative of much of the work done at Biometrics. For example, it is found in many of the evoked potential studies of Paul and Sutton. Either they have really found cases of non-independence, or they don't understand TSD well enough to make good parameter estimations, or to evaluate simultaneous shifts in d' and c appropriately.

Clark, W. C. & Mehl, L. Thermal pain: A sensory decision theory analysis of effect of age and sec on d', various response criterion, and 50% pain threshold. Journal of Abnormal Psychology, 1971, 78, 202-212.

Rating scale procedure (a la Egan et. al.) was used to determine d' and a β-like measure. Older women had a lower d' over the entire sensory range (0-300 mcal/sec/cm^2). At noxious levels, the older females' d' was less than that of all the males. Also at noxious levels, older participants set a higher criterion for reporting pain. The values for d' and L_x (critical liklihood ratio) suggest that older men and, to a lesser extent, older women endure greater pain without reporting it than the younger participants. Differences in thresholds obtained by the method of constant stimuli was shown to be the effect of differences in response bias.

Chapman, C. R. & Feather, B. W. Modification of perception by classical conditioning procedures. J. Exp. Psych., 1972, 93, 338-342.

In a controlled yes-no visual detection task, the group for whom the signal was also a CS in a conditioned fear paradigm d' was higher and c lower after the conditioning. Neither random shock or no shock controls showed any change in either parameter.

Chapman, C. R. & Feather, B. W. Sensitivity to phobic imagery: A sensory decision theory analysis. Behav. Res. & Ther., 1971, 9, 161-168.

A TSD-analysis of sensitivity of deep-muscle relaxed and non-relaxed phobic participants to phobic imagery is reported. Deep muscle relaxation leads to increase in d'. This is contrary to the expectations of Wolpe's theory of systematic desensitization; i.e. counter-conditioning via reciprocal inhibition cannot be the mechanism responsible for desensitization. It is suggested instead that the role of relaxation (and therefore of sensitivity) is to enhance discrimination learning.

Boissonneault, D. R., Dorosh, M. E., & Tong, J. E. The effect of induced heart rate change and neuroticism on the resolution of temporally paired flashes. Psychophysiology, 1970. 7.

Highly extroverted participants with high neuroticism scores were compared with other highly extroverted participants with low neuroticism scores in a two flash flicker threshold task under induced heart rate changes. There was no significant change in either group of the sensitivity measure under the induced heart rate change, although the high neurotics had systematically lower d's under all three conditions (low, medium, and high activation). Both groups showed changes in bias under the different activation conditions. The low neurotics showed both a larger and more orderly change in bias.

Berstein, I.H. & Day, R.H. Size constancy in mental retardates and normals: A signal defectability analysis. Journal of Abnormal Psychology, 1971, 78, 177-179.

Size constancy in institutionalized and non-institutionalized mental retardates were compared with size constancy in institutionalized (prison inmates) and non institutionalized (college students) normals. d_s was used as a measure of sensitivity. The rank order of results, all differences being significant were:

$$MR_{in} < MR_{out} < PI < CS$$

Dandeliker, J. & Dorfman, D.D. ROC curves for taboo and neutral words. Psychonomic Science, 1969, 17, 201-202.

This study evaluates TSD with respect to its application to the recognition of taboo words. On each trial, one of two stimuli was presented, with equal probability, a taboo or neutral word, for a duration of 50 msec. Upon presentation of the stimulus word, the observers responded with one of the two words, and with a confidence rating. The theory was fitted to rating-method data by means of the method of maximum likelihood, and the chi-square test of goodness was used to evaluate the theory. Data were found to be in reasonably good agreement with TSD.

Greenberg, G.Z., Bray, N.W., & Beasley, D.S. Children's frequency-selective detection of signals in noise. Perception & Psychophysics, 1970, 8, 173-175.

Children of median age seven and adults of median age twenty served as observers in a task requiring the detection of auditory signals embedded in noise. A 2AFC procedure was used. 70% of the signals were of 1000 Hz, 30% were probe signals of frequency other than 1000 Hz. Results from adults and children were similar, showing differential P(C) as a function of signal frequency. The results are consistent with a frequency selective, sensory filter model of auditory behavior.

Ulehla, J. Z., Canges, L., & Wackwitz, I. Integration of conceptual information. Psychonomic Science, 1967, 8, 223-224.

The integration of information model of TSD is tested in multiple observation conceptual discrimination tasks. Stimulus materials were sections of English prose selected from a "he-man" magazine and a "confessional" magazine. One, two, or three items from a single source were presented on a given trial. TSD predicts d' for the double presentation condition to be $2^{1/2}$ times single presentation d', and triple presentation d' to be $3^{1/2}$ times single presentation d'. Improvements in the observed d's for the multiple observation conditions were below the predicted values. However, the improvements approximated those theorectically predicted values when instead of a single binary decision at the end of a multiple observation condition observers gave binary decisions and confidence ratings after each stimulus presentation; this permitted d's to be computed for first, second, and third judgments. The observed improvement in d' was evidence for the integration of conceptual information across observations.

Adams, D. K. & Ulehla, Z.J. Signal detection analysis of aggression scale data. Proceedings of the 77th Annual Convention, Washington, D.C. American Psychological Association, 1969, 387-388.

Observers ratings of the consequences of situationally instigated and situationally uninstigated agression were dichotomized into positive or negative expected outcomes. The data were then analyzed using TSD in order to determine whether observers responses discriminated between these two classes of aggression. The observer groups consisted of lower and middle classs anglo-Hispano and Blacks. When the consequences involved physical injury, the overall ratings did not discriminate between the two classes of aggressive acts, though a large negative bias was observed. On the other hand, when the consequences involved peer reactions, d' was--favorable ratings being associated with situationally instigated and unfavorable ratings with situationally uninstigated acts. Futhermore, there were inter-group differences in d's lower class Blacks, for example, showing consistently low d's on all types of consequences. The analysis implies that social behavior is determined both by the ability to discriminate classes of social phenomena and by bias toward one or another form of response.

Ben-Shakar, G., Lieblich, I, & Kugelmass, S. Guilty knowledge technique: Application of signal detection measures. Journal of Applied Psychology, 1970, 5, 409-413.

The results of polygraph readings of GSRs were submitted to a TSD analysis in order to determine the optimal decision rules for information detection. Different pay-off matrices were taken to represent the relative gains and losses typical of security screening and court room situations, and different optimal cut-off points were computed.

