Employing Wideband Gradient-Echo MRI to Map the Functional Activation in Rat Somatosensory Cortex with Enhanced Spatial Resolution

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Target Audience

Investigator who has interests on higher spatial/temporal resolution of functional MRI and the applications using Wideband MRI technique.

Introduction

Functional MRI (fMRI) has been widely used to discover the brain functions by examining the T2* weighted blood-oxygen-level-dependent (BOLD) signals [1]. Although BOLD fMRI maps the neural activation indirectly, its development still revolutionarily impacts the field of neuroscience research. Recent studies have increasingly suggested that higher spatial or temporal resolution can potentially provide more insights into the relationship between the neural activation and physiological processes. For this purpose, a generalized approach to facilitate the fMRI data acquisition is urgently needed. A recent technique, referred to as Wideband MRI, has been developed to accelerate the data acquisition by simultaneously decoding multi-location information, i.e. wider bandwidth [2]. Thus, in this study, we aimed to integrate the Wideband MRI technique with the conventional gradient echo T2*-weighted imaging sequence (GRE) and demonstrate its capability on rodent fMRI experiments with electrical stimulation. With an acceleration factor of 2, the benefit of the reduced scan time was investigated by trading with spatial resolution or slice thickness. Finally, the BOLD signal change and localization of activation among echo-planar imaging (EPI), GRE and Wideband GRE (WB-GRE) were discussed.

Materials and Methods

In this study, our previously reported Wideband MRI technique, referred to as single-carrier Wideband MRI, was integrated with GRE sequence to conduct fMRI [2]. Single-carrier Wideband MRI acquired multi-location information by following two steps. Firstly, reduce the number of phase encoding. Secondly, apply additional separation gradient along readout direction to separate the overlapped images. All MR experiments were conducted on a 7T animal MRI system (Bruker Biospec, Ettlingen, Germany). Three Sprague Dawley rats (male, 250~350g) were scanned under institutional approval. During fMRI, rats were anesthetized with α-chloralose (3.33cc/kg/hr) and the electrical stimulation (frequency of 3Hz and amplitude of 3mA) was applied to the left forepaw. To keep rats physiologically stable, the respiration rate was controlled in 45~50 bpm. Three kinds of experiments were conducted in this pilot study. First, to demonstrate the capability of reducing the scan time, both GRE and WB-GRE were acquired with the following parameters: FOV of 2.5 × 2.5 cm^2, voxel size of 130 × 130 × 1000 μm^3, TR of 100 ms, TE of 4/14/24 ms, and the total scan time of 3m12s and 1m36s for GRE and WB-GRE. Second, to demonstrate the capability of improving the in-plane and through-plane resolution, both GRE and WB-GRE were acquired with the following parameters: FOV of 3.5 × 3.5 cm^2, TR/TE of 600/20 ms, the total scan time of 2m33s, and the voxel size of 136 × 136 × 1000 μm^3 and 68 × 68 × 1000 (136 × 136 × 500) μm^3 for GRE and WB-GRE. Third, to demonstrate the capability of mapping fMRI with WB-GRE, sequences of EPI, GRE and WB-GRE were used with the following parameters: FOV of 2.5 × 2.5 cm^2, TR/TE of 2000/20 ms, repetitions of 120, and the voxel size of 313 × 313 × 1000 μm^3 for EPI and GRE, and 208 × 208 × 1000 μm^3 for WB-GRE. The task-related fMRI data was analyzed using independent component analysis (Group ICA of fMRI Toolbox, GIFT).

Results

Figure 1 shows the T2*-weighted images acquired by GRE and WB-GRE sequences with different echo times. With *half of the scan time*, the images acquired by WB-GRE sequence (fig. 1b, 1d and 1f) show similar contrasts and features as those acquired by conventional GRE sequence (fig. 1a, 1c and 1e). Figure 2 shows the results of acquiring *higher in-plane and through-plane resolution* with WB-GRE sequence. With higher resolution, either in-plane (fig. 2a) or through-plane (fig. 2b), WB-GRE images show more details in cortical structures under the same scan time. The fMRI results with EPI, GRE and WB-GRE are shown in figure 3, including the activation map (fig. 3a, 3b and 3c) and time course in activated area (fig. 3d, 3e and 3f). Here, the results with EPI sequence are used as the standard references for comparing GRE and WB-GRE. By visually inspection, the activated areas corresponding to the left forepaw obtained by GRE and WB-GRE are spatially similar but slightly deviated from that obtained by EPI sequence. All of the time courses show significant BOLD signal changes, which are 3.0% for EPI, 2.7% for GRE and 3.0% for WB-GRE. Although the BOLD signal change of using WB-GRE sequence is comparable with using standard EPI sequence, the time course shows a slightly higher perturbation due to the noise contamination, implying that WB-GRE with higher spatial resolution showed lower temporal signal-to-noise (tSNR) here.

