Balanced Steady-State Free Procession (bSSFP) for Detecting Resting-State Networks in Rat Brain at 7T

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INTRODUCTION: Resting-state fMRI (rsfMRI) has been increasingly used to study brain function on humans and animals [1, 2]. Currently, most rsfMRI studies adopt the gradient-echo EPI sequence which has a blood oxygenation level dependent (BOLD) contrast. However, GE-EPI is affected by signal dropout and image distortion due to nature of GE and long echo time. These problems become more severe at high field and in regions close to air-tissue interface. Balanced steady-state free procession (bSSFP) imaging is free from these problems. Recently it has been demonstrated to detect BOLD-like activation signals for fMRI [3, 4]. In this study, we investigated the feasibility of using bSSFP to detect resting-state networks.

METHODS:

Animal Preparation: Adult Sprague-Dawley (SD) rats (320-350g, N=9) were anesthetized with isofluorane and mechanically ventilated. During experiment, heart rate, respiration rate, oxygen saturation level and rectal temperature were monitored.

MRI Protocol: All MRI experiments were conducted using a 7T Bruker scanner with a quadrature surface coil. rsfMRI measurements were performed with bSSFP and GE-EPI with the same 1.5s temporal resolution and 310 time points. For bSSFP, a flip angle α=19° was estimated by $\cos\alpha = \frac{\frac{T_1}{T_2}-1}{\frac{T_1}{T_2}+1}$ [5] to maximize the signal intensity of cortex regions using the apparent T1 and T2 values measured in a previous study [6]. Other parameters were: RF phase cycling β=180°, TE/TR=1.253/2.506ms, FOV=32×32mm^2, matrix=64×64, no. of average=9, single slice with 1.5mm thickness. The slice was posited at Bregma -3.0/-7.0, covering somatosensory/visual cortex. To test reproducibility, 5 animals were imaged for somatosensory cortex and 3 for visual cortex. For another 2 animals, the slice was posited at Bregma 3.3, covering the olfactory cortex, with a reduced FOV of 26×26mm^2.

Data Analysis: The first 10 time points of each bSSFP scan were discarded due to non-equilibrium effect. Then each scan was registered, detrended, filtered (0.005-0.1Hz) and interpolated to 256×256 (unless when compared to GE-EPI). For each animal, 3 bSSFP scans were concatenated, masked for brain regions and then decomposed to different networks using GIFT v1.3i (Group ICA Toolbox). GE-EPI images were analyzed in the same way.

RESULTS: Fig. 1 shows the somatosensory and visual networks detected by bSSFP in all animals, demonstrating that bilateral networks could be detected robustly. Fig. 2 compares networks detected by GE-EPI and bSSFP in the same animal. Results of the two methods were similar to each other. Fig. 3 shows images of the olfactory cortex acquired with T2 weighted RARE, bSSFP and GE-EPI sequences. bSSFP image showed good agreement with the T2 weighted image while GE-EPI image quality was poor, particularly affected by signal dropout. Fig. 4 shows two intra-hemisphere resting-state networks in olfactory cortex detected by bSSFP, overlaid with rat brain atlas. GE-EPI was unable to detect these networks due to severe signal dropout.

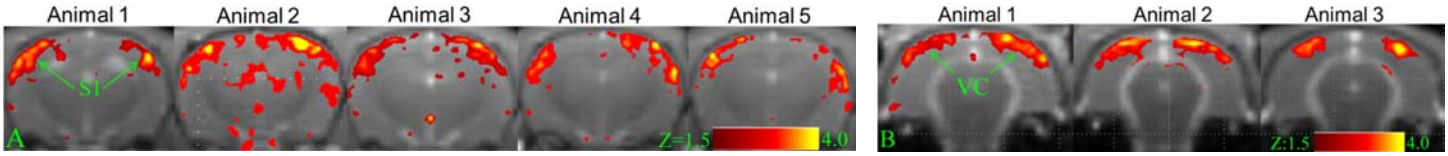

Fig. 1: Resting-state networks detected by bSSFP in somatosensory cortex (A) and visual cortex (B) for 5 and 3 animals, respectively. S1: primary somatosensory cortex (Bregma -3.0) and VC: visual cortex (Bregma -7.0).

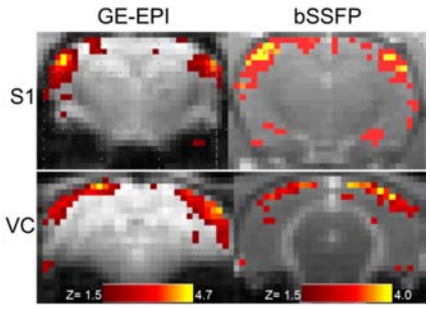

Fig. 2: Comparison of resting-state networks detected by GE-EPI and bSSFP. Results of both methods are similar to each other.

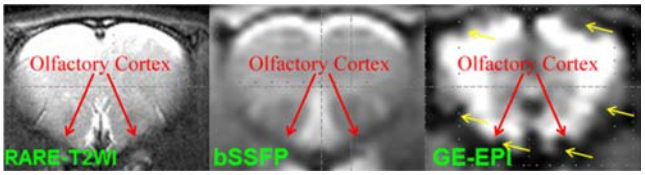

Fig. 3: Images of the olfactory cortex (Bregma 3.3) by T2W-RARE, bSSFP and GE-EPI sequences. Yellow arrows indicate signal dropout in GE-EPI image.

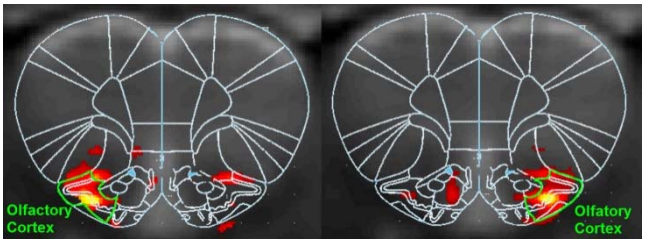

Fig. 4: Resting-state networks detected by bSSFP in olfactory cortex.

DISCUSSION: Our results showed that bSSFP could detect resting-state connectivity. Networks similar to those detected by conventional GE-EPI could be robustly revealed by bSSFP. This similarity is in line with the similarity between their BOLD contrast mechanisms, though bSSFP signal is believed to be more specific to parenchymal regions near small vessels [3, 4]. Our results also suggested that bSSFP can benefit resting-state fMRI since it is free from signal dropout and image distortion. Note that 2D bSSFP can be expanded to 3D, with high resolution. This bSSFP rsfMRI approach can be suited for studying brain regions that are strongly affected by magnetic susceptibility, such as olfactory bulb and cortex, particularly at high field and in investigation of small animal brains.

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