Temporally quasi-stable spatial configurations in fMRI reveal scale-free dynamics similar to that of EEG microstates

Nurhan Erbil[1] and Gopikrishna Deshpande[1,2]

[1]*Department of Electrical and Computer Engineering, Auburn University MRI Research Center, Auburn, Alabama, United States,* [2]*Department of Psychology, Auburn University, Auburn, Alabama, United States*

Introduction: Coherent low frequency fluctuations (<0.1Hz) have been observed in fMRI data from cortical regions, which are known as resting state networks [1, 2]. These fluctuations have been shown to be correlated with smoothed and downsampled versions of EEG microstates [3] which are quasi-stable scalp electrical topographies of approximately 80-100 ms duration. This coupling between fast and slow temporal dynamics of EEG and fMRI, respectively, has been attributed to the fractal properties of EEG microstates, covering scales from 256ms to 16s range [4,5]. If this is true, resting state fMRI must also demonstrate temporally quasi-stable spatial configurations which are scale free, and whose fractal properties are similar to that of EEG microstates. In this study, we test this hypothesis by performing fractal analysis of simultaneously acquired EEG/fMRI data. Resting state being an unconstrained condition, its dynamics can be unique for every run and subject. Therefore, it is imperative to acquire simultaneous EEG/fMRI data in order to test this hypothesis.

Methods: Resting state multiband EPI data [6] were acquired from 4 healthy volunteers in a 3T Siemens Verio scanner using a 12-channel matrix ßhead coil, 30ms TE, 600ms TR, 55° flip angle and 64 x 64 x 16 acquisition matrix. MR-compatible 64 channel EEG amplifiers (Brain Products, Germany) and a MR-compatible EEG cap with 63, 10-20 system distributed scalp electrodes and an ECG electrode were used for simultaneous acquisition of EEG data. The EEG and MRI data acquisition was synchronized using Brain Product's SyncBox. EEG data were digitized at 5 kHz and 0.5 µV resolution, within a DC-250Hz frequency range and with reference to FCz. Impedance at all recording electrodes was less than 20 kΩ. The recorded EEG data were preprocessed to remove gradient and cardioballistic artifact using Brain Vision Analyzer 2.0 software. Data were band-pass filtered between 0.1-40 Hz with Butterworth IIR filter with a roll-off 24dB/octave, downsampled to 100Hz, re-refrenced to Common Average Reference. After standard resting state fMRI pre-processing, mean fMRI time series were calculated from 190 functionally homogeneous brain regions obtained by whole brain spectral clustering of resting state fMRI data [7]. These time series, along with pre-processed EEG, were subjected to microstate segmentation using Cartool software (brainmapping.unige.ch/cartool) for each subject separately. Four template maps for each subject and modality were obtained. For fractal analysis, the microstates were bipartitioned by associating them with a positive and a negative step, respectively [5]. Cumulative sum of the resulting microstate sequence over time was used as random walk embedding and analyzed using continuous Daubechies' orthogonal wavelet transform with five vanishing moments (Fig.1). In order to examine scale-free dynamics, the linear relationship (in log scale) between wavelet coefficients and scale (i.e. power-law) was used [4]. The scaling diagram was used to calculate Hurst exponent (H) for the 3 possible bipartitionings of microstate sequences (Fig.3).

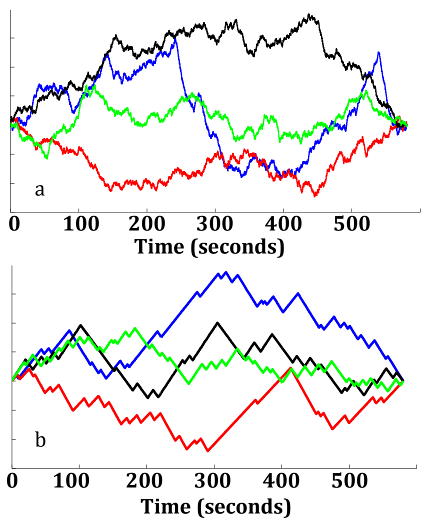

Fig.1 *Random walk embedding curves of EEG (a) and fMRI (b) microstate sequences for all subjects. X axis represents time in seconds.*

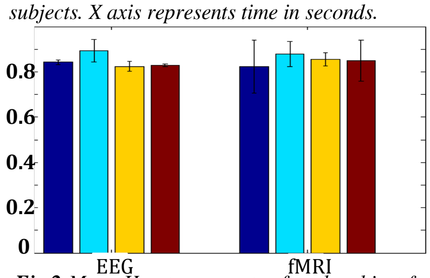

Fig.2 *Mean Hurst exponents of each subject for each modality. Error bars represent one standard deviation.*

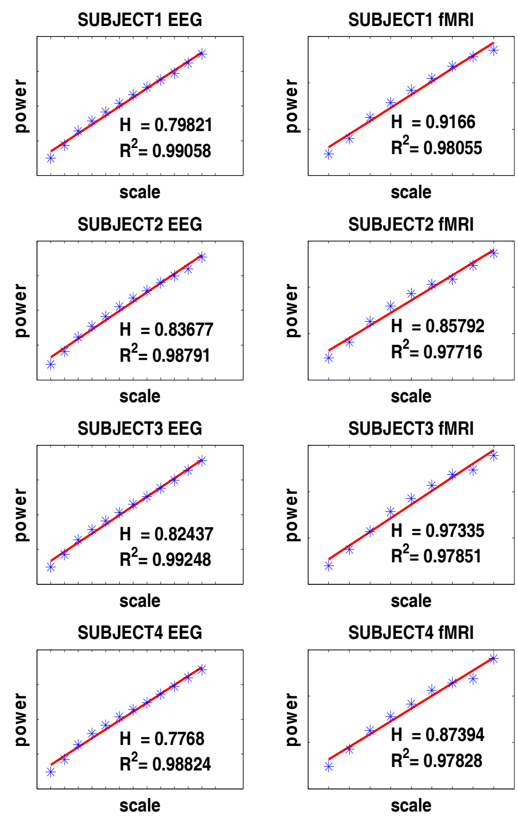

Fig.3 *Log scale Power-law behavior of wavelet coefficients for each subject and modality. H represents Hurst exponents, R^2 represents coefficient of determination of the curve fit.*

Results and Discussion: The random walk embedding obtained from EEG and fMRI (Fig.1) has interesting similarities for 3 out of the 4 subjects (except blue curve). The Hurst exponents in Figs.2 and 3 showed long-range dependencies (H>0.5, P<0.05) and scale-free behavior for both EEG and fMRI. This confirms our hypothesis that temporally quasi-stable configurations from both fMRI are scale free and have interesting temporal similarities with their EEG counterparts. This provides a strong basis to believe that resting state fMRI fluctuations to electrical oscillations underlying fast neuronal processes.

References: 1. Fox et al., *PNAS* 102: 9673–9678, 2005 **2.** De Luca et al., *NeuroImage* 29: 1359 – 1367. 2006 **3.** Yuan et al, *NeuroImage*. 60(4):2062-72, 2012. **4.** Britz et al, *NeuroImage* 52(4): 1162-70, 2010 **5.** De Ville et al., *PNAS* 107(42): 18179-84, 2010 **6.** Feinberg et al., *PLoS One*, 5(12), 2010 **7.** Craddock et al, *HBM*, 33(8):1914-28, 2012.