Observing Resting-State Brain Modules at Different Frequencies Using MREG

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Purpose Common resting-state network analysis looks for coherent BOLD signal fluctuations below 0.1 Hz [1]. In previous studies it has been shown that with a higher sampling rate, we can not only achieve better physiological noise removal, but also observe certain consistent coherent networks at frequencies outside of this conventional range within a much shorter scan time [2].

MR-Encephalography (MREG, [3]) is a fast-imaging technique that uses information from multiple coils to minimize spatial encoding steps and the acquisition time. In this study we used MREG with a single-shot stack-of-spirals trajectory [4] which is able to record a whole-brain time-series at a repetition time of 100 msec. We then applied independent component analysis (ICA) and connectivity analysis to find the overall resting-state network modules at different frequencies.

Methods Resting-state fMRI data from six 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 Stack-of-spirals acquisition scheme has TR = 100 ms and for each session 4095 time frames were collected (total scan time 6 min 50 sec). The first 15 sec were discarded for signal stability consideration. Imaging volume has a 192 × 192 × 192 mm^3 FOV, and was later reconstructed into a 64 × 64 × 64 matrix (3 × 3 × 3 mm^3 resolution) using the forward operator estimated from a non-uniform FFT (nuFFT) algorithm based on coil sensitivity weightings and measured gradient trajectory [5]. 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, 0.5~0.8 Hz, and 1.5~5 Hz). ICA based on Infomax algorithm was performed in GIFT toolbox [6] with different component numbers (from 20 to 100, increment was ten). The resulted components' reliability was checked using ICASSO [7]. The unreliable (quality index I_q < 0.7) and non-neuronal related components were then removed, and the rest were taken as functional nodes and their time courses were used to build a partial correlation coefficient matrix which further generates a weighted undirected connectivity matrix. With this matrix we then constructed the brain network modules and calculate their modularity coefficient Q [8,9]. For each frequency band the component number that gives the highest modularity coefficient was chosen as the final result.

Results and Discussion The results from ICA and connectivity analysis for all three frequency bands are listed in Table 1. The pre-defined numbers of components for ICA that generated the highest modularity coefficients were 80, 40, and 80 for the three frequency bands, respectively. After reliability test and removal of non-neuronal elements, the numbers of remained components were 35, 28, and 40. The left column in Figure 1 shows the weighted connectivity matrices calculated from the time courses of these selected components. One sample slice from each module in each frequency band is also shown in Figure 1. As a result three modules appear across all the frequencies: one that involves precuneus and parietal lobule; one that involves middle temporal and frontal gyrus; and one that involves visual cortex. In addition partial auditory cortex repeatedly appears in combination with different components at three frequencies. Default mode network and motor cortex are seen at the lowest frequency, but not at the other two bands. Here in these preliminary data obtained by high temporal resolution MREG and stack-of-spirals trajectory we observed resting-state networks and temporally correlated modules at frequencies as high as 5 Hz. It would be very interesting to see how these structures change with various subject conditions and diseases, which could provide us with more understandings of the resting human brain.

Table 1 The number of pre-defined ICA components, reliable and relevant components used for connectivity analysis, resulted modules and modularity coefficients for the three frequency bands.

Frequency (Hz)	# of Components	# of Reliable & Relevant Components	# of Modules	Q
0.01 ~ 0.1	80	35	8	0.785
0.5 ~ 0.8	40	28	6	0.508
1.5 ~ 5.0	80	40	7	0.524

References [1] Biswal *et al.*, MRM 34: 537–541 (1995); [2] Lee *et al.*, NeuroImage 65:216–222 (2013); [3] Hennig *et al.*, NeuroImage, 34:212-219; [4] Assländer *et al.*, Proc. ISMRM 2012, pp.328; [5] Grotz et al., MRM 62:394–405 (2009); [6] Calhoun *et al.*, HBM 14:140-151 (2001); [7] Himberg et al., 22(3): 1214-1222 (2004); [8] Newman, Proc. Natl. Acad. Sci USA 103:8577-8582 (2006); [9] Rubinov & Sporns, NeuroImage 52: 1059-1069 (2010).

Acknowledgement
ERC project OVOC #232908

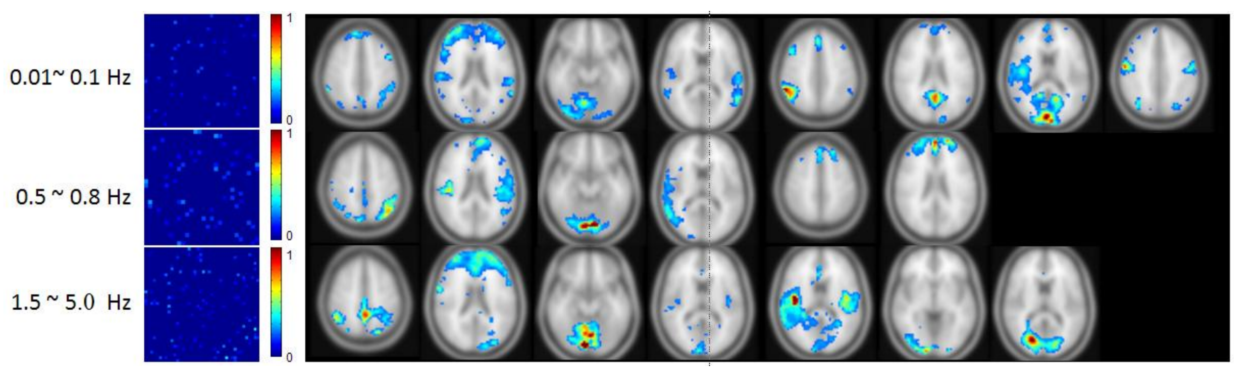

Figure 1 The weighted connectivity matrices (left column) and sample slices from each module of each frequency band.