Integration of Generalized Series and Parallel Imaging (GS-Parallel) for High-Resolution fMRI

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Introduction

Blood oxygenation level dependent (BOLD) fMRI [1] is a technique that measures the hemodynamic response related to neural activity in the brain, which requires a high spatiotemporal resolution. In order to satisfy this requirement, the echo-planar imaging (EPI) has been widely used for this technique. The EPI provides a temporal resolution of 1–2 s and a spatial resolution of 3–5 mm for a whole-brain imaging. While the resolution is sufficient for most fMRI studies, it is inadequate for studying brain function at the millimeter or submillimeter level. With the EPI technique, it is very difficult to increase the spatiotemporal resolution of the fMRI data due to the T_2^* decay. In addition, this value becomes shorter at a higher field. In this study, we propose a high spatiotemporal resolution MRI technique that combines the parallel MRI [2] and the generalized series (GS) [3] techniques with the conventional gradient-echo (GE) sequence for fMRI at high magnetic fields.

Methods

The imaging time of the conventional gradient-echo sequence is generally too slow to perform fMRI studies. To overcome this problem, we proposed a new sampling strategy which has the benefits of both parallel MRI and GS technique. The GS technique has the similar sampling scheme to the key-hole imaging, but the approach to the data reconstruction is more sophisticated than the key-hole imaging and consequently it produces more improved results in the reconstructed images. As shown in Fig. 1d, the proposed method acquires data from near the central k-space by taking advantage of the property of GS technique and takes samples in a lower rate than the Nyquist sampling rate using the parallel MRI property. Let R_{GS} and R_P be the scan-time saving rates achieved by the GS and parallel MRI technique, respectively. Then, the proposed method can achieve R_{GS}•R_P-fold savings of the scan time compared to the conventional Fourier imaging. For comparison, we also showed the sampling schemes of the other imaging techniques in Fig. 1. The reconstruction procedure of the acquired data from the proposed method is described as follows.

1. To reconstruct the images, additional reference data were acquired for both GS and parallel MRI techniques. These reference images were reconstructed using the conventional Fourier transform.
2. The proposed method acquired the data in the sampling format of Fig. 1(d). The GS reconstruction algorithm was applied to this data and then the result data had the sampling format of Fig. 1(c).
3. The parallel MRI reconstruction algorithm was sequentially applied to the result of the above GS reconstruction to obtain the final reconstructed images. In this work, SPACE RIP was used as the parallel MRI technique.

During the GS and parallel MRI reconstruction in our method, Tikhonov regularization, which added a regularization term to the reconstruction equation, was used to make stable and robust reconstruction

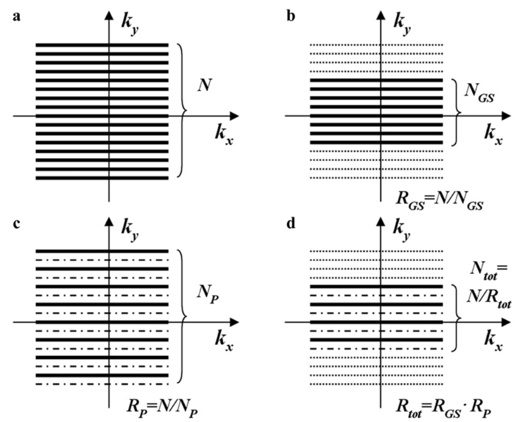

Fig. 1 Sampling schemes for: **(a)** Conventional imaging, **(b)** GS imaging, **(c)** Parallel imaging, **(d)** The proposed method. Dot and the dot/dash line: skipped encoding lines by the GS and parallel imaging techniques, respectively.

Results

We performed block-design motor fMRI using a 3T scanner with a four-channel phased-array coil for three healthy subjects. They were asked to perform a finger tapping using the right and left hands alternatively during the stimulation block. To prove that the proposed method can be used as an alternative fMRI method, we acquired three different fMRI data sets for the same subject with the resolution of 64×64. Each data set was obtained using the sampling scheme of the parallel MRI with 2.67-fold, the GS technique with 2-fold, and the proposed method with 4-fold acceleration, respectively. Fig. 2a shows one slice of the functional map (P <0.005) from each data set for the left hand movement, and Figs. 2c, d, and e show the corresponding time course data. The experimental results for the right hand movement are shown in Figs. 2b, f, g, and h. As shown in the figures, the right and left motor cortices were found to be activated for the left and right hand tapping, respectively. Activation in these areas was consistently detected in all three data sets whose corresponding time course data were also found to have almost identical t-statistics values and showed similar behavior. Using the proposed method, we also performed high-resolution fMRI study with the resolution of 128×128 and 256×256. Figs. 3a and b show three slice images of the functional maps from the 128×128 data for the left and right hand movement, respectively. The 256×256 images are shown in Figs. 3c and d. The contralateral motor cortex was also found to be activated in both the 128×128 and 256×256 data and it was also observed that the activation area were positioned in a more localized region and had a more reduced area than that of the low-resolution experiments.

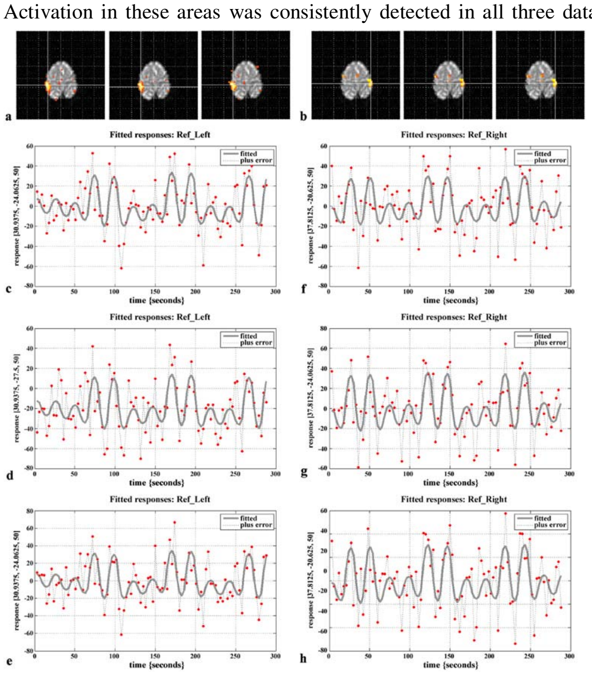

Fig. 2 **(a, b)** Functional maps for the left and right hand movement for three data sets, **(c, d, e)** Time course data for the functional maps of **a**, **(f, g, h)** Time course data for the functional maps of **b**.

Conclusion

By using the proposed method, we could perform the high-resolution fMRI study with the conventional gradient-echo sequence at a high magnetic field.

References

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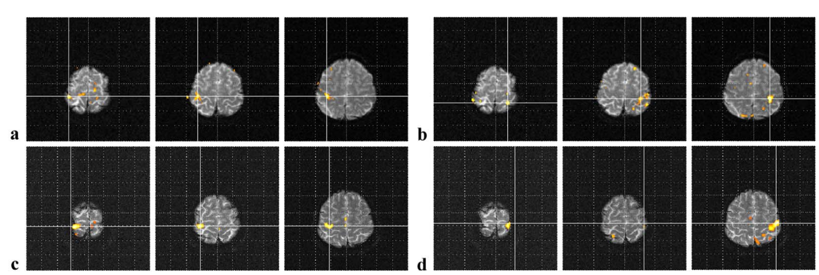

Fig. 3 **(a, b)** Functional maps for the left and right hand movement for 128×128 data set, **(c, d)** Functional maps for the left and right hand movement for 256×256 data set.