THE UNIVERSITY OF MICHIGAN

SENSORY INTELLIGENCE LABORATORY
Department of Psychology

Final Report

STATISTICAL DECISION PROCESSES IN RECOGNITION AND DETECTION

Wilson P. Tanner, Jr.

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This report summarizes work by six personnel of the Sensory Intelligence Laboratory: Dr. Wilson P. Tanner, Jr., Dr. Eli Osman, Mr. Sandford Fidell, Mr. Theodore Cohn, Mr. Gary Sylvester, and Mr. Sabin Head. The work concerns problems in the areas of acquisition of sensory capabilities, multichannel sensory information processing, data processing and decision time in psychophysical tasks, and analysis of cellular information processing in the visual system.

Sabin Head has been working on the measurement of the time involved in input data processing and decision making in psychoacoustics. Many theories dealing with reaction time hypothesize a gradual information gathering process during the latency interval. That is, at early stages only a little signal information has been processed, while at later stages more signal information has been processed; hence, there exists a speed-accuracy trade off. Heretofore, experimentally manipulating either the speed or the accruacy in a precise fashion has been a methodological block. An experiment meant to demonstrate a precise method for controlling the length of the processing interval has been run and is currently being analyzed.

This method is a modification of the standard yes-no auditory signal detection task: a cue is presented to the observer just prior to the signal. The cue can potentially provide information that will help in the detection of the signal, so if the cue has been processed and the information is therefore available during the observation interval for the signal, detection performance should be enhanced relative to the uncued case. This enhancement of performance should then vary with the duration of the processing interval according to the hypothesis, and the processing interval is the interval of time that the cue leads the observation period for the signal. The data for one observer appear consistent with this hypothesis while that for a second are clear for only one of the two signals used and weak there. At the intensities and frequencies we are using, the information processing appears to be essentially complete in 25 msec. This is almost an order of magnitude smaller than most choice reaction times reported in the literature, but it must be remembered that this measuring method is entirely free of any motor component. It is possible that the chief component of reported reaction times is not at all the time to reach a simple discriminating decision, but mainly time to make the response. Analysis of the data is proceeding with a view towards isolating some, as yet unexplained, variability.

Gary Sylvester has presented his conclusions and plans for future study based on research on the development of a theory of experimental design, in a paper entitled "Toward a General Theory of Experimental Design." This paper was submitted with an earlier report.

Wilson P. Tanner has continued his work on the problem of the acquisition of sensory abilities. Some of his results are presented in a paper, as yet unpublished, entitled "Acquisition of Sensory Capabilities." This paper was submitted with an earlier report.

Related to Tanner's work on the acquisition of sensory capabilities is Sylvester's study of processes involved in sensory acquisition which has been made in the form of introducing a task in which frequency as well as time differences were present and in which visual information was present and perfectly correlated with simultaneous auditory inputs. To summarize the results, it is noted that considerable individual differences were observed in ability to perform the task. Using linear fits, fitted by least-squares procedure, to approximate the theoretical curves predicted, acquisition rates and measures of asymptotic levels were obtained showing that those observers receiving visual information performed at higher levels than those who received auditory signals only.

Further analysis of data and theoretical development has proceeded with respect to the learning studies. A 4 x 4 confusion matrix was obtained for each observer for each session with entries of the form $p[(f_i,t_j)/(f_h,t_k)]$ where i, j, h, k ϵ {1,2} and "f" and "t" denote frequency and starting time, respectively. The problem of partitioning the task into one which could be described as involving a composite acquisition of frequency and time relations and the extent to which these physical parameters were treated as independent by the observers was probed. The joint frequency-time decision spaces could then be separated into two independent subspaces, one revealing the acquisition of frequency discrimination ability and the other, time discrimination ability. A simple probabilistic independence model was constructed to determine better the nature of the decisions made in this situation. Certain problems have arisen in testing for the independence of the two decisions due to day-to-day fluctuations which occur and to the difficulty in determining significance levels for rejecting independence. The nonstationary nature of the process being studied complicates this analysis to such an extent that using the undecomposed joint decision space appears to be the feasible approach. No information is lost as long as this large space remains intact. To analyze this space an extension of the theory of recognition to the case of four nonorthogonal signals is necessary and is being examined. Each decision space was obtained on the basis of an estimation procedure operating on the data matrices. The error introduced by this procedure is still being examined. An important question in relation to this concerns the complications which arise in the magnitude of error if other than Euclidean geometries and normal processes are assumed. Some theoretical work has been done in this regard for the case of an ideal observer and the signal known exactly. It appears that the number of cross-correlations which need to be computed may depend upon the nature of the underlying geometry.

