Zoomed GRAPPA (ZOOPPA) for functional MRI

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Introduction: High resolution EPI at high field is severely affected by T2* relaxation and susceptibility artifacts. To address both effects and to keep the echo-time (TE) short, the EPI readout duration must be reduced, which can be achieved using parallel imaging [1]. For sub-millimeter fMRI in humans large acceleration factors (AF) are essential, which are feasible at high field strength [2]. However, inherent SNR losses due to the accelerated acquisition, and also additional noise enhancement due to imperfections in the reconstruction process, continue to limit the maximal achievable AF. Even with dedicated phased array coils with many elements, it is still hard to obtain high quality images with AFs greater than four along a single phase encoding direction (PE). Recently, a combination of reduced FOV imaging (zoomed approach) with parallel imaging was described, which improves the image quality of accelerated single-shot EPI acquisitions [3]: 'Zoomed imaging with GRAPPA' (ZOOPPA). In the current study this approach is optimized to achieve high AFs (up to 5.5), enabling sub-millimeter isotropic resolution fMRI at ultra-high field strength.

Methods: All experiments were performed on a 7T whole-body MR scanner (MAGNETOM 7T, Siemens Healthcare Sector, Erlangen, Germany) with a 24-element phased array head coil (Nova Medical, Wilmington, MA, USA). In vivo scans were performed on four healthy volunteers and informed consent was obtained before each study. A simple visual paradigm (block design) was used for fMRI activation of early visual areas. A zoomed EPI sequence with outer-volume suppression using a SKEWED pulse as described in [4,5] was used. The GRAPPA reconstruction was performed with a 2D convolution kernel [6] with three source points along the readout direction and two source points along the PE direction. The imaging parameters for in vivo scans were: TR = 3500 ms, TE = 27 ms, FOV = 109 x 156 mm^2, image matrix = 169 x 240, 30 slices, voxel size = 0.65 x 0.65 x 0.65 mm^3.

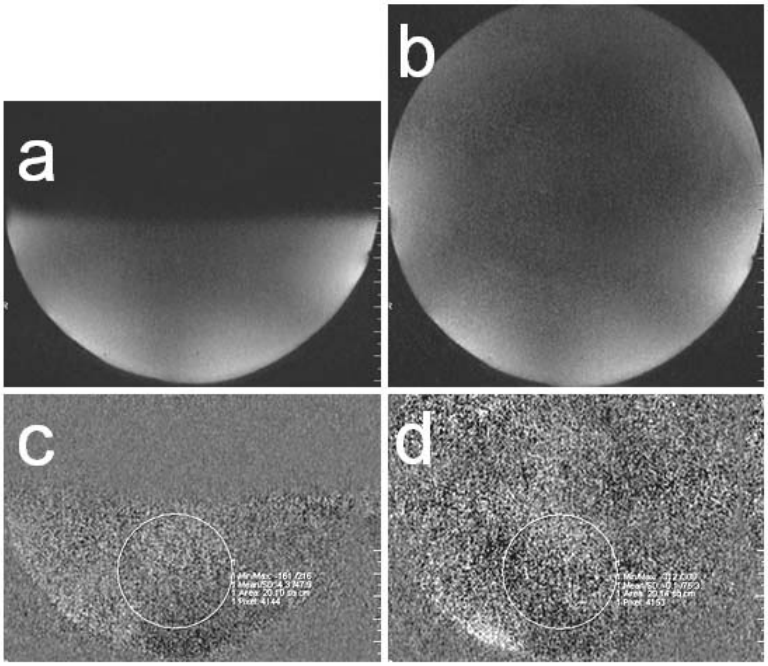

Fig 1: Comparison between (a) ZOOPPA and (b) GRAPPA: EPI with 0.7 mm isotropic resolution and a total AF of four. (c,d) Corresponding noise maps.

Results and Discussion: For the volunteers (phantom) examined in this study a FOV of 200 mm (156 mm), was needed to avoid aliasing along the PE direction. With zoomed EPI, the FOV along PE was reduced to 109 mm (117 mm), which corresponds to an acceleration factor of 1.83 (1.33). The combination of reduced FOV imaging and GRAPPA with an AF of three, results in a total acceleration factor of four in the phantom, and 5.5 in vivo. Figure 1 shows a comparison between ZOOPPA EPI (Fig. 1a) and conventional GRAPPA EPI (Fig. 1b), both with an AF of four. Corresponding noise maps are shown at the bottom. The standard deviation of the noise in the ROIs was 48 for the zoomed GRAPPA approach and 75 for the GRAPPA acquisition. Thus the ZOOPPA reconstruction, which has a net AF of four, has a significantly higher SNR than using GRAPPA alone with an AF of four. For fMRI studies, this enables acquisition of high quality single-shot EPI images with sub-millimeter isotropic resolution (see Fig. 2). The EPI image with 0.65 mm isotropic resolution (Fig. 2a) closely corresponds to the anatomical FLASH image with 0.6 mm isotropic resolution (Fig. 2b).

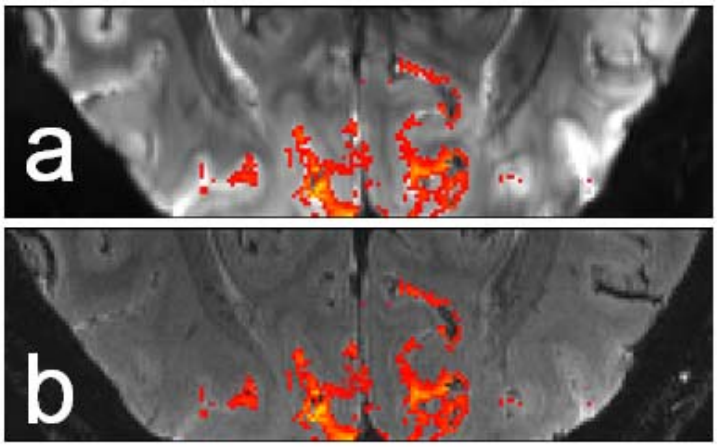

Fig 2: Activation map overlaid on (a) mean ZOOPPA EPI with 0.65 mm isotropic resolution and (b) anatomical FLASH image with 0.6 mm isotropic resolution.

Conclusion: An optimized combination of reduced FOV imaging and parallel imaging (ZOOPPA) achieves very high acceleration factors. Single-shot EPI images accelerated up to a factor of 5.5 are obtained in vivo with high image quality. To demonstrate the usefulness of the ZOOPPA approach, human brain fMRI results with 0.65 mm isotropic resolution at ultra-high field strength are shown.

References: [1] Griswold, et al MRM 1999;41:1236-45. [2] Wiesinger, et al MRM 2004;52:953-64. [3] Heidemann, et al ISMRM 2009 #2442. [4] Hwang, et al JMR 1999;138:173-77. [5] Pfeuffer, et al NeuroImage 2002;17:272-86. [6] Griswold, 2nd Workshop on Parallel Imaging 2004; p. 16-18.