The role of heterogeneity and network topology in emerging epileptiform dynamics

Marinho A. Lopes, Living Systems Institute, University of Exeter, Exeter, UK, M.Lopes@exeter.ac.uk
Marc Goodfellow, Living Systems Institute, University of Exeter, Exeter, UK, M.Goodfellow@exeter.ac.uk
John R. Terry, Living Systems Institute, University of Exeter, Exeter, UK, J.Terry@exeter.ac.uk

Epilepsy is a neurological disorder characterized by recurrent seizures. Two main types of seizures are distinguished depending on the observed EEG patterns: focal and generalized seizures [1]. It has been assumed that focal seizures imply focal abnormalities and generalized seizures widespread pathologies. However, it is becoming increasingly recognized that large-scale brain networks can also be responsible for the emergence of focal seizures [2]. Here, we aim to elucidate the origin of such different activity patterns using a network model of seizure dynamics. We consider a network of neural masses, which we approximate using the theta model [3]. Each node of the network is represented by a phase oscillator, which is able to transit between a ‘normal state’ (a stable fixed point) and a ‘seizure state’ (a stable limit cycle) through a saddle-node on invariant circle (SNIC) bifurcation. Two main factors may influence the emergence of different epileptiform activity patterns: network topology and node excitability. To address the role of network topology in the dynamics, we study different synthetic networks such as regular, small-world, random and scale-free networks. To tackle node excitability, we consider different distributions of phase oscillator’s propensities to undergo the SNIC bifurcation. We find that for homogeneous excitability distributions, network topology determines the emerging seizure-like pattern: focal patterns appear in more heterogeneous network topologies such as scale-free networks, whereas generalized patterns emerge in more homogeneous network topologies such as regular and random networks. On the other hand, sufficiently heterogeneous node excitabilities can balance or even overrule the role of network topology in such a way that emerging epileptiform patterns depend on both network topology and node excitabilities. We further investigate individual node importance for the generation of seizure-like activity in all the different scenarios of network topologies and node excitabilities. Interestingly, we find that node’s importance is mostly dependent on network topology even for strongly heterogeneous node excitabilities. Together the results imply that networks with focal pathologies may generate generalized seizures. Thus, our findings suggest that generalized epilepsies may in some cases be amenable to epilepsy surgery.

References

[1] R.S. Fisher, et al., Operational classification of seizure types by the International League Against Epilepsy: Position Paper of the ILAE Commission for Classification and Terminology, Epilepsia 58(4) pp. 522-530, 2017.

[2] M.P. Richardson, Large scale brain models of epilepsy: dynamics meets connectomics, Journal of Neurology, Neurosurgery and Psychiatry 83 pp. 1238-48, 2012.

[3] M.A. Lopes, et al., An optimal strategy for epilepsy surgery: Disruption of the rich-club?, PLoS Computational Biology 13(8), pp. e1005637, 2017.