Theoretical developments which lead to a more precise description of the process have been accomplished in the construction of an ideal learning device which operates in a Bayesian fashion and in the derivation of performance equations for a multimodal receiver which is ideal with respect to situations in which noise may be correlated between modalities and the signal is specified exactly. The model developed previously was found to be equivalent to a

Bayesian learning model with normal conjugate priors and data-generating processes. In this context, the concept of "memory noise" functions as a misaggregation of prior information with the information-bearing aspects of the input. The ideal receiver has no internal noise sources, possesses a perfect memory, and learns by adjusting certain parameter estimates through an updating process. Since a linear system is assumed throughout, the ideal receiver is equivalent in performance to an observer with a perfect memory in the learning experiment. This model is degraded by adding memory noise and then further degraded by the introduction of a variable memory noise source to yield the descriptive model used to obtain estimates of learning rate parameters and asymptotic level determinants.

Since the second experiment involved perfectly correlated visual information for some observers and signals differing in two physical parameters, the above model was extended by determining the operations performed by an observer which behaves optimally in a two-modality situation. Performance equations were obtained which relate the sensory acquisition measure d' to the internal noise level, to the correlation between modalities, and to correlation which may be induced by nonindependent processing of frequency and time relations. The conjunction of this model with the learning model above provides a suitable model for analyzing data from this rather complex experiment. It also leads to a general description of the interaction and adaptability of processes involved in human perception.

In order to understand such processes even more fully, an experiment using several points (frequency-time positions) organized into arrays suggestive of certain patterns is a natural extension of the previous work. Construction of a model within the framework of the theory already advanced will be necessary and has already been undertaken. This model will be likewise complicated by the interaction of certain functions, in particular those involving parameter estimation. A pattern organizer may operate off of the outputs of parameter estimators coordinating their activity in such a way that computation will be made simpler. Memory storage could be of a smaller capacity due to a reduction in the number of simple point estimates to be constructed. The required size of this memory will be a function of the properties of the pattern organizer.

Sandford Fidell has completed his analysis of data on sensory interaction with respect to Tanner's theory of recognition. The results are presented in his doctoral dissertation entitled "Sensory Function in Multimodal Signal Detection," submitted in the Department of Psychology at The University of Michigan. An abstract of his thesis is included at the end of this report.

Eli Osman has continued his study of extentions of theories of recognition and detection to problems in processing complex inputs over multiple channels. In addition to the multichannel model for the case of the signal known exactly with varying signal and noise interchannel correlations, other models have been considered. The application of such models has been investigated in one particular substantive area, "binaural masking level differences" (BMLD's)—which can be regarded as a special case of processing complex inputs arriving over two input channels.

Osman has developed a "correlation model" of BMLD's, which differs from other models in the literature in that it does not require the receiver to know the interaural signal correlation in order to process the inputs correctly to enhance detection, and it assumes the processing of input data to be always of the same basic form, both for input conditions which yield BMLD's and for those which do not. Input processing is modeled by a weighted sum of energy and cross-correlation quantities derived from the inputs, which leads to a formula for BMLD's dependent on the interaural correlations for signal and for noise. The model provides a good fit to the relevant data in the psychoacoustic literature, and its further development seems promising.

Experiments related to the evaluation of the "correlation model" and of previously developed models are in progress. These are concerned with observer uncertainty with respect to input parameters and decisions about mode of processing, and with temporal aspects of the information processing.

