Improving the spatial resolution of whole-head magnetic resonance inverse imaging using partition-encoding gradient blips

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INTRODUCTION

Using simultaneous acquisition from multiple channels of a radio-frequency (RF) coil array, magnetic resonance inverse imaging (InI) achieves functional MRI acquisitions at a rate of 100 ms per whole-brain volume [1]. InI accelerates the scan by leaving out partition encoding steps and reconstructs images by solving under-determined inverse problems using RF coil sensitivity information. Hence, the correlated spatial information available in the coil array causes spatial blurring in the InI reconstruction. Here, we propose a method that employs gradient blips in the partition encoding direction during the acquisition to provide extra spatial encoding in order to better differentiate signals from different partitions.

METHODS

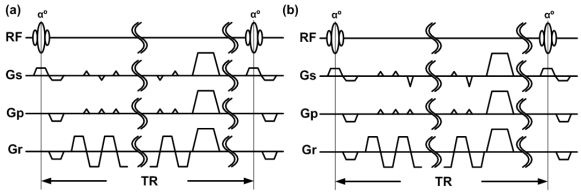

Fig. 1

Figure 1(a) shows the pulse sequence diagram of the bInI, where α denotes the flip angle. This pulse sequence diagram is similar to the conventional single-slice 2D EPI acquisition, except additional partition-encoding gradient (Gz) blips and slab-selective RF pulse. These additional Gz blips are of the same patterns to the ones used in the blipped-CAIPI acquisition sequence for the Simultanous MultiSlice (SMS) acquisition [2]. These Gz blips are in synchrony with the phase-encoding gradient (Gy) blips in order to provide extra spatial encoding along the z axis. Two variants of Gz blips are shown in Figure 1a and 1b, which achieve in-plane shift of FOV/2 (Figure 1a) and FOV/3 (Figure 1b). For the case FOV/2, different phase offsets are introduced by the G_z blips in the even *k*-space lines for difference partitions. Using such G_z blips, strong *N*/2 ghost are observed in the partitions toward the edge of the excitation volume, while central slices show relatively weak *N*/2 ghost. In accelerated bInI acquisition, all the partition encoding steps are removed and consequently all the partitions are integrated. Spatial reconstruction is to solve an ill-posed inverse problem. One common choice is the minimum-norm estimate (MNE) [1, 3]. Repeating this inversion procedure over each time point of the different frequency encoding indices yields the volumetric reconstruction of dynamic images.

RESULTS

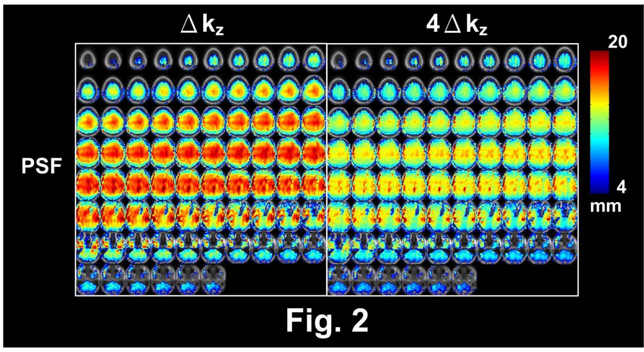

Fig. 2

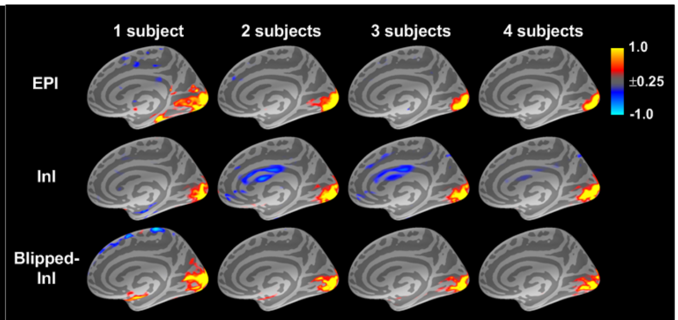

Fig. 3

Figure 2 shows the effects of using different gradient moments in the FOV/2 bInI acquisition. The magnitudes of blip gradient moments change between Δk_z and $4\Delta k_z$. In general, the improvement by bInI is larger over the subcortical regions than over the cortical regions. Compared to InI, bInI with gradient moments of Δk_z and $4\Delta k_z$ improve the spatial resolution in the subcortical regions by 10.5% (1.6 mm) and 32.7% (4.2 mm) respectively.

Figure 3 shows the progressive average of normalized BOLD signal of the conventional EPI, InI and bInI on an inflated cortical surface across four participants. Although InI demonstrates similar BOLD activation with EPI in the visual cortex, the negative BOLD signal shown in the cingulated cortex and the corpus callosum is inconsistent with that of EPI. Blipped InI has no such negative BOLD signal. This result seems to lend support to our simulation data, which suggest that bInI can provide substantial reconstruction improvement in the central part of the brain.

DISCUSSION

Our simulation and experimental results suggest that bInI can be used to reduce spatial blurring and localization error of the InI method. Blipped InI is similar to the SMS blipped CAIPI because both methods utilize the same gradient encodings in acquisition. The difference between these two methods is that blipped InI replaces a multiband excitation with a slab selective excitation to achieve 3D single-shot imaging. Currently, whole-brain imaging using the SMS blipped CAIPI acquisition requires 4 or 5 shots (with a similar matrix dimension as used in this study). Multi-shot imaging has concerns about the consistency across RF excitations. Blipped InI, on the other hand, has no such concerns. Given its demonstrated benefits, bInI could be a useful tool for investigating human brain function in cortical and subcortical areas at high spatiotemporal resolution.

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