Conjoint Observation of Distinct Oscillatory Brain States in Intracranial and Scalp EEG

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***Abstract*— We systematically analyzed the relationship between oscillatory spatial-temporal patterns identified from invasive electrocorticography (ECoG) and scalp EEG. We first performed a fuzzy classification of the principal components of cortical oscillatory activity as one of the three types: localized sources, static waves (distributed oscillators) and propagating waves. Next, we evaluated how this cortical activity correlated with the scalp EEG. Our findings indicate that the scalp EEG best represents, at any frequency, the static wave type of synchronized activity. This observation may aid a more accurate interpretation of the scalp EEG and contribute to the definition of source localization models.**

I. Introduction

Although a lot of phenomenological data has been gathered, the internal characteristics of the brain dynamics that are relevant for information processing remain largely unknown. Computational models suggest that neuronal dynamics may consist of a rich set of synchronized states [1] which are relevant to cognition [2]. There is, however, a considerable gap between the information that can be extracted from the scalp EEG and the rich brain dynamics that can be recorded with invasive recordings [3]. To help address this gap we investigated the correspondence between cortical oscillatory activity and the scalp EEG.

II. Concept and Methods

We studied 1 hour long interictal data epochs from 21 patients undergoing pre-surgical diagnostic evaluation with subdural strip and grid and scalp EEG electrodes [3]. Gabor time-frequency dependent complex amplitudes $G_c(\upsilon, \mathrm{t})$ were derived from the EEG and nearby ECoG electrodes. We used 200 filters, with central frequencies exponentially ranging from 4Hz to 128Hz. Data was analyzed with 20-sec windows, 50% overlap. For each Gabor frequency we studied the properties of Principal Components (PC) of the ECoGs as the normalized eigenvectors V_a^α and eigenvalues E^α of the complex correlation matrix

$$C_{ab}(\upsilon) \equiv \langle G_a(\upsilon,\mathrm{t})\overline{G_b(\upsilon,\mathrm{t})}\rangle_t \qquad (1)$$

Locality (L) and Phase Clustering Index (PCI) are defined as:

$$L^\alpha(\upsilon) \equiv 1 + \sum_{a=1}^{n} |V_a^\alpha|^2 \log(|V_a^\alpha|^2)/\log(n) \qquad (2)$$

$$PCI^\alpha(\upsilon) \equiv {|\sum_{a=1}^{n} V_a^\alpha|} \Big/ {\sum_{a=1}^{n} |V_a^\alpha|} \qquad (3)$$

Quantities (2) and (3) were used to classify the cortical oscillations with the following three features: L as local source, $SW = (1 - L)PCI$ as static wave and $PW = (1 - L)(1 - PCI)$ as propagating wave. To quantify the "observability" of the cortical PC's on the EEG (index s) we use the square-normalized correlation:

$$R_{s\alpha}(\upsilon) \equiv |\sum_a C_{sa}(\upsilon)V_a^\alpha|^2 (\sum_{a,b} V_a^\alpha C_{ab}(\upsilon)\overline{V_b^\alpha}) C_{ss}(\upsilon))^{-1} \qquad (4)$$

Summation of (4) over all PC's produces the ECoG "derivability" of the EEG signal. Aggregation from all ECoG PCs was performed as:

$$Q(\upsilon) \equiv \sum_\alpha Q^\alpha(\upsilon)E^\alpha / \sum_\alpha E^\alpha,\ Q = L, SW, PW, R \qquad (5)$$

III. Results and Conclusions

In Fig. 1 we present features aggregated from all PCs and averaged over all windows and subjects. Static waves dominate the lower, and local sources the higher, frequencies. High frequencies present in the scalp EEG are less likely to be of a cortical origin compared to lower frequencies. For all frequencies the observability of the cortical oscillations is positively associated with the amount of SW type of activity.

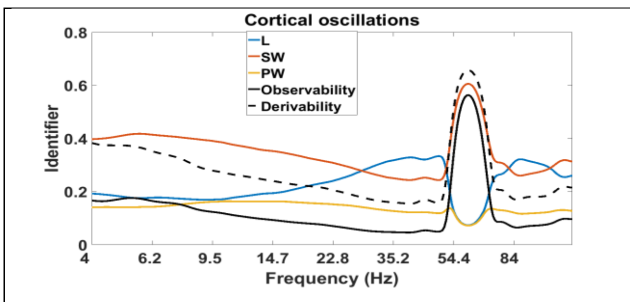

Fig. 1. Averaged aggregates of different oscillatory ECoG states (colored lines), the ECoG state observability (black) and the scalp EEG fraction derivable from the ECoG (dashed).. Note the peak around 60Hz on the SW,derivability and observability traces reflecting the mains frequency induced distributed and phase-coherent artefact.

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