Abstract

Synchronization is a universal phenomenon, which can be observed in systems of two or more coupled oscillators and plays an important role in many different subdomains of physics. Synchronization phenomena also exist in biological systems and in particular in the brain, which can be considered as a system of pulse-coupled oscillators (neurons). Synchronization of populations of neurons is a fundamental property for the function and dysfunction of the human brain. One particular example is the occurrence of resting tremor in Parkinson's disease (PD), which is associated with abnormal synchronization phenomena in specific brain areas. These brain structures are important for voluntary movement control. Several new techniques have been developed in order to counteract pathological synchronization in the brain. A very promising technique is the so called coordinated reset (CR) stimulation, which is administered via electrodes that are deeply implanted within the human brain. In order to get a deeper understanding of this technique, we continued the top-down approach of previous studies and constructed a large-scale computational model of the respective brain areas. Our model considered the spatial anatomical properties of the simulated brain structures and incorporated a detailed numerical representation of the $2 \cdot 10^4$ simulated neurons. We were able to model the physiological and pathological activity of the considered brain structures. Ultimately, we investigated how the model system could be shifted from strongly synchronized (pathological) activity to strongly desynchronized (healthy) activity of the neuronal populations via external perturbation in form of electrical stimulation. We considered different types of stimulation techniques and analyzed their efficacy in restoring desynchronized neuronal activity. Furthermore, we investigated the impact of specific stimulation parameters on the stimulation outcome. For this purpose, we developed a new method which allowed for the estimation of the distribution of synchronized activity in a spatial volume. Although further research is required in order to provide theoretical explanations for experimentally found observations in the application of CR stimulation, our model can be considered as the next step to a biophysical realistic model of the respective brain areas important for the occurrence of pathological neuronal activity in PD. Furthermore, our model has the potential to serve as an useful tool in order to optimize the parameters relevant for electrical CR stimulation.