Optimal time scale for response reliability and stochastic synchronization in real neurons

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Neurons respond to several repetitions of a rapidly fluctuating stimulus in a highly reproducible manner, but not to constant stimuli. This property has been referred to as neural reliability. The biophysical mechanisms underlying this phenomenon are unknown. Some studies have suggested that strong (chaotic) attractors of the single neuron dynamics are responsible for neural reliability. This requires specific interactions between the membrane potential and the ionic currents. However, based on computational studies and electrophysiological experiments, we have recently proposed that reliability is a general property of devices with a resetting threshold, like neurons, that does not require further dynamical constraints. In such devices the average number of threshold crossings (spikes) within a given time window is determined by the input bias (f-I curves). The exact times at which the spikes occur rather depend on the input fluctuations that modulate the firing rate. If the stimulus is constant or if the fluctuations are very slow, the precise timing will be dominated by non-reproducible background noise. On the other hand, if the stimulus fluctuations are too fast, they will add up to fast fluctuations of the background noise (whose power spectrum is roughly constant and therefore contains arbitrarily fast fluctuations), so that the neuron will be able to fire even when it is far from threshold but the precise timing of the spikes will be non-reproducible across trials. In the intermediate case, when the stimulus fluctuations are neither too fast nor too slow, the neuron will most likely fire when it is close to threshold and either the stimulus or the noise pushes it beyond. These arguments led to two predictions that we have verified experimentally: 1) there is an optimal time scale (autocorrelation time) of the stimulus fluctuations that maximizes reliability; 2) reliability increases with increasing amplitude of the input fluctuations. The optimal time scale turns out to be between 3 and 6 ms. As for the amplitude of the input, already 50% of the spikes are reliable as soon as the input fluctuations doubles the background input noise (ca. 10 pA). Our findings on reliability are immediately applicable to stochastic synchronization, where neurons receiving random and fast fluctuating signals that are spatially correlated trigger synchronous spikes.