Phase-Dependent Suppression of Neuronal Oscillations

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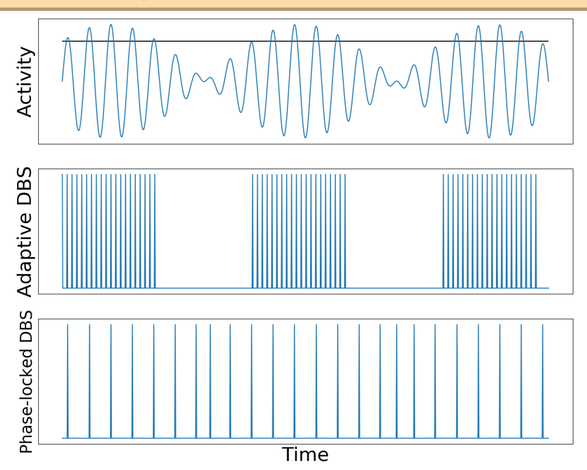
Intruduction

While synchronized oscillations within and between brain areas facilitate normal brain processing, excess synchrony usually is accompanied by a brain disease. A prominent example is the amplified persistent beta-frequency ($\sim$ 20 Hz) oscillations recorded from the cortex and subthalamic nucleus of Parkinsonian brains [1, 2]. Deep brain stimulation (DBS) is known to be an effective treatment for a variety of neurological disorders, including Parkinson's disease and essential tremor (ET). A common procedure is to impose a train of pulses with constant frequency via electrodes implanted into the brain. New 'closed-loop' approach involves delivering stimulation according to the ongoing brain activity and could improve in terms of efficiency and reduce side effects. The success of closed-loop DBS depends on the design of a stimulation strategy that minimizes oscillations in neural activity associated with symptoms [3]. An important step to this end is to construct a mathematical model, which can describe how the brain oscillations should change when stimulation is applied at a particular state of the system.

