

XXI. COMMUNICATIONS BIOPHYSICS*

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RESEARCH OBJECTIVES

Over the past few years the composition of our group and the particular problems under investigation have changed appreciably, and yet the general theme of our research has scarcely varied: Our concern remains with systematic description and analysis of the electrical activity of the nervous system in the presence and the absence of controlled sensory stimulation.

Technical Report 351 has permitted us to summarize a number of the considerations that underlie our data-processing methods (1). This monograph contains a discussion of the quantification problem, followed by a chapter on evoked responses and a chapter on the processing of EEG data. The appendices deal with the following topics: description of random processes, mathematical statistics, and descriptions of the several computers that we used in our studies. Two other recent papers (2, 3) deal more particularly with the problems encountered when one attempts to relate the electrical activity of the nervous system to the sensory performance of organisms.

During the past year we started to use statistical measures other than averages in the analysis of evoked responses; some of the rationale underlying our views in this area is summarized in reference 4. We have started to write computer programs for the analysis of microelectrode records.

The auditory system continues to be studied in electrophysiological (5, 6) and psychoacoustic (7) experiments. The physiological bases of auditory theory have been briefly

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examined (8). Under the leadership of Dr. Kiang, electrophysiological experimentation at the Eaton Peabody Laboratory of Auditory Physiology (Massachusetts Eye and Ear Infirmary) is gaining momentum: several technically intricate procedures have been perfected and promise to enhance the group's experimental style.

The application of correlational analysis to the electroencephalogram has been examined both experimentally (9,10) and theoretically (11). The manner in which unit potentials from a population enter into the neural activity that is seen by gross electrodes has been subjected to a comprehensive mathematical analysis (12) in which the present Goldstein model is compared to the earlier McGill and Frishkopf models.

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A. FIRING PATTERNS OF SINGLE CELLS IN THE AUDITORY CORTEX

A meaningful quantitative description of firing patterns of neurons is not easily obtained. Visual inspection of oscilloscopic displays often does not show whether or not the ongoing activity of a unit has been significantly altered by presentation of sensory stimuli. Compilation of results from single-unit data has usually involved large amounts of tedious "hand and eye" measurement (1), although some schemes have been developed for the automatic display of the repetition of very constant and simple patterns of firing (2). In the present study the TX-0, a general-purpose digital computer, was used for the analysis of more complex "spike" patterns.

Single-neuron and slow-wave activity in the cat's auditory cortex (light nembotal) were recorded with 5-10 μ tungsten microelectrodes. In order to minimize the pulsatile motion of the brain the electrodes were manipulated in a closed, oil-filled chamber threaded into the skull. Acoustic stimulation (clicks at 1/sec) was presented in 15-sec periods which alternated with 15 sec of silence. Both the electrical activity and the stimulus pattern were recorded on FM tape for later processing. A sample of recorded raw data is shown in Fig. XXI-1.

The TX-0 program separately processes the data taken during periods of acoustic stimulation and the data taken during the interleaved "spontaneous" periods to yield two complementary analyses, and the results are presented in two displays: (a) a time histogram -- a histogram of the distribution of action potentials in time relative to the instant of stimulus presentation (summed over many stimulus presentations); and (b) an interval histogram -- a histogram of the distribution of the interspike intervals (i. e., time intervals that separate two successive action potentials).

Neuronal spikes and stimulus pulses from tape are picked out by a discriminator and Schmitt trigger, formed into standard TX-0 pulses, and then fed into the computer without the intermediate step of analog-to-digital conversion. The TX-0 program senses the proper portion of the stimulus pattern, keeps internal time, and compiles the necessary histograms.

An example of a time histogram obtained from the data shown in Fig. XXI-1 is shown in Fig. XXI-2. Note that after the evoked response to the stimulus, cell firing is



Fig. XXI-1. Unprocessed data played back from tape. Upper trace shows stimulus markers 1/sec (total time displayed, 10 sec). Large pulses on lower trace indicate firing of the neuron under study.

