Observing Resting-State Networks at Higher Frequencies with MR-Encephalography and Independent Component Analysis

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Introduction Resting-state fMRI observes spontaneous BOLD signal fluctuations when no specific cognitive task is being performed. Common resting-state network analysis focuses on coherent BOLD signal fluctuations below 0.1 Hz [1], while assuming the connectivity patterns are stationary during a scan session (typically between 5 and 15 minutes). However as functional connectivity analysis on macaque cortex revealed [2], hemodynamic signal responses can occur at a faster rate and have different characteristics at different time scales. The change in functional connectivity can also occur within a smaller period of time [3]. These features cannot be easily detected by conventional resting-state fMRI that uses echo-planar imaging with TR around two seconds.

MR-Encephalography (MREG, [4]) is a fast-imaging technique that can shorten the acquisition time for a whole-brain image to sub-second scale. It has been shown that with high temporal resolution certain coherent networks can be found consistently at frequencies outside of the conventional < 0.1Hz band [5]. In this study we used MREG with a highly under-sampled single-shot concentric shells trajectory [6] to record resting-state fMRI signal at 100-msec sampling rate. We then applied independent component analysis (ICA) to the data to observe the overall resting-state network distribution at different frequencies.

Methods Resting-state fMRI data from five healthy volunteers were acquired on a 3.0 T Siemens Trio scanner (Siemens Healthcare, Erlangen, Germany) with a 32-channel head coil. Subjects were instructed to close their eyes and relax during the scan session. The concentric shells acquisition scheme has TR = 100 ms. For each session 4096 time frames were collected (total scan time 6 min 50 sec), and the first 15 sec were discarded for signal stability consideration. Imaging volume has a 256 × 256 × 256 mm^3 FOV, and was later reconstructed into a 64 × 64 × 64 matrix using the forward operator estimated from a non-uniform FFT (nuFFT) algorithm based on coil sensitivity weightings and measured gradient trajectory. All post-processing was done in MATLAB (The Mathworks, Inc., Natick, MA).

Reconstructed images were first corrected for rigid-body motion in SPM8 (http://www.fil.ion.ucl.ac.uk/spm). Signals were then filtered into desired frequency bands (0.01~0.1 Hz and 0.5~0.8 Hz). ICA based on Infomax algorithm was performed with target component number set to an empirical value 40. The same ICA processing was applied to the full 395-second signal, as well as cropped time-series (the first 60, 120 and 240 seconds). The resulted components were manually inspected and neuro-physiological relevant networks were selected based on the spatial location and signal waveforms of each component.

Results After ICA the visual network component was identified. Figure 1 shows examples of the visual resting-state networks at different frequencies. The top row contains the results of 0.01~0.1 Hz signals and the bottom row contains 0.5~0.8 Hz. As signal length decreases from the left to the right columns, noise levels were raised because of the decreasing number of observations available for the analysis. With a signal length of 60 seconds, the network at 0.01~0.1 Hz no longer has a localized pattern in the visual cortex. Similar to what correlation analysis results suggest [7], the network at 0.5~0.8 Hz showed a more consistent feature with different signal lengths. Figure 2 shows seven other networks found by ICA at the higher frequency band.

Discussion Preliminary results of ICA have presented several coherent resting-state brain networks at frequencies 0.5~0.8 Hz. Those networks are similar to the known networks (or partial networks) found at <0.1 Hz (Note that the common default mode network was curiously not seen). Nevertheless the ICA parameters are yet to be optimized; especially a proper estimation of the number of components is still needed. More data are also required in order to achieve a more reliable group analysis result. Here we have demonstrated that high sampling-rate fMRI data obtained by MREG allows us to find stable resting-state networks within a shorter acquisition time, which will have the benefit of reducing image artifact due to prolonged scan time, such as subject motion. It also has the potential to enable the observation of dynamic resting-state networks over time with a higher temporal resolution.

References [1] Biswal *et al.*, MRM 34: 537–541 (1995); [2] Honey *et al.*, PNAS 104(24):10240-10245 (2007); [3] Chang *et al.*, NeuroImage, 50:81-98 (2010); [4] Hennig *et al.*, NeuroImage, 34:212-219; [5] Lee *et al.*, Proc. ISMRM 2011, pp.1638; [6] Zahneisen *et al.*,MRM, *in press*; [7] Lee *et al.*, NeuroImage, submitted.

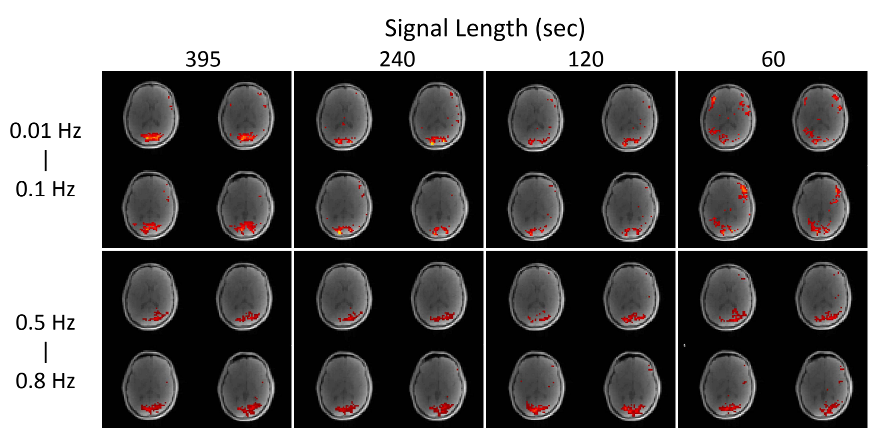

Figure 1 ICA results of visual networks found at different frequencies and signal lengths. At 0.5 ~ 0.8 Hz the network pattern is more consistent when signal length is shortened to 60 seconds.

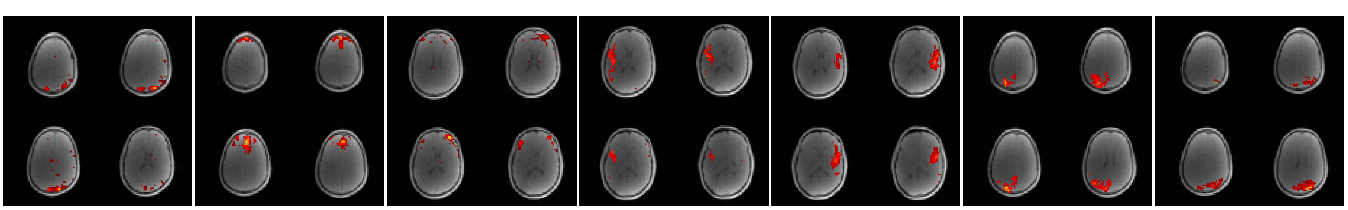

Figure 2 Other networks found at 0.5 ~ 0.8 Hz frequency band. A) cuneus; b) frontal gyrus; c) middle frontal gyrus; d) e) precentral gyrus, superior temporal gyrus; f) g) middle temporal gyrus, precuneus.