

XIX. COMMUNICATIONS BIOPHYSICS

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A. INTRODUCTION

The Communications Biophysics group is concerned chiefly with the electrical activity of the nervous system and with certain psychophysical experiments on temporal characteristics of hearing. The electrophysiological data with which we deal include evoked responses (for example, specific responses that are recorded when acoustic stimuli are presented) and "spontaneous" activity of the brain-wave type. We are also concerned with the study of the interaction of these two types of electrical activities.

Since we record the electrical activity of populations of neural elements, the mathematical models are, appropriately, statistical in character. We emphasize, however, close relations between mathematical models and experimental data. We require of our probabilistic models that they not only describe familiar phenomena, but that they suggest and predict new experimental findings.

Up to this point, we have mainly investigated a zero-interaction model, that is, a model in which the behavior of single units is not affected by what happens to other members of the population. Such a model seems a useful approximation for the most peripheral station of the auditory nervous system. It does not seem to be satisfactory for dealing with cortical activity.

We are developing electrical instrumentation designed to speed up and simplify the analysis of our data. We feel that at the present time small-scale computational devices will not only analyze our data most efficiently but also assist us in developing intuitive thinking about behavior of the nervous system.

W. A. Rosenblith

B. EFFECT OF NOISE ON INTENSITY FUNCTIONS OF N_1

Intensity functions (amplitude of neural response N_1 vs intensity of stimulus) have been obtained at the round window of cats for (a) clicks and (b) clicks against a background of random noise. The results of these experiments, for several different levels of the noise, are shown in Fig. XIX-1.

Certain aspects of these data on N_1 tend to confirm in the neural system under investigation properties that were previously suggested on the basis of other evidence. The elementary component of this system will be called a neural element, which we define as the complex of auditory receptor cell, first-order neuron, and receptor-neural junction.

1. Experimental evidence from several sources suggests that neural elements have thresholds that fluctuate with time. This property has been made the basis of a