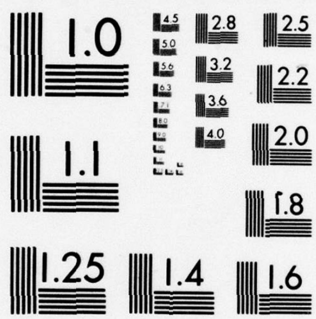
Van Egeren, L. Repression and sensitization: sensitivity and recognition criteria. Journal of Experimental Research in Personality, 1968, 3, 1-8.

Observers were classified as "repressors" or as "sensitizors and were run in a word recognition task. Each of four affective and four neutral words was presented tachistoscopically and on each trial observer had to choose recognition response from a pair of affective words, from a pair of neutral words or from an affectively neutral word pair. Observer was also required to rate the confidence of decision on a three point scale. Proportions of hits and false alarms were computed and indicated that repressors and sensitizors do not differ in their sensitivity to affective and neutral words, nor do their response criteria differ. Across observers, affective words and neutral words were about equally recognizable, but observers set

AD-A059 010 COLUMBIA UNIV NEW YORK PSYCHOPHYSICS LAB F/G 5/10
APPLICATIONS OF TWO-PARAMETER DECISION THEORIES IN PSYCHOLOGY.(U)
AUG 78 E GALANTER N00014-67-A-0108
UNCLASSIFIED PLR-39 NL

2 OF 2
AD
A059010

END
DATE
FILMED
11-78
DDC


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

lower response criteria for the recognition of neutral words. The authors criticize previous threshold measures in the area of perceptual defense against affective words and stress TSD as a model for separating sensitivity from response bias factors.

Brodsky, S.L. Psychologists in the Criminal Justice System. Champaign, IL: University of Illinois Press, 1973.

Although no direct reference to detection theory is made in this book, some of the applications reported could be systematized by TSD analysis. For example, experimental verification of the act itself, actus res, using psychological investigation of the relevant processes is said to lead to probability estimates of the liklihood of events occurring under the supposed conditions of the alleged act. Thus both witness and defendent can have d' and c measured under conditions similar to the conjectured ones, leading to a systematic classification of sensitivity to certain acts and response biases (both report and action). This might facilitate the understanding of the percepts and behavioral proclivities leading up to and resulting from particular situations and actions.

Futhermore, he reports that judges have expressed the desire to understand precisely the outcomes of their judicial decisions. He suggests in particular, the investigation of 1)probability of perceptual errors, 2) assessment of statement veracity, and 3)psychological functioning of juries.

Epilogue

The seven areas of active research that have been discussed in the preceding pages represent the major, but by no means the complete extensions of decision theory as a statistical tool and an analytical concept. Perhaps the most remarkable consequence of the development of this theory is the pervasiveness with which its ideas have become absorbed into the body of psychology. Whole segments of human experimental psychology that, during the undisputed reign of behaviorism were barely alluded to, have now developed into a central segment of human experimental studies under the rubric of cognitive psychology. And although one may have anticipated the development of such a field, it would have been thought to be a "soft" discipline. However the quantitative power of decision theory opened opened options in the analysis of complex behavior, and so motivated the development of other theories to accomodate cognitive aspects of human performance.

These spin-offs of quantitative theory making into areas previously untouched by such formulations have also induced a rebound effect. The fields of sensory psychophysics and physiology have themselves been broadened and deepened by the recognition of a role for central control systems on the sensory apparatus. We mean here not the modulation of sensory inflow by central adaptation effects or enhancement processing, but rather the active nature of the mechanisms implicit in the decision theoretic ideas for the control and selectivity of input information. This is probably best seen in the development of theoretical models for the study of such topics as reading and systems control. Here eye-movement data, so highly structured and ballistic in quality, may ultimately be shown to be the product of complex plans and schema that are themselves the consequential output of decision theoretic and similar abstract mechanisms.

We conclude this monograph by remarking on the vitality of psychological research and its relation to theory construction. Not since the middle thirties has the development of a new psychological theory generated so much interest and activity in so many different fields. Two-parameter decision theories have created an excitement and activity in experimental psychology far beyond the early anticipation of its first proponents and expositors. We can demonstrate this most forcefully by concluding with a quotation from the author's introduction to psychophysics published in 1962.

> "Unlike many other branches of psychology (although by no means all others), laboratory studies in psychophysics make use of highly reproducible stimulating conditions and give rise to repeatable data that can be easily transformed into numerical values. As a consequence of this "quantitative" feature of psychophysics, much theoretical work that depends upon the use of very sophisticated mathematical techniques has been done. In fact, the primary motivation for the conduct of many

psychophysical experiments now is to test various mathematical formulations about the nature of human judgment and decision making in these relatively "pure" contexts. Mathematical theories in psychophysics are being coupled with other theories from its sister field of learning and one forms the impression that a coalition of activity in these two theoretical areas will be forth coming. As a consequence, we can expect to see highly developed theoretical work providing us with a deeper understanding of the nature of human behavior in these restricted situations. The basic faith of scientists working in these fields is that an under standing of behavior within this restricted context will provide a base for generalization to the more elaborate forms of behavior we find in common experience. But whether or not we will ever under stand the complex actions of the person in his natural habitat, we are sure to gain new insight into the bases of behavior on which the complexities of human nature may ultimately depend." (Galanter, 1962)