Discussion

This was the first study to implement Wideband technique on rat fMRI with electrical stimulation. First, in comparison of fundamental scanning parameters, our results show that WB-GRE sequence could *significantly reduce the scan time or trade the scan time with higher in-plane or through-plane resolution*. The benefit may bring faster scan, less motion artifacts, less physiological noise, more anatomical features or relevant functional information into future fMRI studies. Second, although only WB-GRE sequence with an acceleration factor of 2 was implemented in present study, the preliminary results have already shown the capability of employing WB MRI technique on fMRI with higher spatial resolution. Further implementation with a higher acceleration factor will be potentially helpful to gain higher spatial or temporal resolution for conducting advanced analysis of fMRI data. Third, although WB-GRE sequence could detect the similar BOLD signal change as EPI sequence, the spatial sensitivity and tSNR need to be improved.

Conclusions

In present study, our preliminary results demonstrate that WB-GRE could be implemented on rat fMRI experiments with higher spatial or temporal resolution. Future works may include implementation of WB-GRE with higher acceleration factor, improving the spatial sensitivity and tSNR and optimization of EPI sequence parameters for acquiring high-resolution fMRI data. With further integrating wideband technique with parallel Imaging technique, high spatial/temporal resolution WB fMRI could be an important tool for *Brain Informatics Initiative* in the future.

References

[1] Ogawa et al., PNAS 1992. [2] Huang et al., Proc. 21th ISMRM, Salt Lake City, USA, 2013.

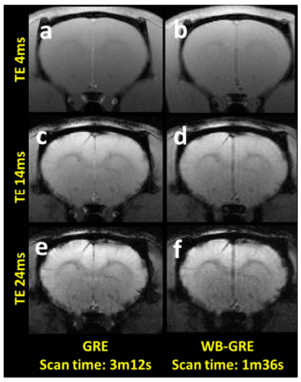

Figure 1. The multi-echo T2 weighted images acquired by GRE (a, c and e) and WB-GRE (b, d and f) sequences.*

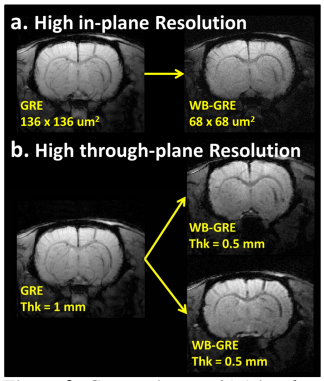

Figure 2. Comparisons of (a) in-plane spatial resolution and (b) through plane resolution (i.e. thickness) between using GRE and WB-GRE sequences.

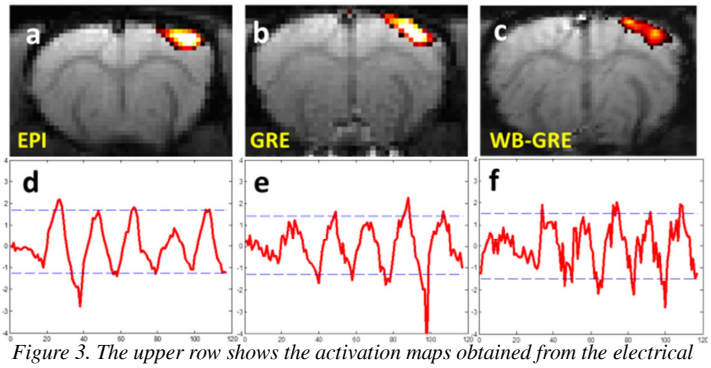

Figure 3. The upper row shows the activation maps obtained from the electrical stimulation fMRI experiments using (a) EPI, (b) GRE and (c) WB-GRE sequences. The analysis was done by ICA approach and the components corresponding to the forepaw stimulation were selected here. The bottom row shows the plots of BOLD time courses in activated areas as shown in their corresponding activation maps for (d) EPI, (e) GRE and (f) WB-GRE.