AN EXPERIMENTAL METHOD OF DETECTING SHORT-LATENCY INTERACTION IN NEURON SYSTEMS

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An experimental method of investigating short-latency interaction in neuron systems is described. The curve of probability distribution for the first-order cross-interval of simultaneously recorded sequences of action potentials of two neurons is assessed by the histogram obtained by simple calculation of the number of points in the corresponding vertical band of the spot oscillogram.

It is becoming increasingly clear that the detailed study of the properties of single neurons (distribution of interspike intervals, mean frequency, on- and off-response to stimulation, and so on) is insufficient to reveal all the functional properties of a center in the nervous system. The obtaining of experimental data on synaptic connections and other sources of interaction in neuron systems thus becomes particularly interesting.

In many cases statistical analysis of the records of activity of only two simultaneously recorded cells is itself sufficient to provide a significantly wider picture of neuronal interaction [3]. However, methods of statistical analysis of spike generation sequences of two neurons so far described necessitate the use of a computer [2-4] or laborious manual analysis of the material [1], because of the complexity of the mathematical apparatus. A method of quantitative assessment of interaction between the work of two simultaneously recorded neurons is described below which, although adequate in its statistical content, is free from these difficulties.

To analyze two simultaneously recorded sequences of action potentials of neurons A and B, it is customary to determine [4]: 1) the interspike interval of the corresponding sequence $\tau_i^A = A_{i+1} - A_i$, $\tau_k^B = B_{k+1} - B_k$; and 2) the first-order cross-interval $R_i = B_j^1 - A_i$, where $B_j^1 = \inf(B_k / B_k > A_i)$ (the precise lower limit of the sequence B_k under the condition that $B_k > A_i$). As has been shown [1], the probability distribution curve for $\{R_i\}$ can be assessed in the usual way by the histogram plotted for an interval $0 \leq t \leq \theta(1)$, where $\theta = \min(\tau_m^A, \tau_m^B)$, and τ_m^A, τ_m^B are the minimal interspike intervals of the corresponding sequences. Under these circumstances, if the neurons are working independently, this histogram for an interval of (1) will have a sufficiently smooth envelope (without significant deviations from its mean-square value for this interval). Deviations on the histogram are assessed by standard methods and can be interpreted physiologically (see, for example [1, 3]).

The apparatus for obtaining such histograms is shown in Fig. 1. Extracellular activity of two neurons in a part of the brain to be investigated is recorded by two microelectrodes (ME) through source followers (SF), amplified by biopotential amplifiers (BPA), and the sequences of action potentials of the two cells are then transformed by a shaper (S) into sequences of pulses of constant amplitude and duration, with the same temporal distribution. The shaped pulses of one of the cells triggers the driven calibration sweep of the oscilloscope with the brightness of the beam completely extinguished, while pulses of the other cell serve to modulate brightness. If during the driven sweep triggered by a spike from cell A, cell B discharges,

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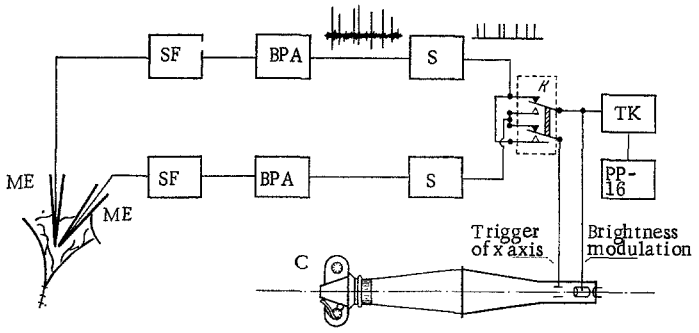

Fig. 1. Block-diagram of experimental set-up (explanation in text).

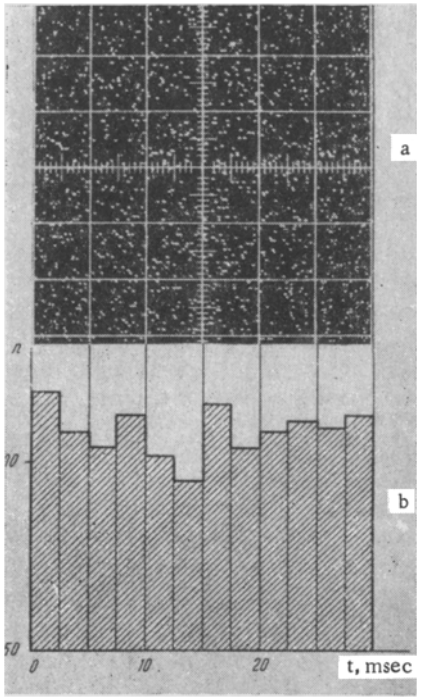

Fig. 2. Spot oscillogram (A) and histogram of cross-intervals of two uncorrelated spike sequences (B) plotted from it.

a bright spot shines on the screen. Clearly, when the time of the driven sweep is chosen, in accordance with equation (1), the first-order histogram cross-intervals described above will accumulate on the screen. It simply remains to shift the beam by degrees along the vertical axis, when the bright spots are sufficiently densely arranged in one band (the shutter of the camera C is open throughout the period of accumulation), which can be done in various ways (for example, by connecting a step-signal generator to the input of the amplifier of vertical deviation, or manually). The number of spots in the band and the total number of intervals accumulated during the experiment are calculated by means of a PP-16 computer through a transistorized key (TK), opened by a spike from cell A during the driven sweep.

A spot oscillogram, in which the ratio between the number of spots in a fixed vertical band [from $j\lambda$ to $(j+1)\lambda$, where λ is the interval of the histogram] and the total number N of points is an estimate of the probability that the randomly chosen cross-interval R_j is greater than $j\lambda$ and less than $(j+1)\lambda$, is thus obtained on one frame of photographic film. By switching the key K, a spot oscillogram of the dependence of firing of cell A after cell B can be obtained on the next frame of the film.

Let us assess the statistical capacity of the method (the number N of cross-intervals per frame) for the condition that duplication of the spots is absent on any band with a probability of 0.9. It is easy to show that the number k of randomly distributed spots on the band satisfying this condition can be found from the equation

$$0.9 = \left(1 - \frac{1}{n}\right) \cdot \left(1 - \frac{2}{n}\right) \cdots \left(1 - \frac{k-1}{n}\right) \cdots , \qquad (2)$$

where n is the maximum number of spots on the band. For a cathode-ray oscilloscope with a working screen area, for example, of 8×8 cm^2, and for a spot of light ~ 0.25 mm in diameter, $n = 320$, and from Eq. (2), $k \approx 8$ and $N \geq 2500$.

The method described above has now been successfully used to investigate interaction in a neuron population in the respiratory center of the medulla. A spot oscillogram and histogram of cross-intervals of two uncorrelated spike sequences, generated by neurons of this center, are shown in Fig. 2 (in this case $\theta = 30$ msec, $N \approx 1300$).

LITERATURE CITED

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