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Network spread of intracranially induced oscillatory activity in the human brain

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1 Introduction

Brain oscillatory activity recorded as rhythmic fluctuations of excitability by sets of neurons has been reported to code for specific cognitive processes such as attentional orienting, motor planning, and memory consolidation [Buzsaki 2004]. Interestingly, the manipulation of oscillatory activity has been found potentially promising to improve normal cognitive function and treat disability in cerebrally damaged patients [Thut 2014], and similar approaches could be used to suppress the spread of epileptic seizures in medication-resistant patients [Mina 2013, Laxpati 2014]. A recent study performed on healthy brain regions of implanted epilepsy patients with 50 Hz Direct Electrical Stimulation (DES) coupled to intracranial electroencephalography (iEEG) has provided evidence of local gamma oscillatory entrainment [Amengual 2016]. However the distribution of these induced rhythms throughout brain networks, the influence of stimulation intensity and the underlying role of white matter connections in their spread remains elusive [Donos 2016]. To address these questions, effective connectivity between synchronized sites measured on iEEG signals during intracranial stimulation was assessed in order to map the spread of the induced effects of rhythmic at different stimulation intensities. We then used a connectomics approach to reconstruct the brain networks based on diffusion MRI (dMRI) and tractography [Hagmann 2008].

2 Method

A multimodal dataset of iEEG, T1- and dMRI recordings acquired for 3 medication-resistant epilepsy patients undergoing concurrent intracortical recording and stimulation mapping procedures were included in this study. These patients were implanted with series of multielectrodes allowing the delivery of 5 seconds bursts of biphasic electric pulses employing rhythmic DES at 50 Hz at 3 intensities (0.5, 1 and 2 mA) coupled to iEEG recordings. We developed a connectomics approach to produce a individual models of the brain's structural connectivity following the following steps : First, the nodes were defined using a high-resolution gray matter parcellation scheme; Second, structural connectivity between each node was assessed using anatomically-constrained probabilistic tractography based on

spherical deconvolution; Finally, graph theory measures were used to characterize the topology of the structural network. Concerning the analysis of iEEG dataset, electrical artifacts induced by DES were corrected using cubic spline signal interpolation [David 2013]. Then synchronization between distant regions was assessed using the Phase Locking Value (PLV) [Lachaux 1999] of the relative phase for iEEG activity and the stimulation signal in the gamma frequency band. In those networks nodes where a significant increase of PLV was observed, a non-linear correlation measure [Lopes 1989] was used to assess the effective connectivity during versus before the 5 seconds episodic bursts of rhythmic 50 Hz DES.

3 Results

Our results reveal signs of local entrainment of gamma activity followed by significant increases in synchronization in distant sites from the stimulated node during rhythmic 50 Hz DES as compared to prior the delivery of the electrical bursts. Additionally, effective connectivity maps estimating non-linear correlation showed that the level of synchronization depended both of the topology of the network and the intensity of stimulation.

4 Conclusion

Our analyses suggest that effective and structural connectivity characterizing frequency-specific interactions between the stimulated brain region and other nodes of its network influences its ability to spread rhythmic activity, a phenomenon which is likely relevant for human cognition and behavior. Our study is also a step towards patient-specific models able to simulate the spread of oscillatory activity induced by rhythmic stimulation, which could be used to stop seizures in medication-resistant epilepsy patients.