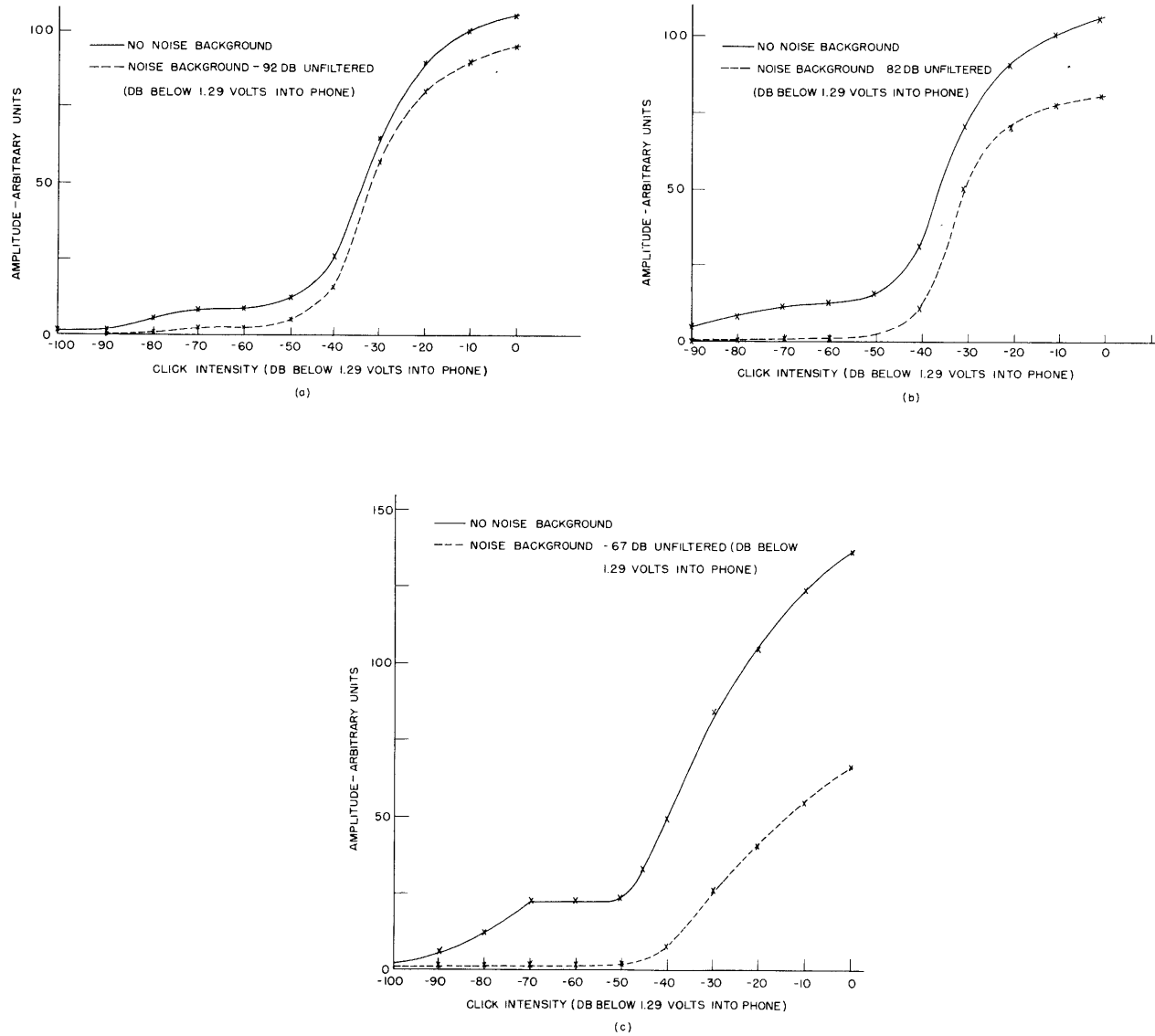


Fig. XIX-1

Intensity functions for clicks with and without noise backgrounds, for several noise levels.

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mathematical model of the peripheral auditory nervous system (Quarterly Progress Report, October 15, 1953, and W. J. McGill: A Statistical Description of Neural Responses to Clicks Recorded at the Round Window of the Cat, Doctoral Thesis, Department of Psychology, Harvard University, 1952). Additional evidence is now adduced from the data of Fig. XIX-1. Observe that two weak noise levels are extremely effective in preventing the system from responding to clicks of much greater intensity. A hypothesis of fixed thresholds would predict no response to click intensities less than or equal to the noise intensities, and increasing response thereafter. This is clearly not the case. The assumption of fluctuating thresholds can, on the other hand, account for the data. Neural elements which in the absence of noise would respond to clicks, are now continually dropping in threshold below the noise level and firing, thus being rendered incapable of fully responding to subsequent clicks of intensity well above the noise level. The data of Fig XIX-1 can be accounted for quantitatively if the rate of threshold variation is suitably chosen (see part C below).

2. The two-stage growth of the intensity function without noise, seen in the upper curves of Fig. XIX-1, is characteristic of all preparations for which intensity functions have been determined over a sufficiently broad stimulus range. Two categories of neural elements are thereby suggested (see Quarterly Progress Report and Doctoral Thesis as quoted above); a neural element is either sensitive or insensitive according as the range of its threshold values coincides with the stimulus range of the low-intensity or high-intensity portion of the growth curve. The alternative to this view, barring fixed thresholds, is that the range of possible threshold values for each neural element extends over the entire range of stimuli which evoke response. In its idealized form, this is the question of two populations vs one population. By 'population' we mean a group of neural elements, all of which have identical threshold distributions.

Previous evidence has favored two populations. Additional evidence in its favor is obtained from the present data. For the intensity function for clicks in the presence of low-level noise shows a two-phase behavior of the sort one would expect from two populations whose average thresholds are clearly separated. Neural elements contributing to the insensitive portion of the intensity function are unaffected by noise of sufficiently low intensity, while sensitive units are completely prevented from firing to the click.

On the other hand, if the system consisted of a single population, one would expect an intensity function of quite a different shape in the presence of low-level noise.