APPENDIX I

Area above Z, Z, and the ordinate -f-

AREA	Z	f	AREA	Z	f
.01	2.326	.0267	.51	-.025	.3988
.02	2.053	.0484	.52	-.050	.3984
.03	1.881	.0681	.53	-.075	.3978
.04	1.750	.0862	.54	-.100	.3970
.05	1.645	.1032	.55	-.125	.3958
.06	1.555	.1192	.56	-.150	.3945
.07	1.476	.1343	.57	-.176	.3928
.08	1.405	.1487	.58	-.201	.3909
.09	1.340	.1625	.59	-.227	.3888
.10	1.281	.1756	.60	-.253	.3864
.11	1.226	.1881	.61	-.279	.3838
.12	1.175	.2001	.62	-.305	.3808
.13	1.126	.2116	.63	-.331	.3777
.14	1.080	.2227	.64	-.358	.3742
.15	1.036	.2333	.65	-.385	.3705
.16	.994	.2434	.66	-.412	.3665
.17	.954	.2532	.67	-.439	.3623
.18	.915	.2625	.68	-.467	.3577
.19	.877	.2715	.69	-.495	.3529
.20	.841	.2801	.70	-.524	.3478
.21	.806	.2883	.71	-.553	.3424
.22	.772	.2962	.72	-.582	.3368
.23	.738	.3038	.73	-.612	.3308
.24	.706	.3110	.74	-.643	.3245
.25	.674	.3179	.75	-.674	.3179
.26	.643	.3245	.76	-.706	.3110
.27	.612	.3308	.77	-.738	.3038
.28	.582	.3368	.78	-.772	.2962
.29	.553	.3424	.79	-.806	.2883
.30	.524	.3478	.80	-.841	.2801
.31	.495	.3529	.81	-.877	.2715
.32	.467	.3577	.82	-.915	.2625
.33	.439	.3623	.83	-.954	.2532
.34	.412	.3665	.84	-.994	.2434
.35	.385	.3705	.85	-1.036	.2333
.36	.358	.3742	.86	-1.080	.2227
.37	.331	.3777	.87	-1.126	.2116
.38	.305	.3808	.88	-1.175	.2001
.39	.279	.3838	.89	-1.226	.1881
.40	.253	.3864	.90	-1.281	.1756
.41	.227	.3888	.91	-1.340	.1625
.42	.201	.3909	.92	-1.405	.1487
.43	.176	.3928	.93	-1.476	.1343
.44	.150	.3945	.94	-1.555	.1192
.45	.125	.3958	.95	-1.645	.1032
.46	.100	.3970	.96	-1.750	.0862
.47	.075	.3978	.97	-1.881	.0681
.48	.050	.3984	.98	-2.053	.0484
.49	.025	.3988	.99	-2.326	.0267
.50	.000	.3989			

References

Adams, D. K. & Ulehla, Z. J. Signal detection analysis of agression scale data. Washington, D. C.: American Psychological Association, 1969, 387-388.

Aiken, E. G. & Lau, A. W. Memory for the pitch of a tone. Perception & Psychophysics, 1966, 1, 231-233.

Allen L. R. & Garton, R. F. Detection and criterion change associated with different text contexts in recognition memory. Perception & Psychophysics, 1969, 6, 1-4.

Allen, L. R. & Garton, R. F. Manipulation of study trials in recognition memory. Perception & Psychophysics, 1970, 7, 215-217.

Annett, J. & Paterson, L. Training for Auditory Detection. Acta Psychologica, 1967, 27, 420-426.

Baekeland, F. & Hoy, P. Vigilance before and after sleep. Perceptual & Motor Skills, 31, 1970, 583-586.

Banks, W. P. Criterion change and response competition in unlearning. Journal of Experimental Psychology, 1969, 82, 216-223.

Banks, W. P. Signal detection theory and human memory. Psych. Bull., 1970, 74, 81-99.

Barr-Brown, M. & White, M. J. Sex differences in recognition memory. Psychonomic Science, 1971, 25, 75-76.

Ben-Shakar, G., Lieblich, I., & Kugelmass, S. Guilty knowledge technique: Application of signal detection measures. Journal of Applied Psychology, 1970, 5, 409-413.

Bernbach, H. A. & Bower, G. H. Confidence ratings in continuous paired-associate learning. Psychonomic Science, 1970, 21, 252-253.

Bernstein, I. H., Clark, M. H. & Blake, R. R. Sensitivity and decisional factors in the psychological refractory period. Perception & Psychophysics, 1970, 7, 33-37.

Bernstein, I. H. & Day, R. H. Size constancy in mental retardates and normals: A signal defectability analysis, Journal of Abnormal Psychology, 1971, 78, 177-179.

Blackwell, H. R. Psychophysical Thresholds, experimental studies of methods of measurement. University of Michigan Press, Engineering Research Institute, 1953, 36.

Boissonneault, D. R., Dorosh, M. E., & Tong, J. E. The effect of induced heart rate change and neuroticism on the resolution of temporally paired flashes. Psychophysiology, 1970, 7, 3.

Boneau, C. A. & Cole, J. L. Decision theory, the pigeon, and the psychophysical function. Psychological Review, 1967, 74, 123-135.

Bothe, G. B. & Marks, L. E. Absolute sensitivity to white noise under auxiliary visual stimulation. Perception & Psychophysics, 1970, 8, 176-178.

Broadbent, D. E. Decision and Stress. New York: Academic Press, 1971.

Brodsky, S. L. Psychologists in the Criminal Justice System. Champaign, Il: University of Illinois Press, 1973.

Broen, W. E., Jr. & Nakamura, C. Y. Reduced range of sensory sensitivity in chronic non-paranoid schizophrenics. Journal of Abnormal Psychology, 1972, 79, 106-111.

Brown, A. E. & Hopkins, H. K. Interaction of the auditory and visual sensory modalities. Journal of the Acoustical Society of America, 1967, 41, 1-6.

Brown, J. & Routh, D. A. Recognition assessed by d' and by a non-parametric alternative (the A-index) as a function of the number of choices. Quarterly Journal of Experimental Psychology, 1970, 22, 707-719

Brown, K. & Warburton, D. M. Attenuation of stimulus sensitivity by scopolamine. Psychonomic Science, 1971, 22, 297-298.

Cahoon, R. L. Vigilance performance under hypoxia. Journal of Applied Psychology, 1970, 54, 479-483.

Carterette, E. C. & Cole, M. Comparison of the receiver operating characteristics for messages received by ear and by eye. Journal of the Acoustical Society of America, 1962, 34, 172-178.

Carterette, E. G., Friedman, M. P. & Wyman, M. J. Feedback and psychophysical variable in signal detection. Journal of the Acoustical Society of America, 1966, 39, 1051-1055.

Chapman, C. R. & Feather, B. W. Sensitivity to phobic imagery; A sensory decision theory analysis. Behav. Res. & Ther., 1971, 9, 161-168.

Chapman, C. R. & Feather, B. W. Modification of perception by classical conditioning procedures. Journal Experimental Psychology, 1972, 2, 93.

Clark, W. C. The psyche in psychophysics: A sensory decision theory analysis of the effect of instructions on flicker sensitivity and response bias. Psychological Bulletin, 1966, 65, 358-366.

