Identification of anti-correlated resting-state networks using simultaneous EEG-fMRI and Independent Components Analysis

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INTRODUCTION

In the absence of an explicit task, temporal synchrony is maintained across brain regions. Taking advantage of this synchrony, resting-state fMRI has been used extensively to identify resting state networks (RSN) [1]. Fox et al. have reported that the default mode network (DMN) is anti-correlated with the task positive network (TPN) [2], reflecting the competing demands of these two networks. The goal of this study was to identify the neuro-electrical signature of these anti-correlated networks, as assessed with simultaneous EEG-fMRI. Prior EEG-fMRI studies have found that the sign of the correlation between global alpha band power and the blood oxygenation level-dependent (BOLD) signal depends on the brain region [3,4,5]. Mantini et al [6] found that the correlation between global alpha band power and the spatial ICA time courses associated with the DMN and TPN have different signs, consistent with the presence of anti-correlation between these networks. Using a group analysis (N=14), Jann et al [7] found some evidence for a link between alpha power global field synchronization and the DMN. In this study, we hypothesized that the relation between alpha power and the DMN and TPN would be stronger when using independent components of the EEG signal, as compared to using the global alpha power.

METHOD

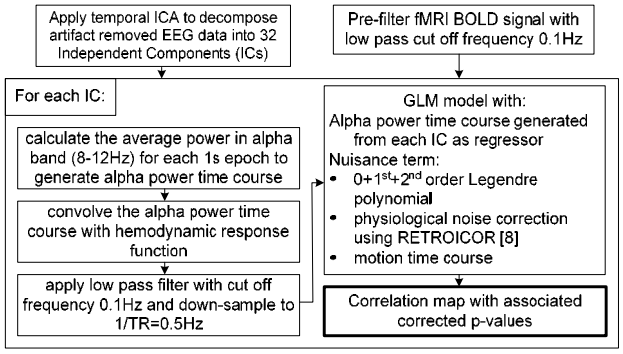


Fig. 1 Our processing scheme (highlighted box as final result)

The procedure of our method is summarized in Fig. 1. A pilot study was conducted on one healthy male subject. One simultaneous EEG-fMRI resting state run was recorded and processed with eyes closed (EC). Data were acquired using a 3 Tesla GE HDX system and a 64 channel EEG system (Brain Products). EEG signals were recorded at 5kHz sampling rate. Vision Analyzer 2.0 software (Brain Products) was used for subtraction-based MR-gradient and CB artifact removal [9,10]. A low pass filter with cut off frequency 30Hz was applied to all channels and the processed signals were down-sampled to 250Hz. ICA (as implemented in EEGLAB [11]) was applied to remove residual artifacts. Noisy ICs were rejected and the remaining ICs were back-projected to form what is defined as "*artifact removed EEG data*". ICA was then performed again on these *"clean"* data. Functional MRI data were acquired with the following parameters: echo planar imaging with 150 volumes, 30 slices, 3.438x3.438x5mm^3 voxel size, 64x64 matrix size, TR=2s, TE=30ms. For each IC, a correlation map with the fMRI data was created and significance was assessed with a corrected p-value threshold of 0.01

We defined a metric called the *Anti-Correlation Index (ACI)*, where n_{pos} and n_{neg} are the number of voxels above the threshold that are positively and negatively correlated with EEG respectively. ACI = 0 implies equal number of positive and negative correlation voxels whereas ACI=1 implies exclusively either positive or negative correlations. In our study, we first extracted 16 ICs with highest $n_{pos}+n_{neg}$. We then ranked the ICs according to their ACI.

