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Modelling re-entry excitation and interventions in a personalized neural field model of the cortex

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Computational modeling and dynamical systems theory enhance our understanding of epileptic seizure dynamics and potentially provide new intervention strategies. Models like the Virtual Epileptic Patient (VEP) aim to make patient-specific predictions about the epileptogenic zone and subsequently identify targets for epilepsy surgery. The VEP is based on individual neuroimaging data, electrophysiological measurements of seizures, and a dynamical model of neural activity to construct a full brain network model of the patient. Currently, the VEP uses low-resolution neural mass models (NMM) to represent individual regions of the brain network. NMMs approximate neural activity within a single point, thus ignoring the spatial extent of the neural tissue and local propagation phenomena like the traveling waves observed in epileptic seizures. Therefore, we extended the model to high-resolution neural fields (NF) that represent the cortical sheet in its spatial extent.
We developed a high-resolution, personalized computational model for a patient with drug-resistant focal epilepsy in the left temporal lobe. Using T1-weighted and diffusion MRI combined with tractography, we reconstructed the cortical surface and estimated connections between surface points at a $1mm^3$ scale. Seizure dynamics were simulated using the two-dimensional Epileptor model in an excitable regime to test reentry effects, as suggested by empirical in-vivo and in-vitro studies. We applied the dynamical model to the cortical surface and explored the parameter space across coupling strengths and reentry frequencies. This approach revealed self-limiting excitations, spiral waves, and sustained reentry excitation. To terminate reentry, we tested two intervention strategies used in epilepsy treatment in our model: virtual thermocoagulation, which involved lesioning fiber tracts in the white matter to modify cortical connectivity, and virtual phase-dependent stimulation via virtually implanted electrodes.
Future research should focus on fine-tuning model parameters to match individual empirical data and optimize interventions.

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