Theodore Cohn has been studying the frog visual system at the cellular level using analytical methods of the theory of signal detection. The results are presented in his doctoral dissertation entitled "The Theory of Signal Detectability: Application to the Analysis of the Recorded Activity in Single Cells of the Frog Visual System," submitted in the Bioengineering Program at The University of Michigan. An abstract of his thesis is included at the end of this report.

APPENDIX

ABSTRACT

SENSORY FUNCTION IN MULTIMODAL SIGNAL DETECTION

Sanford Fidell

Chairman: Wilson P. Tanner, Jr.

Five observers detected a sinusoid in noise in a two interval forced choice experiment. The signal occurred on an earphone, on an oscilloscope, or on both devices simultaneously. Detection performance was studied as related to 1) mode of occurrence of the signal(s); 2) the external noise correlation in the auditory and visual channels; and 3) the observers' a priori knowledge of the mode of occurrence of the signal.

The observed improvement in sensitivity (measured in d' units) as a function of bimodal signal presentation closely followed the predictions of a statistical summation model, and was much lower than predicted by linear and probabilistic addition models. Under conditions of independence of noise in the auditory and visual channels some improvements in sensitivity were almost as great as 3 dB. The improvement in sensitivity afforded by a priori knowledge of the mode of occurrence of the signal was less for bimodal signals than for unimodal signals.

ABSTRACT

THEORY OF SIGNAL DETECTABILITY: APPLICATION TO THE ANALYSIS OF THE RECORDED ACTIVITY IN SINGLE CELLS OF THE FROG VISUAL SYSTEM

by

Theodore Elliot Cohn

Co-Chairman: Wilson P. Tanner, Jr.

Co-Chairman: Daniel G. Green

This thesis introduces a method of generating Receiver Operating Characteristic (ROC) curves from distributions of the count of the number of action potentials recorded from a single cell. A method of computing detectability, d_e', a measure of sensitivity related to the Shannon information measure, is described. Experiments reported were designed to examine the recorded activity of frog Class IV (Dimming) optic nerve fibers where light of fixed intensity and short pulse decrements of that intensity are presented. Single dimming fibers of the optic nerve of *Rana Pipiens* were monitored by usual extracellular recording techniques. ROC curves from the distributions of the number of action potentials recorded in a fixed interval following the presentation of a background plus decrement, or just the background, are found. The ROC curves are monotone increasing with monotone decreasing slope. ROC curves indicate greater information processed for higher energy dimming signals than for lower energy dimming signals. d_e' is found to be proportional to

signal energy difference when, on each trial, one of two signals is presented. d'_e is found to be proportional to the energy of one signal if the energy of the other possible signal is zero. d'_e is found to be inversely proportional to the square-root of the background intensity, except at the highest background tested. d'_e can be depressed by added external noise. The slope of the ROC curve on normal-normal probability paper is greater than one, indicating that the variance of the underlying signal distribution is less than the variance of the underlying no-signal distribution. The results listed above except the last are consistent with at least two models of the frog visual system. The first model characterizes the frog as an ideal photodetector which can make use of a fixed fraction of the available photons. In this instance the performance in the task of detecting the presence or absence of a light pulse decrement is said to be limited by the inherent quantum fluctuation of the light. The second model characterizes the frog as a device with a nonlinear transducer that attenuates inputs according to the square-root of the background (automatic gain control) and for which performance is limited by internal noise added to the attenuated signals. The last result mentioned is consistent with the prediction of the quantum fluctuation model and rejects the particular added internal noise model mentioned. The high background inconsistency amongst the results reported indicates the possibility of Weber's Law at still higher backgrounds. Several possible

causes, both physiological and experimental, of the inconsistency in these experiments are discussed. The empirical relation between d_e' and background is inconsistent with the previous findings that this particular cell obeys Weber's Law. It is suggested that the inconsistency with previous findings may be due to methodological differences. The method can be extended to situations where ROC curves are generated from distributions of any parameter of measured physiological events.