A new information theoretic approach to quantify resting-state fMRI synchrony

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Introduction:

Resting-state functional MRI (rs-fMRI) has been an important tool to study the brain network. While most rs-fMRI studies aim to evaluate instantaneous temporal correlations of the BOLD signal across brain regions to infer functional connectivity (Biswal et al. 1995, Cordes et al. 2001, Beckmann et al. 2005), the intrinsic fluctuation patterns of the fMRI signal over time and the information these patterns carry are less understood, but could be important for a better understanding of brain functions. In this work, as a complementary tool to conventional rs-fMRI quantification methods, we utilize a information theoretical framework(Crutchfield and Feldman 2003) to quantify synchrony in temporal fluctuation of rs-fMRI to untangle the intrinsic information that rs-fMRI fluctuations carry from randomness.

Methods:

Viewing rs-fMRI signal fluctuation as a process whose underlying temporal pattern is unknown, the challenge is to quantify how difficult it is to predict a pattern. In other words, we attempt to measure the amount of randomness and synchrony that are inherent in rs-fMRI signals.

In the probabilistic framework developed by Crutchfield (Crutchfield and Feldman 2001, 2003), several quantities were introduced to quantify the process of synchrony in stochastic fluctuations: 1) Block Entropy H(L), defined as the total Shannon entropy of all possible signal blocks of length L. It measures the randomness associated with a length of L blocks. The unit is bits. 2) Excess Entropy E, defined as the mutual information between past and future, measures the intrinsic memory of consecutive measurements. 3) Transient information TI, defined as the difference between H(L) and E taken over all L blocks, reflects how difficult it is to overcome uncertainty and thus can be interpreted as a measure of the synchrony of the process. Figure 1 depicts the relationships between H(L), E and TI(L).

Experiments

Resting-state fMRI data from 10 healthy subjects (5 female) between the age of 65 and 78 years (mean age: 74 years) from the Alzheimer's disease Neuroimaging Initiative (ADNI) were analyzed. These subjects were scanned using 3T Philips System. The task free, 7-min fMRI sequence parameters are: TR/TE = 3000/30 msc, number of averages = 1. Echo number = 1. Flip angle = 80 degree. Number of measurement = 140. 48 slices were acquired with spatial resolution 2.88x2.88 mm, slice thickness = 3.31mm. In addition, high-resolution T1-weighted magnetization prepared rapid gradient echo (MPRAGE) scans (1x1x1mm resolution) were also acquired for each subject for the purpose of anatomical localization.

Rs-fMRI data were preprocessed using conventional fMRI procedures for motion correction, smoothing, linear detrending, and bandpass filtering (0.01Hz-0.08Hz). The signals were then discretized into ten levels according to the intensity. H(L), E, and TI(L) were computed for the whole brain using the discretized fMRI signals.

Results:

Figure2 demonstrates TI maps for three representative subjects. As the block length L increases, TI values of grey matter increase faster than those of white matter. As the TI values reach an equilibrium at about block length L = 10, the maps show further that TI remains higher in gray matter(GM) than white matter(WM), indicating fluctuations in GM have more coherent structure (less randomness) than those in WM.

Conclusions:

To our knowledge, this is the first attempt of quantifying the internal synchronization process of rs-fMRI signals while simultaneously capturing the intrinsic memory that the signals carry. The finding that rs-fMRI fluctuations of GM on average have more internal structure and carry more memory than in WM are consistent with the view that cortical activations have a coherent underpinning. An extension to quantifying the similarity in TI across brain regions is in progress. Transient information could provide a new metric for rs-fMRI to quantify functional processes and to study functional networks in healthy brain

