Synaptic Noise as a Source of Variability in the Interval between Action Potentials

Abstract. *The source of variability in the interval between action potentials has been identified in a class of cat spinal motoneurons. The observed random fluctuations in membrane potential (synaptic noise) together with an empirical description of spike generation accurately predict the statistical structure of variability observed to occur in the neuron's discharge.*

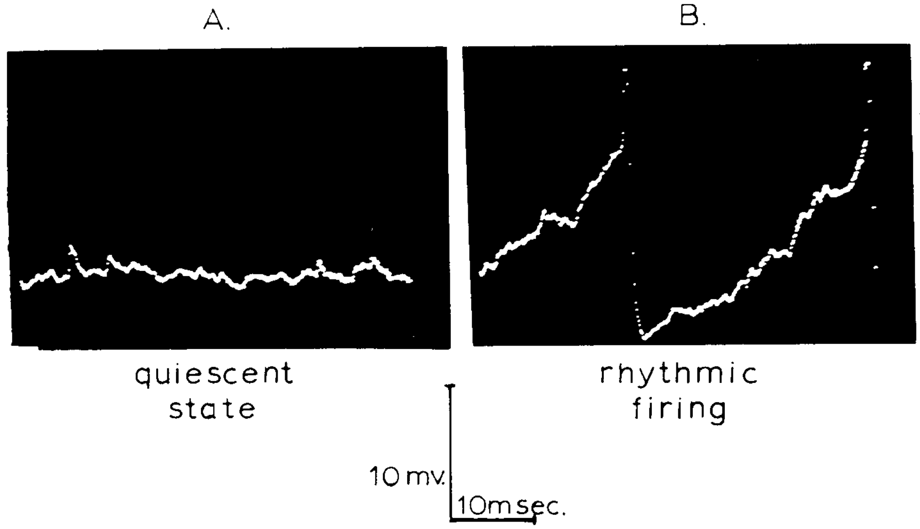

Fig. 1. Displays of membrane potential as a function of time showing synaptic noise in a quiescent motoneuron (A) and the ramp-like approach to the firing level with superimposed noise (B) when repetitive firing was induced by current passed through the membrane. Note that the action potentials are off scale in B. Because these records are displays of digitalized data from LINC memory, the separate data samples are visible as dots where the membrane potential was changing rapidly.

The marked variability characteristic of most neurons' steady-state output has been of considerable interest (*1*), because it has been believed to add uncertainty to the information transmitted by the neuron and because it may provide clues about the mechanisms underlying the transformation of input to output. Despite considerable investigation, the sources of variability in the interval between action potentials (the interspike interval) have not yet been clearly identified for any type of neuron. One obvious possible source is the haphazard fluctuations in membrane potential (*2*) seen even in the quiescent neuron. The question arises as to whether such input fluctuations (synaptic noise) can account for the output (interspike interval) variability. We have shown that synaptic noise, together with a simple model for spike generation, can indeed account for variability in the interspike interval in one class of cat spinal motoneurons.

Intracellular recordings (Fig. 1) from spinal motoneurons suggest a mechanism by which synaptic noise could produce variability in the interspike interval. During natural stimulation, or when a constant current is passed through the recording electrode, many previously silent spinal motoneurons discharged repetitively. Immediately after a spike the membrane repolarizes, and then the membrane potential rises approximately linearly to the firing level where another spike is generated (Fig. 1B). Superimposed upon this ramp-like approach of the membrane potential to the firing level, however, are random voltage fluctuations that look much like the synaptic noise of the quiescent neuron. These fluctuations in voltage appear to cause the membrane potential to reach the firing level at randomly varying times instead of at a fixed time, as would be the case if no fluctuations were present. According to this model then, synaptic noise produces variability in the interspike interval by causing variations in the time at which the membrane potential first crosses the firing level.

Although data from intracellular recordings are in qualitative agreement with our proposed model, only quantitative evidence can establish that more complicated assumptions are unnecessary. For example, it would be very difficult, on the basis of mere inspection of records, to say that some source of noise other than synaptic noise is not present, or that synaptic noise does not interact with the ramp generating processes instead of simply adding to the membrane potential as it approaches the firing level.

Specifically, then, we find that the statistical structure of variability in the interspike interval can be accurately predicted from the observed properties of synaptic noise together with

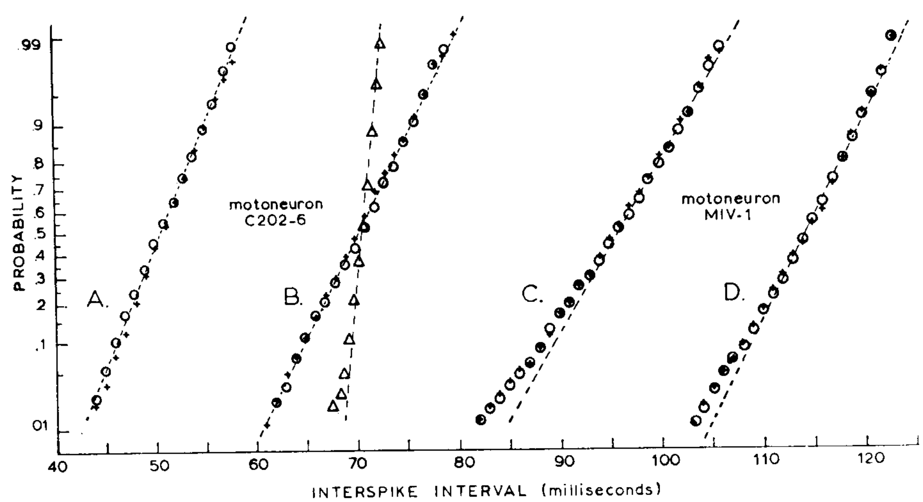

Fig. 2. Observed and predicted cumulative histograms of interspike intervals from two motoneurons. The ordinate is a probability scale on which a Gaussian distribution gives a straight line. Two sets of data from a motoneuron whose firing level increased linearly with time after a spike are shown (+) in (A) and (B), while results from a second motoneuron with a constant firing level are shown (+) in (C) and (D). Predictions made from synaptic noise and the observed characteristics of the spike-generating mechanism (open circles) are in good agreement with observed histograms; if the time dependence of the firing level in (B) is ignored and if a constant firing level is used for making the predictions, the predicted points (open triangles) deviate markedly from the observed. For clarity of the illustration, the points in (B) have been shifted 15 msec to the right along the time axis.