Frequency Specificity of Functional Connectivity in Brain Networks

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Introduction

The synchronous low-frequency fluctuations during the resting state fMRI have been utilized as a tool to investigate brain functional connectivity [1-2]. A recent study [3] suggested that the spontaneous fluctuations within individual networks were associated with electroencephalography (EEG) power fluctuations in predefined frequency bands, but it remains unknown if coherent spontaneous fluctuations of the resting state fMRI signal have distinct frequency characteristics in different neuronal networks. In this study, we investigated the spectral characteristics of the spontaneous fluctuations of the resting-state fMRI signal in four brain networks (sensorimotor, visual, default mode, and limbic systems). Results show common and distinct characteristics of spectral responses in these networks.

Methods

Resting-state fMRI data were collected from 20 healthy participants on a Siemens 3T scanner. Each scan contained 180 volumes, acquired in 6 minutes using a gradient-echo EPI sequence (TR/TE = 2000/27 ms). Thirty-nine slices were prescribed along the AC-PC line with whole brain coverage (FOV=220 mm, MTX=64×64, slice thickness=4 mm). The data were pre-processed by motion correction, linear de-trending, spatial normalization and smoothing (6mm FWHM). Six datasets were generated for each subject utilizing Chebyshev type-II filters with frequency ranges of 0-0.01, 0.01-0.02, 0.02-0.04, 0.04-0.06, 0.06-0.08, 0.08-0.10 Hz. Four sets of spherical seed voxels (6 mm in diameter) were chosen from the primary sensorimotor cortex (right), posterior cingulate cortex (PCC), amygdala (right), and primary visual cortex (right) to investigate the motor, default-mode, visual, and limbic networks, respectively. A cross-correlation method, excluding the influences of white matter and head motions, was conducted for the group analysis ($p < 10^{-4}$).

Results

Fig. 1 shows the functional connectivity maps for each frequency band in the four networks. The strongest connectivity is found within 0.01-0.02 Hz in the visual and sensorimotor systems, and within 0.02-0.04 Hz for the default-mode network. However, the bilateral connection in the limbic system is always distributed in the observed frequency range (0-0.1 Hz). The “long-distance” connections only appear in the frequency bands of 0.01-0.06 Hz and fade away at higher frequencies, such as the contralateral motor cortex of the sensorimotor system and the anterior cingulate cortex (ACC) of the default-mode network, while the “short-distance” connections exist for lager frequency ranges, such as the supplementary motor area (SMA). Fig. 2 shows the average correlations in the four networks over the frequency bands. In the sensorimotor, default-mode, and visual systems, the spectral distributions peak at 0.01-0.04 Hz and decrease substantially at higher frequency bands. Instead, the trend in the limbic system decreases slightly and monotonically as a function of frequency.

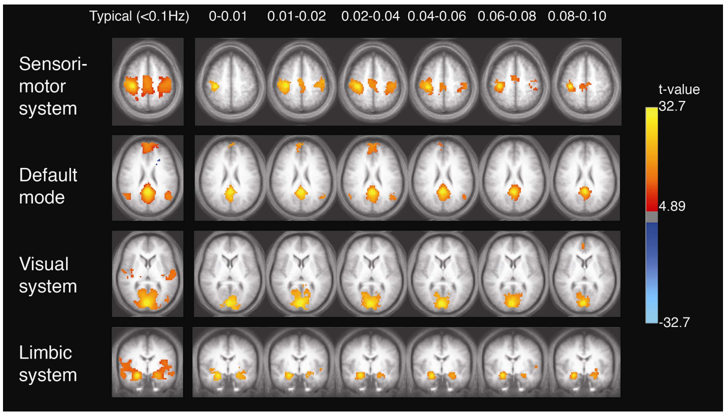

Fig. 1 The connectivity maps of the sensorimotor, default-mode, visual, and limbic networks (n=20). The strongest connections between ROIs can be observed in distinctive frequency bands for different brain networks.

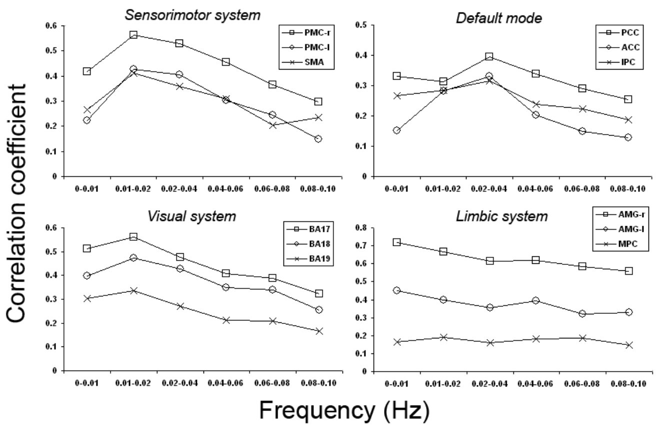

Fig. 2 The average correlations from selected ROIs of the four brain networks over the frequency range (n=20). PMC-r (-l): right (left) primary motor cortex, SMA: supplementary motor area, ACC: anterior cingulate cortex, IPC: bilateral inferior parietal cortex; BA17-BA19: Brodmann area 17-19, AMG: amygdala; MPC: medial prefrontal cortex.

Discussion and Conclusion

In this study, the frequency responses from four brain networks were assessed and compared. The results show that similarities and differences exist in the spectrogram of the spontaneous oscillation between networks, especially in the ultra-low frequency range within 0.01-0.06 Hz. The results are consistent with electrophysiological findings that brain networks may have different frequency characteristics at rest, although the correlation between electrophysiological and fMRI signals remains unknown. Our data showed that long-distance connections seem to be more frequency specific (peaking at a frequency band), whereas short-distance connections are distributed in a wider frequency range. This discrepancy might be attributed to a lager attenuation of synchrony for brain regions separated with longer distance and/or connected with more synaptic steps.

References

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