Modeling and Analysis Methods:

fMRI Connectivity and Network Modeling

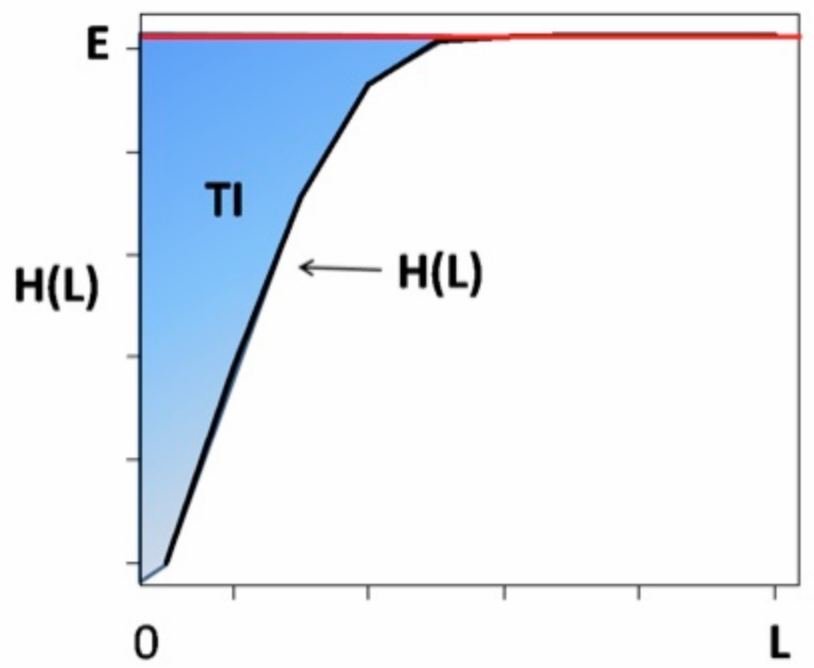

Figure 1. Schematic plot of block entropy H(L) growth versus block size L. The shaded area is the transient information TI.

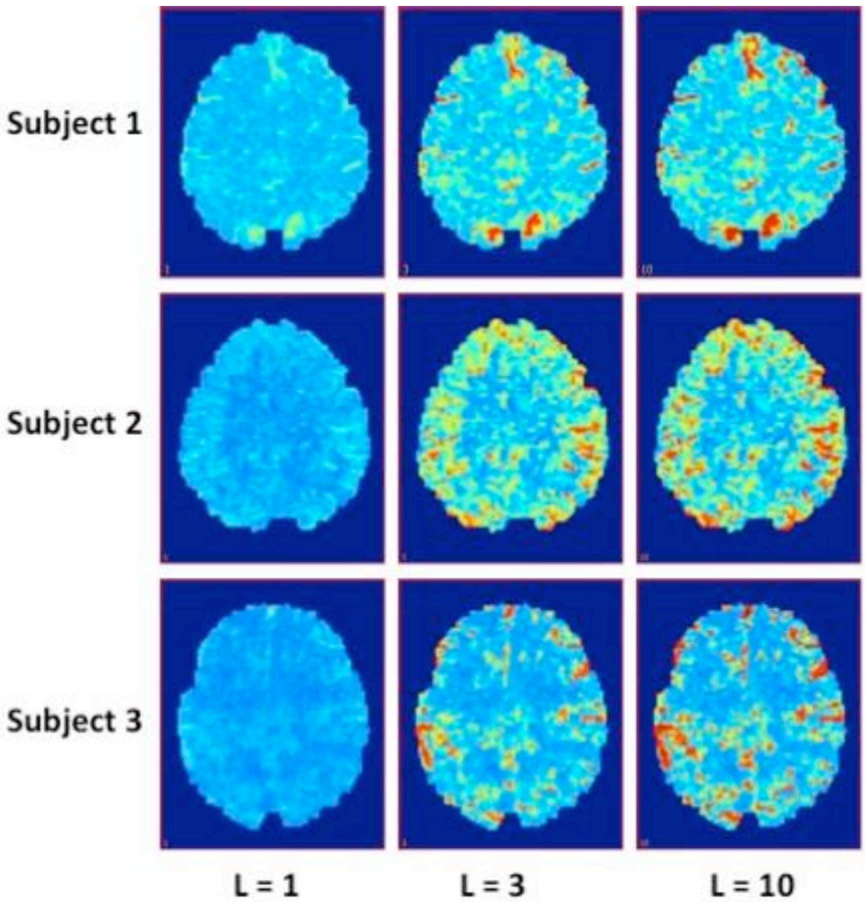

Figure 2. Transient information maps of three different subjects, with different block length(L=1,3,10)

Abstract Information

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