Analysis of Neuronal Source Dynamics and Connectivity During Seizure

Tim Mullen1,2*, Zeynep Akalin Acar1, Jason Palmer1, Gregory Worrell3, Scott Makeig1

1 Swartz Center for Computational Neuroscience/ING, 2 Dept. of Cognitive Science, UC, San Diego, 3 Dept. of Neurology, Mayo Clinic

Abstract

Understanding the dynamics of neural processes critically involved in initiating and propagating a seizure may help in devising novel methods of seizure detection, intervention and treatment. Furthermore, applications of novel dynamical analysis methods in clinical situations where there is some, "ground truth" can reveal insights into the general applicability to cognitive neuroscience. In this post, we analyze neuronal dynamics during epileptic seizures using adaptive multivariate autoregressive (VAR) models applied to quasi-independent (ICA) sources of intraarcal EEG (EEG) ECoG data recorded from subdural electrodes implanted in a human patient for presurgical monitoring. We analyze the time-frequency dynamics of directed information flow between sources using a multivariate granger-causal method, identifying distinct information flow motifs in different stages of the seizure. We then further examine the spatial distribution in the cortical source domain of causal sources and sinks of ictal activity using a novel combination of graph theoretic and sparse Bayesian analysis. Finally, we apply an eigendecomposition method to decompose the VAR model into a system of coupled oscillators and relaxators (ergonomodes) with characteristic damping times and frequencies. We demonstrate that analyses of a small subset of the most dynamically important stationary ergonomodes allow effective detection of ictal onset and offset, while also yielding insight into the dynamical structure of the neuronal system. Convergent evidence from these analyses reveals distinct stages in the seizure which correspond to shifts in the spatiotemporal dynamics and connectivity structure between sources in or near the clinically-identified ictal epicenter.

Dynamical Systems Analysis and Multivariate Granger Causality

We utilize several graph-theoretic metrics to help simplify complex network structure and identify cortical areas that act as ictal-causal "hubs" or drivers (e.g. epileptogenic focus) - which we define as a causal "source" as opposed to a "sink." Our novel spatiotemporal analysis allowed us to locate causal source and sink hubs emerging during seizure.

Seizure ECoG Data

Theory: Channel or Source?

For forward (b-d) show, respectively, (a) shows a sequence of running lead-field inverses (b) shows a sequence of running lead-field inverses (c) shows a sequence of running lead-field inverses (d) shows a sequence of running lead-field inverses (e) shows a sequence of running lead-field inverses (f) shows a sequence of running lead-field inverses (g) shows a sequence of running lead-field inverses (h) shows a sequence of running lead-field inverses (i) shows a sequence of running lead-field inverses

Graph Theoretic Measures

Multi-lag Eigenmode Analysis of Principal Oscillational Patterns

Any stable M-dim VAR[p] process can be decomposed into M-p, M-dim eigendecomposition, each of which can be characterized as a stochastic-moment-damped oscillator or relaxator with a characteristic time constant and damping time [5]. The damping time provides a measure of how long, on average, an oscillation is seen before noise an unobserved or nonlinear dynamical processes become increasingly important. The most dynamically important eigenvectors provide a measure of the principal oscillation pattern of the system.

Visualisation

We developed a novel method that visualized univariate graph-theoretic metrics associated with specific IC sources (e.g. causal flow, outflow, etc.) directly on the cortical surface/projecting these metrics through the SBL solution. This allows an interactive spatiotemporal visualization of cortical dynamics, network structure, and ictal flow.

Conclusions

Our novel spatiotemporal analysis allowed us to localize ictal source and sink hubs emerging during seizure. We observed distinct stages of principal oscillation pattern shift and alternating information flow between driver and observer cortical areas which may be maintained by different patterns of ongoing neural activity. This analysis was carried out.

References and Acknowledgements


* Correspondence: tim@con.ucsd.edu

1. Swartz Center for Computational Neuroscience/ING, 2 Dept. of Cognitive Science, UC, San Diego, 3 Dept. of Neurology, Mayo Clinic