EPI 2D ghost correction and integration with multiband : application to diffusion imaging at 7T.

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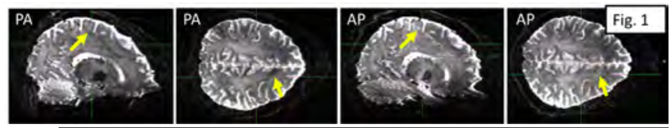
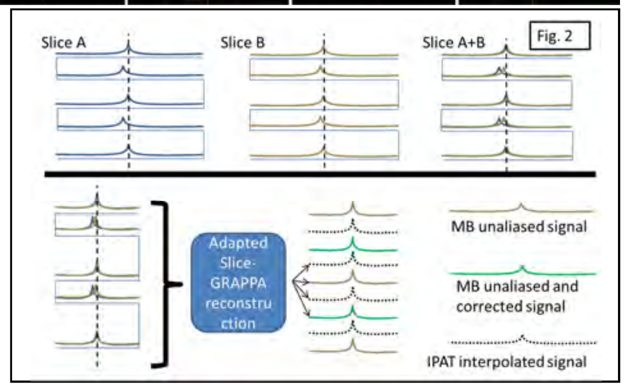
TARGET AUDIENCE: Those interested in mitigation of image artifacts in EPI based diffusion MRI.

INTRODUCTION: The simultaneous acquisition of multiple slices, along with phase encode based accelerations, permit the acquisition of high spatial and temporal resolution echo planar images[1,2]. The acquired data is spatially undersampled and the use of parallel imaging is used to separate the aliased signal. Generating sensitivity profiles can be challenging in the presence of image distortions, such as those commonly seen in EPI. The use of the slice-GRAPPA technique is beneficial due to not requiring the explicit formation of sensitivity profiles and the straight forward application to FOV shifting with blipped-CAIPI. The use of slice-GRAPPA has been improved both with the addition of slice-blocking (Split slice-GRAPPA[3]) to reduce residual aliased signal, and also the use of a dual-kernel[2]. The dual kernel formulation combines an approach where different patterns of readout lines (e.g. odd-even-odd and even-odd-even) are unaliased with different kernels, such that the echoes shifts from different slices (which can be different) are more effectively unaliased with slice-GRAPPA. In addition to the common temporal shifts of echoes, which can be well corrected with a 3-line navigator[4], and handled with the dual-kernel and slice-GRAPPA algorithms, additional trajectory errors can be present – especially in the presence of concomitant fields or when using oblique slice-orientations. These errors result in "bunched" types of trajectories, requiring additional strategies to mitigate image ghosting. The use of bunched encoding has been demonstrated[5], and GRAPPA based algorithms for resampling have been used for conventional gradient echo imaging, where the trajectories are purposely on a non-Cartesian or non-regular grid[6,7]. Trajectory errors have not previously been applied to EPI, or multiband EPI. Integrating such additional corrections into EPI reconstructions are considered.

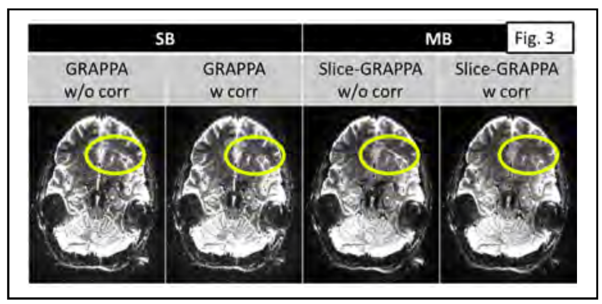


PROBLEM: The use of high resolution single-shot SE-EPI for diffusion imaging, with a single oblique orientation (using MB2, R=3 and 1.05 mm resolution, FOV=210x210x138.6mm[3]), results in an image ghost at low b-values, originating from aliased CSF signal. The ghost is present in both single-band reference images and in unaliased images from an MB acquisition. The current 7T HCP protocol[8] utilizes a b=0 s/mm^2 image with a slightly larger spoiler gradient (b=60 s/mm^2), which reduces the artifact to some extent. Additionally, in the case of correcting for susceptibility-induced distortions using phase-reversed data[9], combining the opposite phase-encoding directions mitigates the problem. However, the ghosting artifact is still present and most clearly visible as aliasing of signals from the frontal area (see fig 1). The source of the ghosting artifact appears to be due to k-space trajectory errors (see fig 2) which are not corrected with the standard 3-line navigator.



PURPOSE: To propose a k-space based trajectory correction that is compatible with Slice-GRAPPA, and is consistent with current protocols. The 2D echo alignment ghost would be mitigated by this trajectory correction.

METHODS: To estimate the difference in 2D echo-alignment between the even and odd echo lines (after navigator correction with a 3-line acquisition), the ACS data is used to reconstruct the even and odd-lines separately. In the spatial domain, a 1st order 2D-polynomium is used to estimate the difference between the images from the even and odd echoes. Using the estimated phase, a modified GRAPPA algorithm is employed using the estimated phase-error. A multi-kernel slice-GRAPPA kernel is calculated from the combination of the acquired single-band data and the corrected single-band data, schematically illustrated in figure 2.



DISCUSSION: The concept of dual kernel and trajectory shifts, in both the phase-encoding and readout directions, can also be extended to conventional single-band EPI imaging. For Multiband EPI combined with in-plane undersampling, slice-GRAPPA can be applied in a similar manner as the trajectory correction for single-band imaging, as illustrated in figure 3 for both single and multiband EPI with a 3X in-plane undersampling.

RESULTS: Consistent trajectory errors in EPI imaging can be mitigated with a GRAPPA interpolation kernel. The GRAPPA kernel for re-sampling the data to a regular grid can be obtained from a reference scan on a Cartesian grid (e.g a FLASH scan), combined with an estimate for the trajectory shift, which can be either data-driven or obtained independently. The use of data-resampling likely has confounding factors, and the correction of the native images must be balanced against any additional noise amplification due to signal resampling.

Fig1: b=0 s/mm^2 diffusion images reconstructed with two different phase-encoding directions. The sagittal reformat illustrates the persistent ghost, and the axial slices shows how it can be masked with anatomy. **Fig 2 (top):** Schematic of the effect from different echo-shift from different slices. **Fig 2(bottom):** Illustration of how the adapted slice-GRAPPA must be used to reconstruct additional signal in the presence of trajectory errors, as opposed to a standard slice-GRAPPA kernel **Fig 3:** Reconstruction of single-slice EPI with GRAPPA, without and with trajectory errors. With integration into the slice-GRAPPA algorithm similar reduction in ghost can be obtained.

REFERENCES: 1. Moeller MRM 63(5); 2. Setsompop MRM 67(5); 3. Cauley MRM 72(1); 4. Bruder MRM 23(2); 5. Breuer MRM 60(2); 6. Griswold MRM 54(6); 7. Seiberlich MRM 61(3); 8. Ugurbil Neuroimage 80; 9. Andersson, NeuroImage 20

FUNDING: This work was supported by NIH grants including P41 EB015894, S10 RR026783, and in part by the Human Connectome Project (1U54MH091657)