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depressed for approximately 150 msec. This is extremely hard to see by looking at the raw data because the cell is firing only 2 or 3 times per second. Such inhibition appears to some extent in the analysis of almost all cells that we have recorded. Similar post-response inhibition has been previously observed for some rapidly firing ($\gg 10/\text{sec}$) cortical cells in the taste system (3) and elsewhere (4,5). For such rapidly firing cells the inhibition is readily visible on the oscilloscope. Cohen et al. (3) point out (and we also have observed) that such inhibition can be demonstrated even during an injury discharge. They suggest that "the inhibition . . . appears to be an active process exerted directly on the cell, and not merely due to a lack of stimulation or to refractoriness in the cell itself."

Figures XXI-3 and XXI-4 show raw data and time and interval histograms for what seems to be another type of cell. The postresponse inhibition is present, but there are also preferred times of firing, separated by about 100 msec. Examination of oscillographic traces shows that such a cell frequently fires in bursts of 2 or 3 spikes. This is also shown on the interval histogram by the high peak at the small interspike interval of about 10 msec. The lower peak on the interval histogram corresponds to the preferred 100-msec interval between bursts.

The interval histograms of Fig. XXI-4 are similar for the "stimulated" and "spontaneous" conditions, although the time histograms show a considerable amount of difference in the firing pattern. This difference might be interpreted as a resetting of the cell "rhythm" by the stimulus.

Cells of the type shown in Fig. XXI-4 have usually been observed in preparations

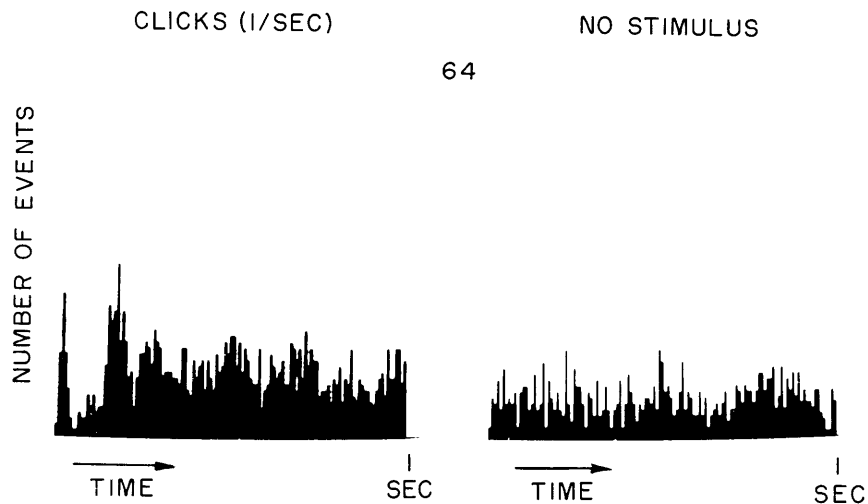


Fig. XXI-2. Time histogram (see text) for 15 minutes of the data shown in Fig. XXI-1. "Stimulated" condition at left; "spontaneous" at right. Time is subdivided into bins of 8 msec duration (or width).



Fig. XXI-3. Unprocessed data played back from tape for a neuron isolated at 2700μ below the cortical surface. Total time displayed, 1 sec.