$$ACI = \frac{|n_{pos} - n_{neg}|}{n_{pos} + n_{neg}}$$

RESULTS AND DISCUSSION

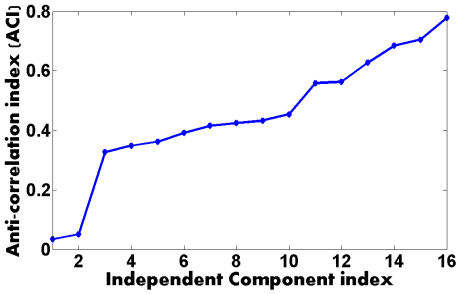


Fig. 2

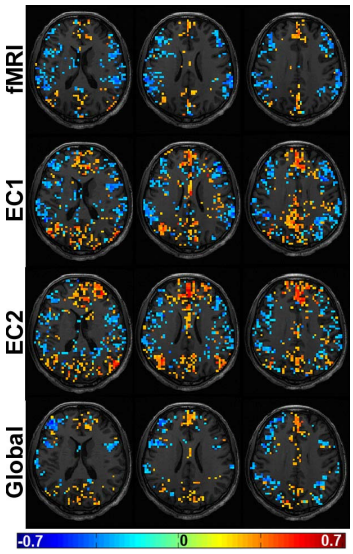
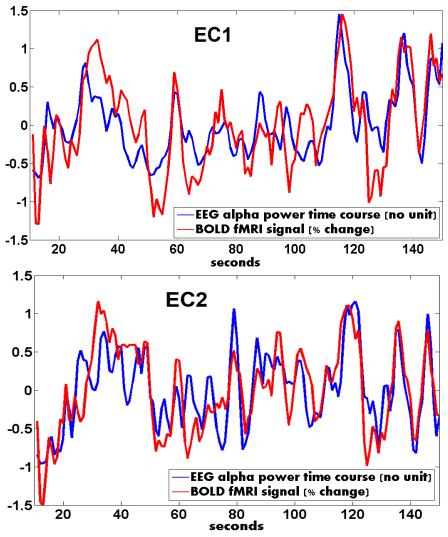


Fig. 3a



3b (Alpha power time course vs BOLD signal)

Fig. 2 shows the sorted ACI values of the 16 extracted ICs. The first two ICs (denoted as EC1 and EC2) have noticeably lower ACI values than the remaining ICs. The top row of Fig. 3a shows the default-mode network (DMN in red) and the task-positive network (TPN in blue) in a resting-state correlation map obtained from the BOLD fMRI data only, where the seed signal was obtained from an ROI in the posterior cingulate cortex (PCC) with a corrected p-value threshold of 0.01. The middle two rows in Fig 3a show the correlation maps between the BOLD fMRI signal and the first two EEG ICA components (EC1 and EC2). The spatial locations of the anti-correlated networks (DMN and TPN) in the EEG-fMRI correlation maps show good agreement with the regions found in the resting-state fMRI correlation map. In contrast, the correlation map obtained with global alpha power (average from all electrodes) shows much weaker agreement with the fMRI correlation map. Fig. 3b shows the correlation pattern between the alpha power time course of each of the EEG IC components and the corresponding BOLD signal averaged from voxels with correlation>0.4. In conclusion, we found that the alpha powers in two EEG independent components were strongly associated with the DMN and TPN anti-correlated networks. These results suggest that ICA decomposition of the EEG data can be used to more readily identify the relation between resting-state EEG and BOLD signals.

[1] Fox et. al., Nat. Rev. Neurosci. 2007, 8:700-711. **[2]** Buckner et. al., Neuroimage 2007, 37:1091-1096. **[3]** Goldman et. al., Neuroreport 2002, 13:2487-2492. **[4]** Moosman et. al., Neuroimage 2003, 20:145-158. **[5]** Laufs et. al., Neuroimage 2003, 19:1463-1476. **[6]** Mantini et. al., Neuroimage 2007, 34:598-607. **[7]** Jann et. al., Neuroimage 2009, 45:903-916. **[8]** Glover et. al., MRM. 2000, 44:162-167. **[9]** Allen et. al., Neuroimage 1998, 8:229-239. **[10]** Allen et. al., Neuroimage 2000, 12:230-239. **[11]** Delorme et. al., J of Neuroscience Methods 2004, 134:9-21.