Clark, W. C. Sensory decision theory analysis of the placebo effect on the criterion for pain and thermal sensitivity (d'). Journal of Abnormal Psychology, 1969, 74, 363-371.

Clark, W. C. Acupunctural analgesia? Evaluation by signal detection theory. Science, 1974, 184, 1096-1098.

Clark, W. C., Brown, J. C., & Rutschmann, J. Flicker sensitivity and response bias in psychiatric patients and normal subjects. Journal of Abnormal Psychology, 1967, 72, 35-42.

Clark, W. C. & Greenberg, D. B. Effects of stress, knowledge of results, and proactive inhibition on verbal recognition memory (d') and response criterion (L_x). Journal of Personality and Social Psychology, 1971, 17, 42-47.

Clark, W. C. & Nehl, L. Thermal pain: A sensory decision theory analysis of effect of age and sex on d', various response criterion, and fifty percent pain threshold. Journal of Abnormal Psychology, 1971, 78, 202-212.

Clark, W. C. & Mehl, L. Signal detection theory procedures are not equivalent when thermal stimuli are judged. Journal of Experimental Psychology, 1973, 97, 148-153.

Clement, D. E. & Hosking, K. E. Scanning strategies and differential sensitivity in a visual signal detection task: Intrasubject reliability. Psychonomic Science, 1971, 22, 323-324.

Clement, D. E. & Sullivan, D. W. No risky shift effect with real groups and resl risks. Psychonomic Science, 1970, 18, 243-244.

Colquhoun, W. P. & Baddeley, A. D. Role of pretest expectancy in vigilance decrement. Journal of Experimental Psychology, 1964, 68, 156-160.

Creelman, C. D. Human discrimination of auditory duration. Journal of the Acoustical Society of America, 1962, 34, 582-593.

Creelman, C. D. & Donaldson, W. ROC curves for discrimination of linear extent. Journal of Experimental Psychology, 1968, 77, 514-516.

Dandeliker, J. & Dorfman, D. D. ROC curves for taboo and neutral words. Psychonomic Science, 1969, 17, 201-202.

Davenport, W. G. Vibrotactile vigilance: The effects of cost and values on signals. Perception & Psychophysics, 1969, 5, 25-28.

Dodwell, P. C., Standing, L. G. & Thio, H. Are thresholds reduced by illusion? An attempt at replication. Quarterly Journal of Experimental Psychology, 1969, 21, 127-133.

Doehrman, S. The effect of visual orientation uncertainty in a simultaneous detection-recognition task. Perception & Psychophysics, 1974, 15, 519-523.

Donaldson, W. & Glathe, H. Recognition memory for item and order information. Journal of Experimental Psychology, 1969, 82, 557-560.

Donaldson, W. & Murdock, B. B., Jr. Criterion change in continuous recognition memory. Journal of Experimental Psychology, 1968, 76, 325-330.

Dorfman, D. D., Keeve, S. & Saslow, C. Ethnic identification: A signal detection analysis. Journal of Personality & Social Psychology,

Dorosh, M. E., Tong, J. E. & Boissoneault, D. R. White noise, instructions, and two-flash fusion with two signal detection procedures. Psychonomic Science, 1970, 20, 98-99.

Ducharme, W. M. A review and analysis of the phenomenon of conservatism in human inference. Houston, Tx: Rice University, Interdisciplinary Program in Applied Mathematics and Systems Theory, Systems #46-5, 1969.

DuCharme, W. M. Response bias explanation of conservative human inference. Journal Experimental Psychology, 1970, 85, 66-74.

Durlach, N. I. & Braida, L. D. Intensity perception. I. Preliminary theory of intensity resolution. Journal of the Acoustical Society of America, 1969, 46, 372-383.

Earle, D. C. & Lowe, G. Channel, temporal and composite uncertainty in the detection and recognition of auditory and visual signals. Perception & Psychophysics, 1971, 9, 177-181.

Egan, J. P. Recognition memory and the operating characteristic, Bloomington, In: Indiana University, Hearing and Communication Laboratory, 1958, AFCRC TN 58 51, AD-152650.

Eijkman, E. & Vendrik, J. H. Can a sensory system be specified by its internal noise? Journal of the Acoustical Society of America, 1965, 37, 1102-1109.

Elfner, L. F. & Delaune, W. R. Detection of shift in binaural images: A rating method approach. Perception & Psychophysics, 1970, 8, 158-160.

Emmerich, D. S. ROCs obtained with two signal intensities presented in random order, and a comparison between yes/no and rating ROCs. Perception & Psychophysics, 1968, 3, 35-40.

Erdelyi, M. H. Recovery of unavailable perceptual input. Canadian J. Psychology, 1970, 1, 99-113.

Evans, T. R. Differential effects of dexamphetamine and phenidylate on auditory detection. Psychonomic Science, 1969, 17, 139-140.

Exner, S. Pflug. Arch. ges. Phy., 1873, 7, 601.

Friedman, M. P., Carterette, E. C., Nakatani, L., & Ahumada, A. Comparisons of some learning models for response bias in signal detection. Perception & Psychophysics, 1968, 3, 5-11.

Galanter, E. An axiomatic and experimental study of sensory order and measure. Psychological Review, 1956, 63, 16-28.

Galanter, E. Contemporary psychophysics. Newcomb, T. (ed.) New Directions in Psychology. New York: Holt, Rinehart, & Winston, 1962, 89-156.

Galanter, E. Signal detection, Yearbook Science & Technology. New York: McGraw-Hill, 1966, 387-389.

Galanter, E. Psychological decision mechanisms and perception. Carterette, E. & Friedman, M. (eds.) Handbook of Perception. New York: Academic Press, 1974, II, Ch. 4.

Galanter, E. Psychophysics: An overview. Wolman, B. (ed.) International Encyclopedia of Psychiatry, Psychology, Psychoanalysis, and Neurology. New York: Aesculapius Publishes, Inc., 1977, 283-288.

Galanter, E. & Gerstenhaber, M. On thought: The extrinsic theory. Psychological Review, 1956, 63, 218-227.

Galanter, E. & Holman, G. L. Some invariances of the isosensitivity function and their implications for the utility function of money. Journal of Experimental Psychology, 1967, 73, 333-339.