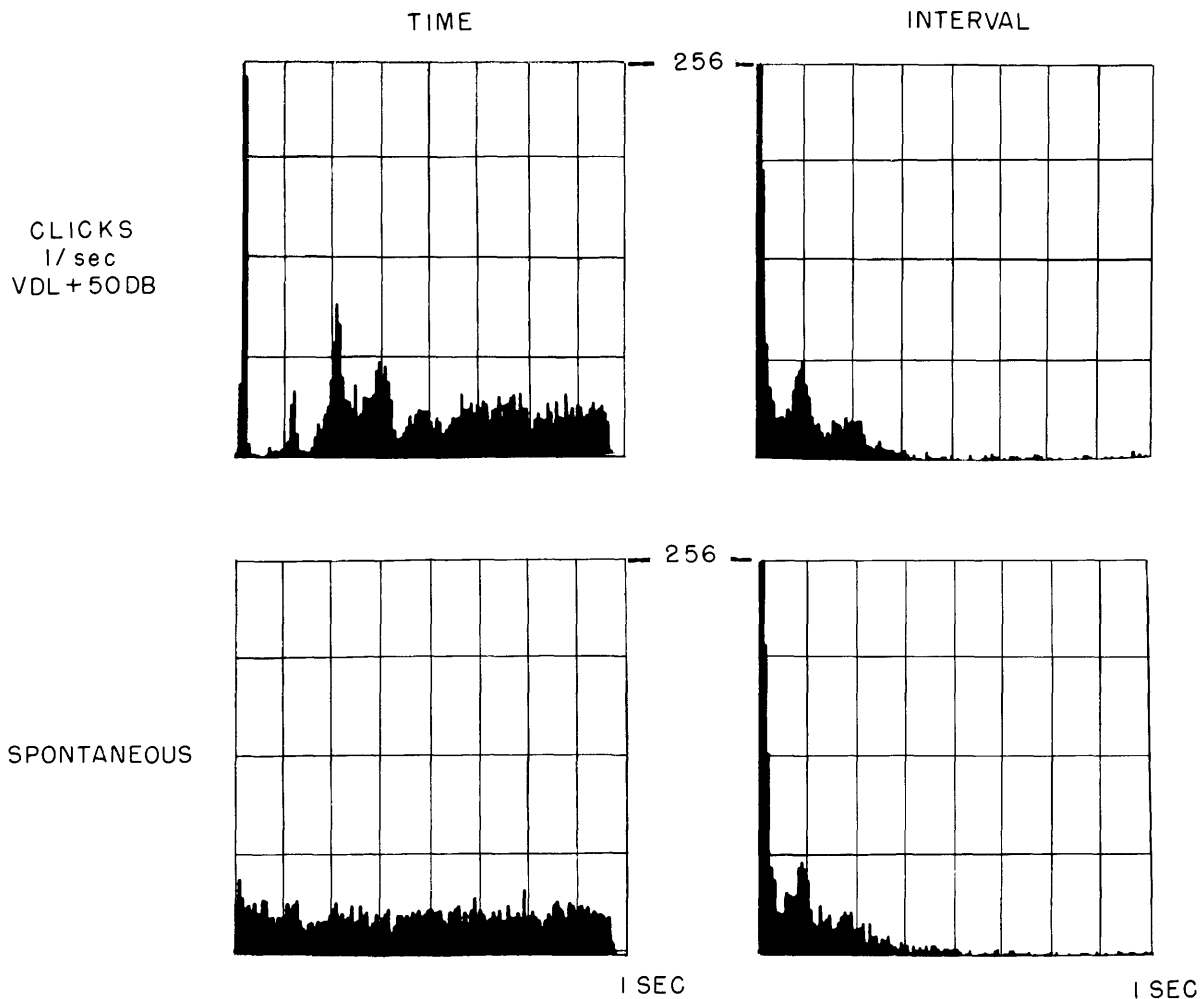


Fig. XXI-4. Analysis of the data shown in Fig. XXI-3. All bin widths, 8 msec. Left column: time histogram for 352 stimulus intervals (or seconds). Stimulus, 15 clicks alternating with a 15-sec silence. Only the last 13 of each grouping were processed. Right column: interval histogram for 2048 spikes. Upper row summarizes data taken during acoustic stimulation; lower row summarizes data from silent periods.

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that also exhibit several repetitive slow waves after the evoked response. Presumably, these phenomena are volume effects and cannot be attributed to the activity of a single cell. Such "repetitives" are often time-locked to the delivery of the stimulus at intervals of about 100 msec and can therefore be meaningfully averaged by the average response computer, ARC-1 (6). It is interesting to note that the preferred neuronal firing times shown in the "stimulated" time histogram of Fig. XXI-4 coincide with the negative peaks of the averaged slow waves at the same location. The relationship of the two phenomena is being investigated under various conditions.

In summary, the results obtained from the small, and probably biased, population of cells that have been studied include the following:

- (a) Average firing rates lie in the range 1-10/sec.
- (b) For a poststimulus time less than approximately 150 msec, almost all cells are less likely to fire. This inhibition is complete in some cases and only partial in others.
- (c) For a poststimulus time greater than approximately 150 msec, some cells tend to fire at preferred times, separated by approximately 100 msec.
- (d) Although the time histograms for most cells show a considerable amount of difference between stimulated and spontaneous conditions, in some cases the interval histograms are almost identical for the two states.

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