DBS strategies

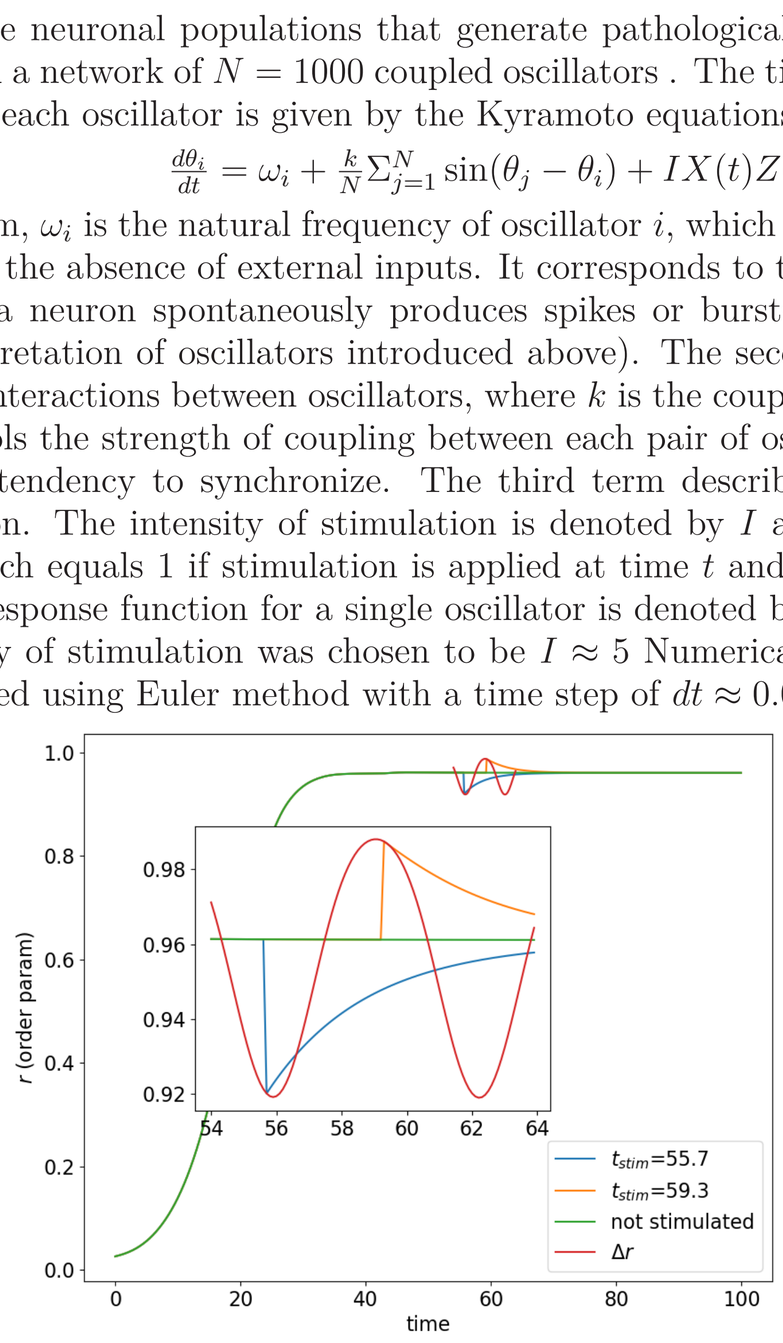


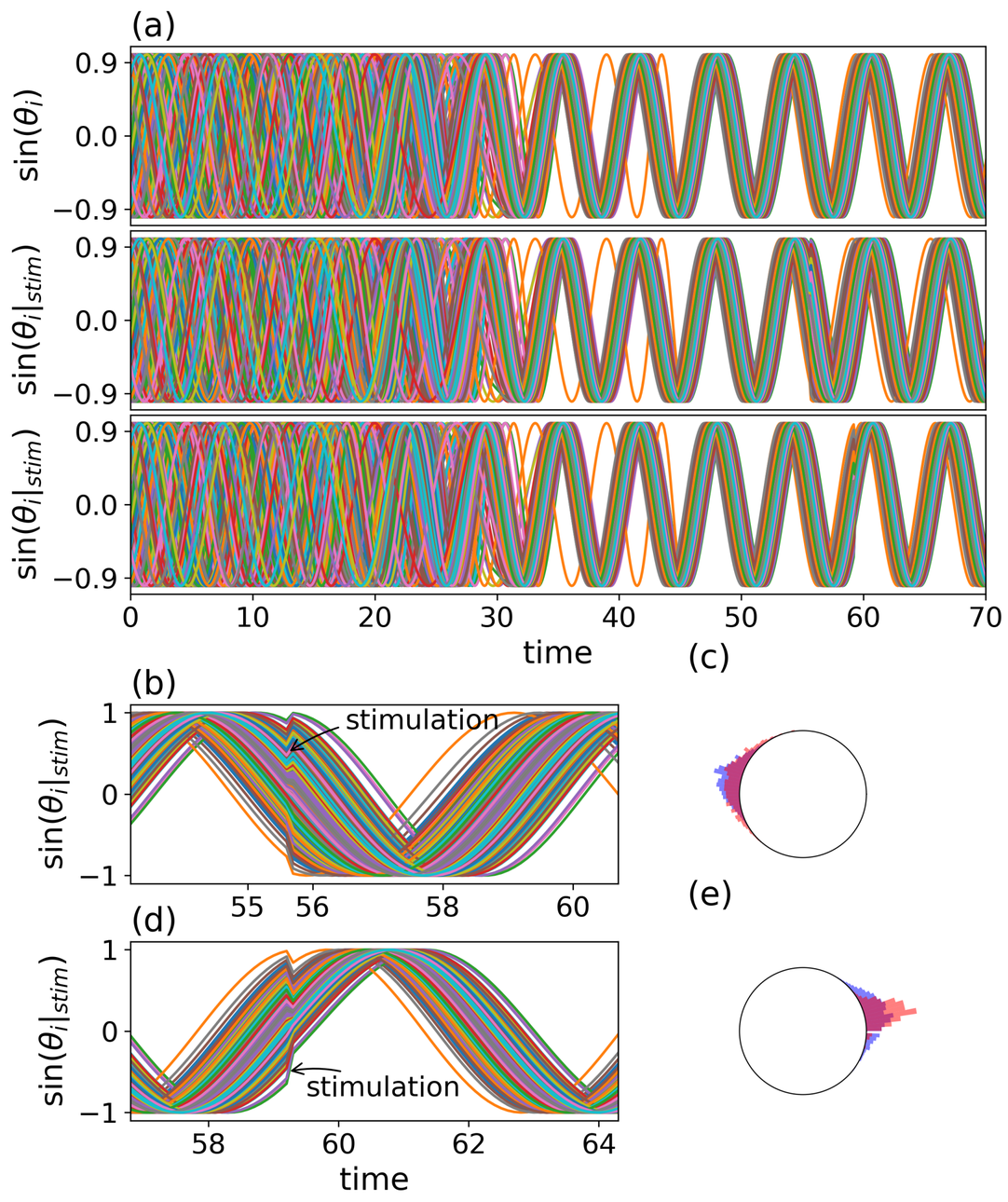
Numerical results

To model the neuronal populations that generate pathological oscillations, we have used a network of $N = 1000$ coupled oscillators . The time evolution of the set of each oscillator is given by the Kyramoto equations

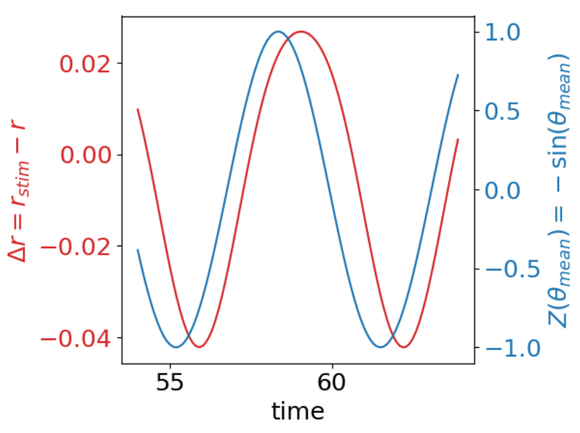
$$\frac{d\theta_i}{dt} = \omega_i + \frac{k}{N}\Sigma_{j=1}^{N}\sin(\theta_j - \theta_i) + IX(t)Z(\theta_i)$$

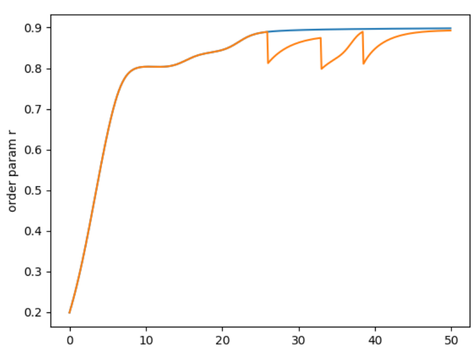
The first term, ω_i is the natural frequency of oscillator i, which describes the frequency in the absence of external inputs. It corresponds to the frequency with which a neuron spontaneously produces spikes or bursts (depending of the interpretation of oscillators introduced above). The second term describes the interactions between oscillators, where k is the coupling constant which controls the strength of coupling between each pair of oscillators and hence their tendency to synchronize. The third term describes the effect of stimulation. The intensity of stimulation is denoted by I and $X(t)$ is a function which equals 1 if stimulation is applied at time t and 0 otherwise. The phase response function for a single oscillator is denoted by $Z(\theta_i)$.
The intensity of stimulation was chosen to be $I \approx 5$ Numerical integration was performed using Euler method with a time step of $dt \approx 0.01$.





Discussion





Applying multiple stimulations

Conclusion

The amplitude of collective oscillations could be modulated depending on the specific phase at which the stimulation is applied.
Also, we could predict the *good time* for applying stimulation to get the maximum reduction in the oscillation amplitude based on the phase response curve (PRC) of oscillators.

Future research

The fact that signals often take physiologically significant time to reach their destinations is fundamental to the design of neuronal networks. Thus, time-delays are essential because neuronal networks have finite signal transmission speed. In the next step we are going to include the effects of interaction time delay to our model.

References

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