Gescheider, G. A., Barton, W. G., Bruce, M. R., Goldberg, J. H. & Greenspan, M. J. Effects of simultaneous auditory stimulation on the detection of tactile stimuli. Journal of Experimental Psychology, 1969, 81, 120-125.

Gescheider, G. A., Wright, J. H., & Evans, M. B. Reaction time in the detection of vibrotactile signals. Journal of Experimental Psychology, 1968, 77, 501-504.

Gibson, K. L. Criterion shifts and the determination of the memory operating characteristic. Psychonomic Science, 1967, 9, 207-208.

Goodman, N. Science and simplicity. Morgenbesser, S. (ed.) Philosophy of Science Today. New York: Basic Books, Inc., 1967, 7, 68-78.

Gordon, S. K. & Clark, W. C. Application of signal detection theory to prose recall and recognition in elderly and young adults. Journal of Gerontology, 1974, 29 (1), 64-72.

Gourevitch, V. & Galanter, E. A significance test for one parameter isosensitivity functions. Psychometrika, 1967, 32 (1), 25-33.

Graham, C. & Ratoosh, P. Notes on some inter-relations of sensory psychology, perception, and behavior. Koch, S. (ed.) Psychology: A Study of a Science, New York: McGraw-Hill, 1962, 4, 483-514.

Green, D. M. Psychoacoustics and detection theory. Journal of the Acoustical Society of America, 1960, 32, 1189-1203.

Greenberg, G. Z., Bray, N. W., & Beasley, D. S. Children's frequency-selective detection of signals in noise. Perception & Psychophysics, 1970, 8, 173-175.

Gross, H. A., Boyer, W. N., & Guyot, G. W. Determination of a DL using two point tactual stimuli: A signal detection approach. Psychonomic Science, 1970, 21, 198-199.

Gruzelar, J. H. & Corballis, M. C. Effects of instructions and drug administration on temporal resolution of paired flashes. Journal of Experimental Psychology, 1970, 22, 115-124.

Guralnick, M. J. & Harvey, K. G. Response requirements and performance in a visual vigilance task. Psychonomic Science, 1970, 20, 215-217.

Hack, M. H. Signal detection in the rat. Science, 1963, 139, 758-760.

Halpern, J. & Ulehla, S. Z. The effect of multiple responses and certainty estimates on the integration of visual information. Perception & Psychophysics, 1970, 7, 129-132.

Hammerton, M. An investigation into changes in decision criteria and other details of a decision making task. Psychonomic Science, 1970, 21, 203-204.

Hardy, G. R. & Legge, D. Cross modal induction of changes in sensory thresholds. Quarterly Journal of Experimental Psychology, 1968, 20, 20-29.

Hare, R. D. Detection thresholds for electric shock in psychopaths. Abnormal Psychology, 1968, 73, 268-272.

Hatfield, J. L. & Soderquist, D. R. Practice effects and signal detection indices in an auditory vigilance task. Journal of the Acoustical Society of America, 1969, 46, 1458-1463.

Hatfield, J. L. & Soderquist, D. R. Coupling effects and performance in vigilance tasks. Human Factors, 1970, 12, 351-359.

Hood, D. C. Visual sensitivity. Wolman, B. (ed.) International Encyclopedia of Psychiatry, Psychology, Psychoanalysis, and Neurology. New York: Aesculapius Publishers, Inc., 1977.

Henderson, L. Simple reaction time, statistical decision theory and the speed-slowness tradeoff. Psychonomic Science, 1970, 21, 323-324.

Hershman, R. L. & Small, D. Tables for d' for detection and localization. Perception and localization. Perception & Psychophysics, 1968, 3, 321-323.

Hickson, R. H. Signal detection in a paired-associate learning task. Psychonomic Science, 1968, 12, 253-254.

Hillyard, S. A., Squires, K. C., Bauer, J. W., & Lindsay, P. H. Evoked potential correlates of auditory signal detection. Science, 1971, 172, 1357-1360.

Hochouse, L. Correct response discrimination as a function of multiple recognition choices: Effect of guessing on type II d'. Journal of Experimental Psychology, 1970, 84, 458-461.

Huckle, H. Signal detection in the albino rat. Seattle, WA: University of WAshington, Unpublished doctoral dissertation, 1972.

Hume, A. L. Auditory detection and optimal response biases. Perception & Psychophysics, 1974, 15, 425-433.

Irwin, F. W. & Preston, M. G. Avoidance of repetition of judgments across sense modalities. Journal of Experimental Psychology, 1937, 21, 511-520.

Irwin, R. J. & Terman, M. Detection of brief tones in noise by rats, Journal of the Experimental Anals. of Behavior, 1970, 13, 135-143.

Jacobs, D. C. & Galanter, E. Estimates of utility function parameters from signal detection experiments. New York: Columbia University, Psychophysics Laboratory Report, 1974, 32.

Jerison, H. J. & Pickett, R. M. Vigilance: The importance of the eliciated observing rate. Science, 1964, 143, 970-971.

Johanson, A. M. The influence of incentive and punishment upon reaction-time. Archives of Psychology, 1922, 54.

John, I. D. A statistical decision theory of simple reaction time. Australian Journal of Psychology, 1967, 19, 27-34.

Katz, L. A comparison of type II operating characteristics derived from confidence ratings and from latencies. Perception & Psychophysics, 1970, 8, 65-68.

Kinchla, J. Discrimination of two auditory durations by pigeons. Perception & Psychophysics, 1970, 8, 299-307.

Kinchla, R. A. & Allan, L. G. Visual movement perception: A comparison of sensitivity to vertical and horizontal movement. Perception & Psychophysics, 1970, 8, 399-405.

Kintsch, W. An experimental analysis of single stimulus tests and multiple-choice tests of recognition memory. Journal of Experimental Psychology, 1968, 76, 1-6.

Kintsch, W. & Carlson, W. J. Changes in the memory operating characteristic during recognition learning. Journal of Verbal Learning & Verbal Behavior, 1967, 6, 891-896.

Klatzky, R. L. & Loftus, G. R. Recognition memory as influenced by number of reinforcement and type of test. Psychonomic Science, 1969, 16, 302-303.

Kleinmutz, B. The processing of clinical information by man and machine. Kleinmutz, B. (ed.) Formal Representation of Human Judgment. New York: Wiley, 1968.

