CIFAR progression report

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1 Overview

We first present the research questions that we are interested in, and go on to describe the data and methods proposed to tackle those questions. In particular, we explain how we model the high-frequency envelope amplitude of ECoG signals located in regions of interests and estimate parametric Granger causality from these models. The concordance of Granger causality estimation from parametric and non parametric techniques suggest that these approach are interesting to model information flow between regions of interest across resting state and stimulus presentation conditions and warrants further inferential statistical analysis. Representative figures can be found in the slides accompanying this report.

2 Research questions

We have the opportunity to work with a very unique ECoG dataset, and to exploit our expertise [1, 2, 3, 4, 5] on functional connectivity analysis to study it. The unusually high signal-to-noise ratio of the ECoG signal allows us to study its high frequency properties (60-180Hz), which have been shown in previous studies to correlate with local firing rate [6]. We want to leverage the opportunity offered by such a unique dataset to explore functional connectivity and signal diversity of the high-frequency envelope of ECoG signals from electrodes across the whole cortex under different conditions, including resting state, visual stimuli and sleep. More precisely we are investigating the following questions:

- How does the functional connectivity and signal diversity of high-gamma amplitude from visually responsive electrodes vary between resting state and visual stimulus presentation?
- How does the functional connectivity and signal diversity of ECoG signals at frequencies of interest vary across different sleep stages, and how does it compare with resting state?
- How do our functional connectivity results relate to other published accounts and hypotheses about visual processing and conscious level?

3 Data description (slide 2 and 3)

We analyse ECoG datasets recorded from 10 epileptic patients with varying electrode placement across the whole cortex (slide 3). For each patient, the data contains (slide 2):

- Two periods of resting state, eyes closed, 200 seconds each.
- Two sessions of picture viewing, recorded immediately after the resting-state period: 132 seconds each, 28 pictures of famous faces and places in total, 1500 ms duration, 750 ms inter-trial interval.)The data were recorded as part of a memory experiment.)
- 6 hours of night sleep

Two versions of the data are available: the first contains a raw, unfiltered signal, referenced to a vertex screw or sub-dermal electrode and re-sampled at 500Hz. In the second version the data has been converted to bipolar montage and filtered at 60Hz (and harmonics) for line-noise contamination.

4 Preprocessing (slide 4,5)

The raw data are rereferenced using a bipolar montage scheme. Line noise is removed using the "ZapLine" algorithm [7] (slide 4 top right figure); this is a highly effective (and Granger causality-friendly) alternative to notch filtering. To suppress low-frequency transients in the raw data and thus improve stationarity, we perform a robust detrending by subtracting a fitted sinusoidal signal on sliding, overlapping windows of duration 5 seconds [7] (slide 4 bottom left figure). The high-frequency broadband (HFB) envelope is a key signal of interest, standing as a "proxy" for local firing rates. The HFB envelope is constructed as follows: the (preprocessed bipolar-montage) LFP data is band-pass filtered, using a generalised Remez FIR filter of order 100, in 20Hz bands between 60 and 120Hz. For each narrow-band filtered signal, the corresponding analytic signal is derived using the Hilbert transform. In order to take into account the $1/f$ spectral characteristics of the LFP, the HFB envelope is then taken as the average of the normalised narrow-band amplitude envelopes (slide 5).

5 Modeling (slide 6,7,8)

In accordance with our collaborators findings [8] the amplitude of the HFB envelope shows significant baseline increase from rest upon stimulus presentation in some electrodes located in visual areas. Slide 6 shows an example of such baseline shift. We are interesting in modeling the HFB envelope at rest and post-stimulus to explore directed functional connectivity in these two conditions. We model the HFB envelope using linear state-space modelling, which has been suggested to be preferable to VAR modelling [9, 5], as state-space models can take into account moving-average components induced by subsampled signals and other preprocessing interventions. Slide 7 shows a representative example of VAR model identification of an HFB envelope from 28 trials of 1251 observations (2.5 second windows) from 8 visual electrodes upon stimulus presentation. We obtain stable models with spectral radius of 0.992 and model order of 7 according to a likelihood ratio test. Similarly slide 8 shows a stable state space (SS) model with spectral radius of 0.987 for the same multitrial HFB envelope. Our modeling techniques are therefore able to produce stable models that will be used for further parametric functional connectivity analysis. To validate the parametric modelling approach, we also performed nonparametric estimation of Granger causality via spectral factorisation of the cross-power spectral density matrix [10]; results agree well with the state-space GC estimates. One should keep in mind that the HFB amplitudes following stimulus presentation are highly non-stationary, a feature that neither parametric nor nonparametric GC estimation as described takes into account. Our proposed resolution—which we are currently exploring—is to use use the spectral factorisation approach, but based on time-frequency wavelet cross-spectra.

6 Functional connectivity (slide 9)

We deploy our state-space models to explore directed functional connectivity from parametric Granger causality estimation [9, 5]. We consider visually responsive electrodes from a single subject and compare Granger causality of the $N = 28$ multi-trial, 2.5 seconds window, HFB envelope at resting state and face presentation (slide 9). We observe some change in the connectivity pattern; in particular there seems to be stronger connection between electrodes in Brodman region MT during resting state, which then reduces during stimulus. In addition, stronger Granger-causal

connection appears between visual electrodes in V1 and V2 during face presentation, suggesting stronger information flow between these higher-order visual ROIs upon stimulus presentation as compared to resting state. These results are so far only qualitative; more rigorous quantitative analysis relying on robust statistical inference is warranted, and will be pursued in future work.

7 Signal diversity (slide 10 and 11)

Signal diversity is another quantity of interest that measures the amount of "randomness" in the signal (roughly, the rate at which previously unseen temporal sequences appear) by computing Lempel-Ziv complexity on a quantised neural time series [11, 12]. We are interested in measuring how signal diversity changes across different regions and conditions. We have done some preliminary analysis by computing binary normalised Lempel-Ziv complexity of the HFB envelope from visual electrodes in resting state and stimuli condition (slide 10, 11) averaged over $N = 28$, 2.5 seconds trials. Slide 10 suggest that LZc is well behaved, as the ranking of LZc stays the same as the sequence length increases. Looking at the bar chart obtained in slide 11, interestingly LZc seems to decrease for some visual electrodes in V1, V2, MT at stimulus presentation with respect to rest; however one should interpret this figure with care as more robust statistical inference is needed.

8 Discussion and future work

We have performed qualitative directed functional connectivity analysis via parametric state space modelling on visual electrodes during resting state and stimulus presentation. Comparing functional connectivity across these electrodes suggest a change in functional connectivity with stronger information flow in higher order visual areas during stimulus presentation. More robust statistical inference is warranted to confirm or falsify these observations. We also plan to extend this analysis on sliding windows and using time-frequency spectral analysis, and taking into account more interesting channels. It will also be interesting to keep track of the high-frequency spectral Granger causality estimated directly from the (montaged) LFP; previous in-house VAR simulation suggests that it measure something quite distinct from the HFB envelope GC. We also plan to measure undirected functional connectivity from information-theoretic measures that we have previously developed and can be estimated directly in a nonparametric way. Finally it would also be interesting to perform a similar analysis on sleep stages.

9 References

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