Varying the amplitude and frequency of a sinusoidal current injection can modulate the reliability and precision of neuronal discharge.

The response of a neuron driven with multiple frequency components cannot be wholly predicted by the responses to single sinusoids.

We study the dependence of spike-time reliability on:
1. The relative phase of two frequency components.
2. The choice of the second (higher) frequency.
3. The distribution of power between two frequency components.

Methods

Materials: We injected cells with currents of the form:
\[ I(t) = A_0 + A_1 \sin(w_1 t) + A_2 \sin(w_2 t + \phi) \]

Stimuli:
1. The relative phase of two frequency components.
2. Varying the “gamma” frequency.
3. Varying the balance of power.

Results

Varying the relative phase offset changed the response from highly reliable to highly unreliable (\( \sigma = 5 \) msec). The reliability minimum occurs at a spike-timing bifurcation, due to the coexistence of two spike-timing attractors.

Significance:
Nowak et al. showed adding gamma-power to a theta rhythm could increase spike-time precision, possibly enhancing neural encoding. The optimal “gamma” frequency for enhancing reliability and precision depends both on the noise of the neural dynamics and on the decoding time scale.

Varying the “gamma” frequency.

Results:
We observe a reliability peak for the interactions of different frequency components on different time scales (different sigmas).

On a fast (1-5 msec) timescale the interaction of 5 Hz and 20 Hz gives two reliability peaks: one at 20 Hz and another at 40-50 Hz. Firing times show both theta-scale and gamma-scale precision for gamma frequencies < 50 Hz.

Varying the balance of power.

Results:
Shifting power from the theta component to the gamma component can either increase or decrease reliability. Cells with precise locking to pure theta show enhanced reliability when some power shifts to gamma. Cells with less precise locking to pure theta undergo a spike-timing bifurcation to two different gamma-cycles, reducing reliability.

Significance:
Fries et al. observed a shift between theta-band and gamma-band coherence during attentional modulation of local field activity. A precision-threshold for reliability could enhance correlation-based modulation of information flow in cortical networks.

Conclusions

Nonlinear superposition: Combining two frequencies in a neuron’s input leads to novel effects, including:
Relative Phase
There are optimum phases for peak reliability and unreliability, respectively.
Choice of Gamma
The optimum gamma-frequency depends on the decoding time scale and internal noise.

Power Balance
Shifting power from theta to gamma frequencies can either increase or decrease reliability.

References


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Analysis of Reliability: We monitored the correlation of spikes with the stimulus and the reliability of the response to the filtered stimulus. We then calculated the correlation between the averaged filtered stimulus and the filtered stimulus. We then calculated the correlation of firing times, which was a measure of the reliability of the filtered stimulus. This was done in a 10-msec time window.

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