Kopell, B. A & Wittner, W. K. The effects of chlorpromazine and methamphetamine on visual signal-from-noise detection. Journal of Nervous and Mental Disease, 1968, 147, 418-424.

Kopp, I. & Livermore, I. Differential discriminability or response bias: A signal detection analysis of categorical perception. Journal of Experimental Psychology, 1973, 101, 179-182.

Kuechler, H. A. & Dodwell, P. C. Auditory signal detectability as a function of pre-experimental shock. Quarterly Journal of Experimental Psychology, 1968, 20.

Lawrence, C. M. & Ross, J. Information available from brief visual presentations using two types of reports. Psychonomic Science, 1968, 13, 199-200.

Lee, W. Choosing among confusably distributed stimuli with specified likelihood ratios. Perceptual & Motor Skills, 1963, 16, 445-467.

Lee, W. Preference strength, expected value difference and expected regret ratio. Psychological Bulletin, 1971, 75, 186-191.

Levy, B. A. & Murdock, B. B., Jr. The effects of delayed auditory feedback and intralist similarity in short-term memory. Journal of Verbal Learning & Verbal Behavior, 1968, 7, 887-894.

Lieblich, I., Kugelmass, S., & Ben-Shakar, G. Efficiency of GSR detection of information as a function of stimulus set size. Psychophysiology, 1970, 6, 601-609.

Lieblich, A & Lieblich, I. Arithmetical estimation under conditions of different pay-off matrices. Psychonomic Science, 1969, 14, 87-88.

Light, L. L. & Carter-Sobell, L. Effects of changed semantic context on noun recognition memory. Journal Verbal Learning & Verbal Behaviour, 1970, 9, 1-11.

Linker, E., Moore, M. E. & Galanter, E. Taste thresholds, detection models and disparate results. Journal of Experimental Psychology, 1964, 67, 59-66.

Lockhart, R. S. & Murdock, B. B. Memory and the theory of signal detection. Psychological Bulletin, 1970, 74, 100-109.

Loeb, M. & Binford, J. R. Examination of some factors influencing performance on an auditory monitoring task with one signal per session. Journal Experimental Psychology, 1970, 83, 40-44.

Loeb, M., Hawkes, G. R., & Alluisi, E. A. The influence of d-amphetamine, benactyzine, and chlorpromazine on performance in an auditory vigilance task. Psychonomic Science, 1965, 3, 29-30.

Lowe, G. Interval of time uncertainty in visual detection. Perception & Psychophysics, 1967, 2, 278-280.

Lucas, P. A. Human performance in low-signal probability tasks. Journal of Acoustical Society of America, 1967, 42, 153-178.

Luce, R. D. & Green, D. M. A neural timing theory for response times and the psychophysics of intensity, Psychological Review, 1972, 79, 14-57.

Lusted, L. B. Signal detectability and medical decision-making. Science, 1971, 171, 12-17.

Mackworth, J. J. The effect of amphetamine on detectability of signals in a vigilance task. Canadian Journal Psychology, 1965.

Mackworth, J. F. Vigilance and attention: A Signal Detection Approach. Baltimore, Md: Penguin Books, 1970.

McGill, W. Neural counting mechanisms and energy detection in audition. Journal of Mathematical Psychology, 1967, 4, 351-376.

Malpass, R. S. & Kravitz, J. Recognition for faces of own and other race. Journal of Personality & Social Psychology, 1969, 13, 330-334.

Marill, T. Detection theory and psychophysics. Cambridge, MA: MIT, Research Laboratory of Electronics, 1956.

Martin, E. & Melton, A. W. Meaningfulness and trigram recognition. Journal of Verbal Learning & Verbal Behavior, 1970, 9, 126-135.

Massaro, D. W. Forgetting: Interference or decay? Journal of Experimental Psychology, 1970, 83, 238-243.

McNicol, D. & Willson, R. J. The application of signal detection theory to letter recognition. Australian Journal of Psychology, 1971, 23, 311-315.

Milner, A. P., Beech, H. R., & Walker, V. J. Decision processes and obsessional behavior. British Journal Social & Clinical Psychology, 1971, 10, 88-89.

Milosevic, S. Effect of time and space uncertainty on a vigilance task. Perception & Psychophysics, 1974, 15, 331-334.

Morrison, G. R. & Norrison, W. Taste detection in the rate. Canadian Journal Psychology, 1966, 20, 208-217.

Moskowitz, H. & Depry, D. Differential effect of alcohol on auditory vigilance and divided-attention tasks. Quarterly Journal of Studies on Alcohol, 1969, 29.

Moss, S. M., Myers, J. L. & Filmore, T. Short-term recognition memory of tones. Perception & Psychophysics, 1970, 7, 369-373.

Munsinger, H. & Gummerman, K. Simultaneous visual detection and recognition. Perception & Psychophysics, 1968, 3, 383-386.

Muntz, W. R. An experiment on shape discrimination and signal detection in octupus. Quarterly Journal Experimental Psychology, 1970, 22, 82-90.

Murdock, B. B., Jr. Signal detection and short-term memory. Journal of Experimental Psychology, 1965, 70, 443-447.

Murdock, B. B., Jr. The criterion problem in short-term memory. Journal of Experimental Psychology, 1966, 72, 317-324.

Murdock, B. B., Jr. Response latencies in short-term memory. Quarterly Journal Experimental Psychology, 1968, 20, 79-82.

Murphy, E. H. & Vernables, P. H. Ear asymmetry in the threshold of fusion of two clicks: A signal detection analysis. Quarterly Journal Experimental Psychology, 1970, 22, 288-300.

Neal, J. M., McIntyre, C. W., Fox, R., & Cromwell, R. L. Span of apprehension in acute schizoprenia. Journal Abnormal Psychology, 1968, 74, 593-596.

Nevin, J. A. On the form of the relation between response rates in a multiple schedule. Journal Experimental Anals Behavior, 1974, 21, 237-248.

Norman, D. A. Sensory thresholds response bases and the neural quantum theory. Journal Mathematical Psychology, 1964, 1, 88-120.

Norman, D. A. & Wickelgren, W. A. Short-term recognition memory for single digits and pairs of digits. Journal of Experimental Psychology, 1965, 70, 479-489.

Ogasawara, I. Relation between detectability and personality traits: An application of signal detection theory. Japanese Journal of Educational Psychology, 1968, 16, 80-86.