L. S. Frishkopf, D. H. Raab, R. M. Brown

C. NOTE ON A PROBABILISTIC MODEL FOR THE BEHAVIOR OF NEURAL ELEMENTS (PERIPHERAL AUDITORY SYSTEM)

A model has been proposed (Quarterly Progress Report and Doctoral Thesis as quoted in subsection B) to account for the observed behavior of the first neural

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component N_1 of the peripheral response, recorded at the round window. Neural units, mathematical idealizations of neural elements, with the following properties are postulated.

- a. The response of a unit obeys the all-or-none law.
- b. The threshold of a unit, in its resting state, fluctuates and is described by a threshold probability distribution.
- c. A unit is characterized as either sensitive or insensitive, depending upon the value of its mean threshold. A simplification is introduced by assuming that each of these populations consists of units having identical threshold distributions.
- d. The firing of a unit alters its threshold distribution, which then becomes a function of the time $\Delta\tau$ since firing. For times $\Delta\tau$ that are sufficiently long the unit returns to the resting distribution.

The experiments described in subsection B give additional validity to postulates b and c.

An extension of the model to include some description of the rate of threshold fluctuation is made possible by the data of Fig. XIX-1, as follows:

Associated with a neural unit is a threshold probability distribution, determined experimentally from the intensity function of the appropriate neural population. Let us assume that threshold fluctuations occur in the following way: a unit occupies a definite threshold state (or value) for a time τ whereupon it 'jumps' or makes a transition, in a time short compared to τ , to a new threshold state, and so forth. Let us assume in addition that threshold is a random variable on the set of possible threshold states. The probability that the threshold of a unit will in time T (T/τ transitions) occupy one or more states in an interval I subtending a total threshold probability α is given by

$$p = 1 - (1 - \alpha)^{T/\tau} \quad (1)$$

If α is now chosen as the probability that the threshold lies below the noise level (obtained from the sensitive population intensity function), then for a selected value of τ , p gives the probability that in time T a unit will fire to the noise. With T of the order of 2 msec, p is approximately given as $1 - R_N/R$, where R_N and R are respectively the maximal responses of the sensitive population to clicks with and without noise background. For the actual situation is approximately equivalent to one in which amplitude of response is zero if a unit is excited within about 2 msec after firing, and totally recovered thereafter. Inserting values obtained from the data of Fig. XIX-1 (noise level -92 db) and $T = 2$ msec into Eq. 1, yields $\tau \approx 1/2$ msec. Using this value of τ in conjunction with the data for the -82 db noise level gives $p \approx 15/16$, which agrees with the data within the limits of error of the experiment. This is to be regarded only as an order-of-magnitude calculation for τ .

A somewhat different experiment is underway that we hope will test the consistency

of the model, provide a more accurate value of τ , and provide data concerning the change and recovery in time of the threshold distribution of a unit after firing.

L. S. Frishkopf

D. ANALOG CORRELATOR FOR ELECTROENCEPHALOGRAPHY

Minor modifications have been made on the analog correlator for the analysis of electroencephalographic (EEG, or brain potentials) activity (Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., January 15, 1953, pp. 47-49). This computer has been adapted from the correlator at the Imperial College of Science and Technology, London (J. N. Holmes, J. M. C. Dukes: A Correlation Function Computer for the Analysis of Speech Wave Forms, Proc. Inst. Elec. Engrs., Part III (in press)). Additional correlation functions (see, for example, Fig. XIX-2) have been obtained with the modified apparatus in conjunction with the magnetic drum developed by K. Goff of the M.I.T. Acoustics Laboratory. A description of the magnetic drum has appeared (K. Goff: Proc. I.R.E., 41, 1578-1584, 1953) and the operating principles of the correlator are described in a paper to be published (J. S. Barlow, M. A. B. Brazier: A Note on a Correlator for Electroencephalographic Work, EEG. Clin. Neurophysiol. (in press)).

