Unaliasing of multiband multislice EPI and GRE imaging with GRAPPA

S. Moeller[1], E. Yacoub[1], E. Auerbach[1], C. Ohlman[1], and K. Ugurbil[1]

[1]Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, Minnesota, United States

Background/Theory: To achieve faster whole brain coverage, multislice multiband was previously proposed in [1] for GRE acquisitions. The reconstruction of slice aliased signal was formulated as a SENSE type problem in [2] and proposed solved with a modified GRAPPA algorithm introduced in [1]. These techniques were applied in [3] for GE-EPI, to achieve high spatial and temporal resolution fMRI data together with whole brain coverage. For standard unaliasing, the sensitivities that are captured with the GRAPPA kernel are smooth and therefore well described by local kernels typically employed (e.g. 5x4 or 3x4 are used). For multiband unaliasing with GRAPPA, the sensitivities are concatenations of different sensitivities and the assumptions of within slice aliasing may not hold. For EPI, the additional phase errors due to reversal of the gradient direction is evaluated in combination with multiband multislice acquisitions In typical GE-EPI fMRI applications the ROI can be shimmed well, this is, however, challenging for whole brain applications – in particular at ultra high fields

Methods Imaging experiments were performed on a 7 Tesla magnet (Magnex Scientific, UK) equipped with a Siemens (Erlangen, Germany) TIM console, Siemens AC-84 head gradient hardware, and an 8 kW RF amplifier. A 16-channel transmit/receive head coil [8] was used, with the RF power split evenly among the channels (Werlatone, Brewster, NY, USA). Multi-band excitation pulses were created by combining standard 5-lobe sinc pulses, with frequency offsets (phase ramps) applied to each constituent pulse to realize a spacing of 45 mm between bands. Images were acquired using GE-EPI (T_E/T_R = 25/1500 ms, 60º FA, 1.5 mm isotropic resolution, 30 excitations (4-bands) for 120 total slices) and using GE-EPI (T_E/T_R = 25/6000 ms, 60º FA, 1.5 mm isotropic resolution (FOV: 19.2 x19.2 cm^2, 128 x 128), 120 slices). The readout direction was placed in the head-foot direction to facilitate full use of the 16 circumferentially placed elements for acceleration. The phase correction was either applied optimally for each acquisition, or used identically for all data and then corrected after unaliasing; this ordering is indicated in equation (2) and (3) respectively.

(1) $MB = [SB_1 \; SB_2][\delta_1 \; \delta_2]^T$

(2) $MB\Theta = [SB_1\Theta_1 \quad SB_2\Theta_2][\delta_1 \; \delta_2]^T$

(3) $MB\Theta = [SB_1\Theta \quad SB_2\Theta][\delta_1' \; \delta_2']^T \quad \delta_i = \delta_i'\Theta_i\overline{\Theta}$

Eq (1) is the multiband (dual band) formulation for GRE data, where δ_i denotes the desired single band signal, MB and SB the multiband data and single band sensitivity profile respectively. Eq (2) and (3) are for EPI data, where $MB\Theta$ denotes the phase correction (navigator) applied to the data. The SB data are used for estimation of the GRAPPA kernels

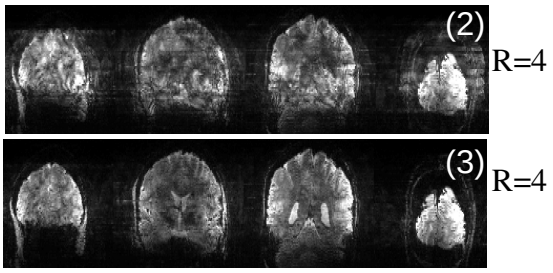

Fig1: Top row: multiband segmented EPI unaliasing using eq. (2) with phase correction correct for multi and single band acq. Bottom row: with phasecorrection from the multiband acquisition applied, and corrected after slice unaliasing.

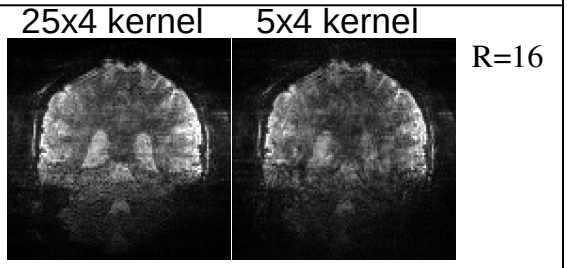

Fig2: From whole brain acquisition representative quad band with 4 fold undersampling in PE reconstructed data using two different GRAPPA kernels. Unaliasing in the PE is followed by slice unaliasing. Both performed with GRAPPA. The improved quality is noticeable in the ventricles.

Results. *Navigators:* Multiband unaliasing for whole brain reconstructed GE-EPI are shown in figure 1 with two different orderings of navigator correction. Each slice was acquired with a four segmented acquisition, in order to directly evaluate high resolution slice unaliasing for GE-EPI. Only 4 out of 120 slices are shown. The top row shows residual aliasing when the navigators from the single band acquisitions are applied. The bottom row shows the reconstruction when the navigator from the multiband acquisition is applied to the single band needed for ACS calibration. For the images in the bottom row of figure 1 an additional correction is applied after unaliasing to match the slice dependent distortions.

GRAPPA kernel: With an additional acceleration factor of 4 in the PE direction a maximal aliasing of 16 is achieved. In figure 2, two different reconstructions of the same data are shown with a maximal aliasing factor of 16. The kernel for both PE and slice unaliasing is 25x4 and 5x4 respectively. Increasing the size of the GRAPPA kernel clearly produces improved image quality.

Conclusion For whole brain fMRI to be feasible, algorithms that maintain the full use of the excellent data quality achievable at 7T are essential. Two critical components for fMRI acquisitions, phase correction and GRAPPA kernel have here been targeted. Conventionally, navigator corrections are applied immediately, but for multiband applications further considerations must be used to maintain consistency between the phase of the acquisition and the phase of the sensitivities during the multiband acquisition. Additionally, the need for larger GRAPPA kernels is observed because the concatenation of smooth kernels for slice unaliasing, as in [1], is a net sensitivity profile that is not as smooth. Similarly, the collapse of multiple slices results in net sensitivity profiles that are not as smooth as for single slice applications, requiring the use of a bigger kernel for PE reconstruction of multiband data. The benefits of increasing the GRAPPA kernel for multiband applications have also been validated with GRE imaging (not shown). Kernel sizes, such as 25x4, are computationally more intense and rank reduction techniques can be applied to decrease the computationally burden. With the approaches outlined here, significant image improvements were attained in rapid whole brain coverage using 16 fold acceleration, with 4 fold originating from simultaneous acquisition of multiple slices, and 4 fold from conventional reduction of k-space coverage in the PE direction. These improvements enhance the ability to perform rapid, whole brain fMRI at ultrahigh fields like 7T, as previously demonstrated [3]

Reference: [1] Blaimer, JMRI(24) 2006, [2] Larkman, JMRI 2001, [3] Moeller, ISMRM 2008

Acknowledgement P41 RR008079, P30 NS057091, R01MH70800, R01EB000331, The Keck Foundation, The MIND institute.