Parducci, A. & Sandusky, A. J. Limits on the applicability of signal detection theories. Perception & Psychophysics, 1970, 7, 63-64.

Pastore, R. E. & Scheirer, C. J. Signal detection theory: Consideration for general application. Psychological Bulletin, 1974, 81, 945-958.

Parks, T. E. Signal detectability theory of recognition-memory performance. Psychological Review, 1966, 73, 44-58.

Parks, T. E. & Kellicutt, M. H. The probability-matching decision rule in the visual discrimination of order. Perception & Psychophysics, 1968, 3, 356-358.

Paul, D. & Sutton, S. Evoked potential correlates of response criterion in auditory signal detection. Science, 1972, 177, 362-364.

Paul, D. & Sutton, S. Evoked potential correlates of psychophysical judgments: The threshold problem. A new reply to Clark, Butler, and Rosner. Behavioral Biology, 1973, 4, 421-433.

Peterson, W. W., Birdsall, T. G., & Fox, W. C. The theory of signal detectability, I. R. E. Transactions, P. G. I. T., 1954, 4, 171-212.

Pollack, I., Norman, D. A. & Galanter, E. An efficient non-parametric analysis of recognition memory. Psychonomic Science, 1964, I, 327-328.

Price, R. H. Signal detection methods in personality and perception. Psychological Bulletin, 1966, 66, 55.

Price, R. H. & Eriksen, C. W. Size constancy in schizophrenia: A reanalysis. Journal of Abnormal Psychology, 1966, 71, 155-160.

Rappaport, M. & Hopkins, H. K. Signal detection and chlorpromazine. Human Factors, 1971, 13 (4), 387-390.

Rappaport, M., Hopkins, H. K., Silverman, J., & Hall, K. Auditory signal detection in schizophrenics. Psychopharmacologia, 1972, 24, 6-28.

Rappaport, M., Silverman, J., Hopkins, H. K., & Hall, K. Phenothiazine effects on auditory signal detection in paranoid and non-paranoid schizophrenics. Science, 1971, 12, 723-725.

Raser, G. A. Meaningfulness and signal detection theory in immediate paired-associate recognition. Journal of Experimental Psychology, 1970, 84, 173-175.

Rees, J. N. & Botwinick, J. Detection and decision factors in auditory behavior of the elderly. Journal of Gerontology, 1971, 26 (2), 133-136.

Rees, J. F. & Fishbein, H. D. Test of TSD model in human eyelid conditioning: A priore probability and pay-off maniuplations. Journal of Experimental Psychology, 1970, 83, 291-298.

Rollman, G. B. Detection models: Experimental tests with electrocutaneous stimuli. Perception & Psychophysics, 1969, 5, 377-380.

Ryder, P. & Pike, R. Criteria placement in detection: Implication for Kogan and Wallach's theory of risk-taking. Australian Journal of Psychology, 1973, 25, 211-216.

Ryder, P., Pike, R. & Dalghish, L. What is the signal in signal detection: Perception & Psychophysics, 1974, 15, 479-482.

Schneider, E. W. & Carpenter, J. A. The effect of ethyl alcohol on auditory signal detection. New York: Eastern Psychological Association, 1967.

Schneider, E. W. & Carpenter, J. A. The influence of ethanol on auditory signal detection, Journal of Studies on Alcohol, 1969, 30, 357-370.

Schoeffler, M. S. Theory of psychophysical learning. Journal of the Acoustical Society of America, 1965, 37, 1124-1133.

Schuck, J. R., Cross, H. A. & Mills, D. H. A signal detection analysis of the rod and frame test. Perception & Psychophysics, 1970, 7, 276-]80.

Schulman, A. I. Word length and rarity in recognition memory. Psychonomic Science, 1967, 9, 211-212.

Schulman, A. I. & Greenberg, G. Z. Operating characteristics and a priori probability of the signal. Perception & Psychophysics, 1970, 8, 317-320.

Schulman, A. I. & Lovelace, E. A. Recognition memory for words presented at a slow or rapid rate. Psychonomic Science, 1970, 21, 99-100.

Segal, S. J. & Fusella, V. Influence of imagined pictures and sounds on detection of visual and auditory signals. Journal of Experimental Psychology, 1970, 83, 458-464.

Sekuler, R. W. Choice times and detection with visual backward masking. Canadian Journal of Psychology, 1966, 20, 34-42.

Semb, G. The detectability of the odor of butonol. Perception & Psychophysics, 1968, 4, 335-340.

Shiffrin, R. M. & Grantham, D. W. Can attention be allocated to sensory modalities? Perception & Psychophysics, 1974, 15, 460-474.

Shipley, E. F. A signal detection theory analysis of a category judgment experiment. Perception & Psychophysics, 1970, 7, 38-42.

Shusterman, R. J. Low false alarm rates in signal detection by marine animals. Journal of the Acoustical Society of America, 1974, 55 (4), 845-848.

Smith, E. E. Short-term memory impairment in chronic schizophrenic. Canadian Journal Psychology, 1969, 23, 114-126.

Smith, M. & Wilson, E. H. A model of the auditory threshold and its application to the problem of the multiple observer. Psychological Monograph, 1953, 67.

Snodgrass, J. G., Luce, R. D., & Galanter, E. Some experiments on simple and choice reaction time. Journal of Experimental Psychology, 1967, 75 (1), 1-17.

Stanford, R. G. Response bias and the correctness of ESP test responses. Journal of Parapsychology, 1967, 31, 280-289.

Steinmetz, G., Pryor, G. T.,& Stone, H. Effect of blank samples on absolute odor determinations. Perception & Psychophysics, 1969, 6, 142-144.

Stevens, S. S. & Galanter, E. Ratio scales and category scales on a dozen perceptual continua. Journal Experimental Psychology, 1957, 54, 377-412.

Strickland, B. R. & Bodwan, A. S. Relation of certain personality variables to decision making in perception. Perceptual & Motor Skills, 1964, 18, 353-359.

Sturmer, G. Von Time perception, vigilance and decision theory. Perception & Psychophysics, 1968, 3, 197-200.

Suboski, M. D. The analysis of classical discrimination conditioning experiments. Psychological Bulletin, 1967, 68, 235-242.

Suboski, M. D. Signal detection analysis of recall paired-associates learning. Psychonomic Science, 1967, 7, 357-358.