The number of record-playback heads on the FM magnetic tape recorder (Ampex) has been increased from two to five. This modification will make it possible to reproduce for correlation analysis any two of five channels of EEG recorded with a similar five-channel instrument in the Neurophysiological Laboratory at the Massachusetts General Hospital. To shorten the time of analysis, a speedup of 5 or 10 times takes place between the recording and the playing back on the two instruments.

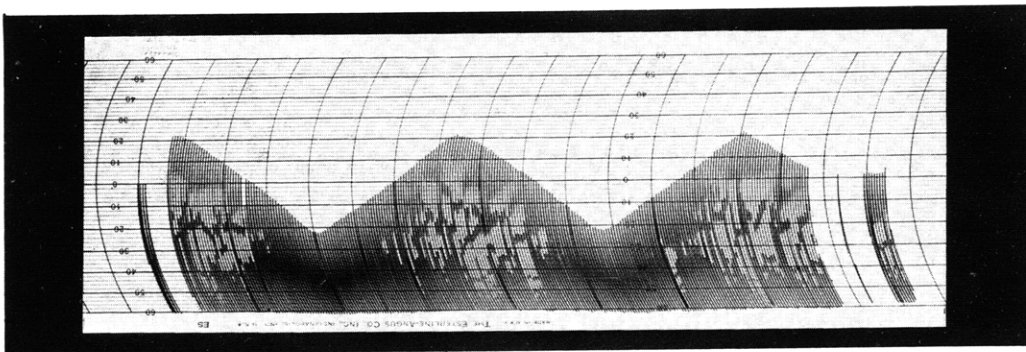


Fig. XIX-2

Autocorrelation of a square wave (150 cps). Integration time, 5 sec; $\Delta\tau = 1/16$ msec.

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A magnetic drum similar to that developed by Goff is being constructed, with which the FM carrier frequency of the tape recorder will be delayed during computation of the correlation functions. In contrast to the earlier method of making an endless loop of tape for analysis, an automatic recycling system for the magnetic tape recorder is planned similar to that now in operation for the M. I. T. digital correlator.

Several recordings of both human and animal EEG's, with and without evoked responses to flash, have been recorded on tape at the Massachusetts General Hospital, and two such recordings have been analyzed. The EEG of a cat has been recorded on paper in the Research Laboratory of Electronics and the recorded tracing is now being autocorrelated by means of the manual correlator of the M. I. T. Servomechanisms Laboratory (N. Zabusky: A Mechanical Correlation Computer, Engineering Report No. 32, Servomechanisms Laboratory, M. I. T., 1951). This analysis should yield information regarding the maximum delays that it will be necessary for the analog instrument to handle.

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(Massachusetts General Hospital Neurophysiological Laboratory),
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E. THE TIME-GATED AMPLITUDE QUANTIZER (TGAQ)

Since the completion of final tests on the TGAQ, the operation of the equipment has been checked under actual experimental conditions. Eighty-six electrical responses to single high-intensity clicks from the round windows of cats have been analyzed by comparing the results obtained by the TGAQ with those obtained by conventional visual analysis with the aid of a microfilm reader.

1. Visual analysis using quantized categories placed 78 percent of the responses in or on the boundary of the levels registered by the TGAQ.
2. Visual quantization placed the remaining responses into the two levels adjacent to the level indicated by the TGAQ.
3. The unquantized data showed that the absolute value of the amount of discrepancy between the results of the two techniques was less than one-half level out of 40 levels.

Although the results of visual quantization are not sufficiently accurate to be used as a standard of absolute accuracy for the TGAQ, the experiment shows that the TGAQ adequately replaces the visual technique, at least for work with peripheral responses N_1 to single clicks.

Use of the TGAQ in this and other experiments has also shown that although the assumption of constant latency of components of peripheral responses for a stimulus of fixed intensity is a reasonable one, the necessity for readjusting the clamp circuit for changes in stimulus intensity limits the usefulness of the instrument.

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Electronic equipment designed to measure the latency of response components in order to trigger the signal selection circuits of the TGAQ at the proper time is now being developed by A. K. Hooks and R. M. Brown.

K. Putter