Resting-State Networks at Higher Frequencies: a Preliminary Study

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Introduction Resting-state network analysis looks for coherent spontaneous BOLD signal fluctuations at frequencies lower than 0.1 Hz [1], where the most energy is stored. However hemodynamic signal responses can occur at a faster rate and will not show in this frequency range. Functional connectivity analysis on macaque cortex revealed different characteristics at different time scales [2]. Also common whole-brain resting-state fMRI uses echo-planar imaging (EPI) with TR around two seconds, which has a Nyquist frequency ~ 0.25 Hz. Faster signal fluctuations are thus not perceivable at this sampling rate.

In this study we used a highly under-sampled single-shot concentric shells trajectory [3] which was capable of acquiring the whole brain image at a TR of 100 msec. We were then able to isolate frequency components up to 5 Hz. We ran resting-state network analysis on both 0.01~0.1 Hz and 1.5~5 Hz bands, to see if BOLD coherence also exists at higher frequencies.

Methods Resting-state fMRI data from three healthy volunteers were acquired on a 3.0 T Siemens Trio scanner (Siemens Healthcare, Erlangen, Germany). Subjects were instructed to look at a cross on a projected screen and relax during the scan session. The concentric shells acquisition scheme with TR = 100 ms was used to collect 4096 time frames (total scan time 6 min 50 sec, first 30 sec discarded). Imaging volume had an FOV of 256 × 256 × 240 mm³. All post-processing was done in MATLAB (The Mathworks, Inc., Natick, MA). Based on coil sensitivity weightings and measured gradient trajectory, a 64 × 64 × 48 image matrix was reconstructed using the forward operator evaluated with a non-uniform FFT (nuFFT) algorithm.

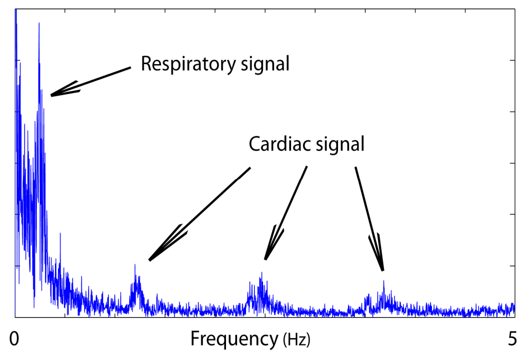

Figure 1 Frequency spectrum (0~5 Hz) of the global signal from one subject before post-processing.

Typical fMRI signal spectrum from 0 to 5 Hz looks similar to the curve in Figure 1 before post-processing. Most signal power exists at low frequencies, with respiratory noise at around 0.2~0.3 Hz, and cardiac noise at 1~1.2 Hz and its multiples. Reconstructed images were corrected for rigid-body motion and spatially smoothed in SPM8 (http://www.fil.ion.ucl.ac.uk/spm). Global signal regression was applied to reduce non-neural signal correlations [5]. Physiological noises and their harmonics were regressed out using parallel-acquired ECG and respiratory signals as reference for RETROICOR algorithm [4]. Signals were then high-pass filtered at a cut-off frequency of 1.5 Hz. We manually selected seeds for visual and sensory-motor networks and applied an iterative correlation calculation to obtain converged correlation maps [6]. Networks were defined as the area where the correlation coefficient r ≥ 0.4. Connectivity strength was defined as the average of correlation coefficients over all the voxels in that network. Same correlation analysis was also applied to signal at 0.01~0.1 Hz for comparison.

Results Results from one representative subject are shown in Figure 2. Coherent BOLD fluctuations in visual (Fig.2a) and sensory-motor networks (Fig.2b) were found at both frequency ranges. More intriguing results are with the initial seeds prescribed at left and right inferior parietal lobule, respectively. After the iterative calculation the two correlation maps at 0.01~0.1 Hz approached each other (Fig. 2c and 2d, bottom). However the correlation maps of signal frequencies >1.5Hz remained as two distinct maps (Fig. 2c an 2d, top).

Discussion We have observed coherent resting-state brain networks at frequencies greater than 1.5 Hz. Preliminary results here show that the spatial features of signal coherence in both frequency bands can be similar in some networks, but differ in others. Compared to signals below 0.1 Hz, those at higher frequencies tend to yield a flatter correlation coefficient distribution (reflected in the slightly lower average connectivity strength). Also slightly larger network areas were often found at the same cut-off thresholds (in this study at *r* = 0.4). We may also be able to find stable networks at higher frequency in a much shorter scan time (down to several seconds, which leads to insufficient frequency resolution for the 0.01~0.1 Hz band). More data and further studies are needed to better understand the characteristics of this higher frequency signal, and to explore how much additional information about resting-state neural activities it can provide.

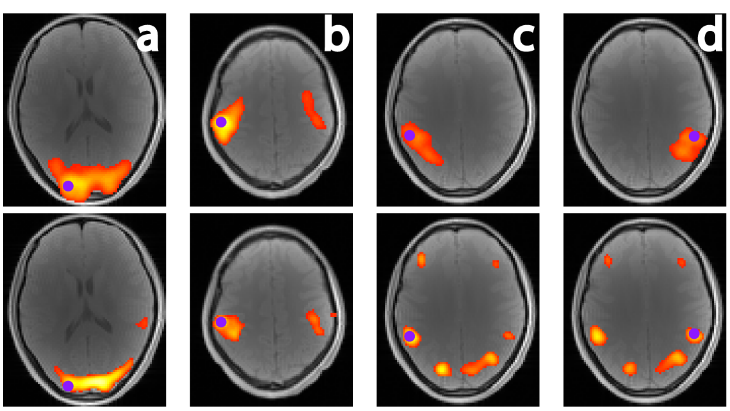

Figure 2 Correlation maps with different initial seeds indicated by purple dots: (a) visual; (b) sensory-motor; (c) left inferior parietal lobule; (d) right inferior parietal lobule. Top row: >1.5 Hz; bottom row: 0.01~0.1 Hz frequency bands. The connectivity strength of high/low frequency bands are: (a) 0.45/0.48; (b) 0.51/0.52; (c) 0.45/0.52; (d) 0.45/0.52.

References

[1] Biswal *et al.*, MRM 34: 537–541 (1995);
[2] Honey *et al.*, PNAS 104(24):10240-10245 (2007);
[3] Zahneisen *et al.*, ISMRM 2011 (submitted);
[4] Glover *et al.*, MRM 44:162-167 (2000);
[5] Hampson *et al.*, Hum. Brain Mapp. 15, 247-262 (2002);
[6] Lee *et al.*, Proc. ISMRM 2010, pp.3493.