Suboski, M. D. & Khosla, S. UCS intensity and instructional set in classical eyelid conditioning: Discrimination conditioning and signal detection analysis. Canadian Journal of Psychology, 1969, 23, 389-401.

Suboski, M. D., Pappas, B. A. & Murray, D. J. Confidence ratings in recall paired-associates learning. Psychonomic Science, 5, 1966, 147-148.

Swets,, J. A. Signal detection theory applied to vigilance. Mackie, R. R. (ed.) Vigilance: Theory, operational performance, and physiological correlates. New York & London: Plenum Press, 1977.

Swets, J. A. & Birdsall, T. G. Deferred decision in human signal detection: A preliminary experiment. Perception & Psychophysics, 1967, 2, 15-28.

Swets, J. A., Markowitz, J. & Franzen, O. Vibrotactile signal detection. Perception & Psychophysics, 1969, 6, 83-88.

Swets, J. A. & Sewall, S. T. Invariance of signal detectability over stages of practice and levels of motivation. Journal Experimental Psychology, 1963, 66, 120-126.

Tanner, T. A., Rank, J. A. & Atkinson, R. C. Signal recognition as influenced by information feedback. Journal of Mathematical Psychology, 1970, 7, 259-274.

Tanner, W. P., Jr. & Swets, J. A. A decision making theory of visual detection, Psychological Review, 1954, 61, 401-409.

Teichner, W. H. The detection of a simple visual signal as a function of time of watch. Human Factors, 1974, 16 (4), 339-353.

Torgerson, W. S. Theory and Methods of Scaling. New York: Wiley, 1958.

Torgerson, W. S. Distances and ratios in psychophysical scaling. Acta Psychologica, 1961, 19, 201-205.

Thijssen, J. M. & Vendrik, A. J. H. Internal noise and transducer function in sensory detection experiments: Evaluation of psychometric curves and of ROC curves. Perception & Psychophysics, 1968, 3, 387-400.

Ulehla, Z. J., Canges, L., Wachwitz, F. Signal detectability theory applied to conceptual discrimination. Psychonomic Science, 1967, Section Human Experimental, 8.221.

Ulehla, J. Z., Canges, L. & Wachwitz, I. Integration of conceptual information. Psychonomic Science, 1967, 8, 223-224.

Ulehla, Z., Little, K. B. & Weyl, T. C. Operating characteristics and realism of certainty estimates. Psychonomic Science, 1967, 9, 77-78.

Valenti, M. & Galanter, E. The SEU function determines the iso-sensitivity curve. New York: Columbia University, Psychophysics Laboratory Report, No. 38, 1975.

Van Egeren, L. Repression and sensitization: Sensitivity and recognition criteria. Journal of Experimental Research in Personality, 1968, 3, 1-8.

Verplanck, W. S., Cotton, J. W., & Collier, G. H. Previous training as a determinant of response dependency at the threshold. Journal of Experimental Psychology, 1953, 45, 10-14.

Viehmeister, N. F. Intensity discrimination: Performance in three paradigms. Perception & Psychophysics, 1970, 8, 417-419.

Westendorf, D. H. & Fox, R. Binocular detection of positive and negative flashes. Perception & Psychophysics, 1974, 15, 61-65.

Whalen, R. E. Sexual motivation. Psychological Review, 1966, 73, 151-163.

White, M. J. Signal detection of laterality differences: Some preliminary data, free of recall and report-sequence characteristics. Journal of Experimental Psychology, 1970, 83, 1974-176.

Wickelgren, W. A. Consolidation and retroactive interference in short term reconition memory for pitch. Journal of Experimental Psychology, 1966, 72, 250-259.

Wickelgren, W. A. Associative strength theory of recognition memory for pitch. Journal of Mathematical Psychology, 1969, 6, 13-61.

Wickelgren, W. A. & Becker, G. M. Decisions based on conflicting and inaccurate observations. Journal of Mathematical Psychology, 1965, 2, 180-189.

Williges, R. C. Within-session criterion changes compared to an ideal observer criterion in a visual monitoring task. Journal of Experimental Psychology, 1969, 81, 61-66.

Winograd, E. & Saal, W. V. Discriminability of association value in recognition memory. Journal of Experimental Psychology, 1966, 72, 328-334.

Winterfeldt, D. & Fischer, G. W. Multi-Attribute utility theory: Models and assessment procedures. Ann Arbor, Mi: University of Michigan, Technical Report Engineering Psychology Laboratory, 1973.

Wolfendale, G. L. Decision times in signal detection. Acta Psychologika, 1967, 27, 154-159.

Wright, A. A. & Nevin, J. A. Signal detection methods for measurement of utility in animals. Journal of Experimental Analysis of Behavior, 1974, 21, 373-380.

Yager, D. & Duncan, I. Signal-detection analysis of luminance generalization in goldfish using latency as a graded response measure. Perception & Psychophysics, 1971, 9, 353-355.

Yost, W. A., Turner, R. & Bergeot, B. Comparison among four psychophysical procedure used in lateralization. Perception & Psychophysics, 1974, 15, 483-487.

Zeidenberg, P., Clark, W. C., Jaffe, J., Anderson, S. W., Chin, S. & Malitz, S. Effect of oral administration of delta-9 Tetrahydrocannibinol on memory, speech, and the perception of thermal pain. Comprehensive Psychiatry, 1973, 14 (6).

Zerdy, G. A. Incidental retention of recurring words presented during auditory monitoring tasks. Journal of Experimental Psychology, 1971, 88, 82-89.

TECHNICAL REPORTS DISTRIBUTION LIST

Code 455

Director, Engineering Psychology
Programs, Code 455
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217 (5 cys)

Defense Documentation Center
Cameron Station
Alexandria, VA 22314 (12 cys)

Commanding Officer
ONR Branch Office
ATTN: Dr. J. Lester
Building 114, Section D
666 Summer Street
Boston, MA 02210

Commanding Officer
ONR Branch Office
ATTN: Dr. Charles Davis
536 South Clark Street
Chicago, IL 60605

Commanding Officer
ONR Branch Office
ATTN: Dr. E. Gloye
1030 East Green Street
Pasadena, CA 91106

Journal Supplement Abstract Service
American Psychological Association
1200 17th Street, N. W.
Washington, D. C. 20036 (3 cys)