fMRI with 16 fold reduction using multibanded Multislice sampling

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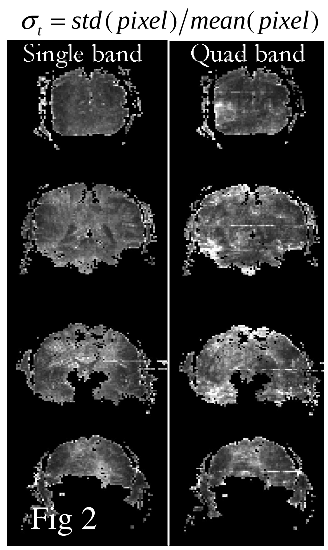
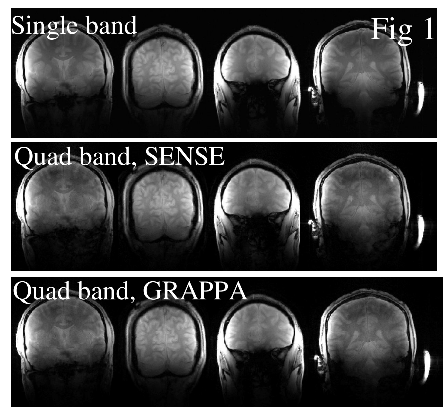
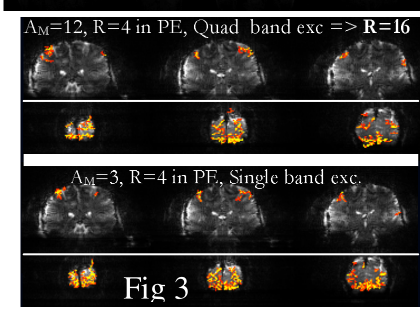
Introduction: The use of partial parallel imaging (PPI) is usually associated with a loss in SNR which can be estimated as the product between *g*-factor and the square root of data reduction R, $g\sqrt{R}$ [1]. However, the SNR loss is limited to g only when the reduction of gradient encoding is performed with multi-band RF excitation pulses [2]. The use of multi-band excitation was initially proposed for spine imaging [3], and the aliasing was solved using a SENSE formulation (for Cartesian undersampling) for directly resolving aliased pixels. Later alternative methods that shift the aliasing between slices have been proposed [4, 5]. The use of multi-band pulses does increases average SAR [2] relative to single-band excitation, but for e.g. GE-EPI this is not a serious limitation – even at high and ultra-high fields. It has been shown that the use of PPI in GE-EPI fMRI is very favorable [6], since the statistical power is not reduced by $g\sqrt{R}$, in particular when the temporal noise is dominated by non-thermal noise. This paper investigates the use of multiband multislice GE-EPI to fMRI.

Background: With a 16-channel head coil at 7T, it has been shown that a reduction of 4 in the PE direction is associated with a mean g-factor of ~1.36 [6], providing a net SNR loss of 2.7. For multi-band acquisitions the corresponding g-factors have been evaluated for aliasing of coronal slices, and a separation of 35 mm is feasible with acceptable g-factors [mean 1.7, max 3]. Separating aliased slices is normally formulated in terms of a SENSE type reconstruction, but similar to the technique from e.g. [7], a GRAPPA type reconstruction can be used by reformatting the data. In addition to aliasing from the multi-band pulse, reduced sampling can be used in the phase encoding direction.

Methods: Imaging experiments were performed on a 7 Tesla magnet (Magnex Scientific, UK) equipped with a Siemens (Erlangen, Germany) TIM console, Siemens Avanto body 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 35 mm between bands. FLASH images (T_E/T_R = 3.4/210 ms, 10º FA, 1×1×5 mm resolution, 28 slices) were acquired for localization of anatomy. Functional images were acquired using GE-EPI (T_E/T_R = 25/1500 ms, 15º FA, 2×2×5 mm resolution, 28 slices, 100 repetitions). The readout direction was placed in the head-foot direction to facilitate full use of the 16 circumferentially placed elements for acceleration. Reconstructions using GRAPPA and SENSE were performed offline. Phase-correction lines were acquired prior to each acquisition, and a non-linear phase correction was applied. We have investigated the use of multi-band excitation for fMRI. Additionally, we have evaluated three different reconstruction approaches: 1D GRAPPA in the PE direction & 1D SENSE in the slice direction, 2D SENSE, and 1D GRAPPA in the PE direction & 1D GRAPPA in the slice direction.







Results and Discussion: FLASH images acquired with single- and quad-band pulses, reconstructed with SENSE and GRAPPA respectively are shown in Figure 1. GE-EPI images have been evaluated for temporal stability, and normalized temporal noise maps indicate that the 1D GRAPPA in the PE direction and 1D GRAPPA in the slice direction provides the least noise amplification. These maps are shown for 4 slices in Figure 2. The temporal fluctuations with a quad-band excitation, relative to a single-band excitation, had only an average increase of 17%, with 7% of the voxels having an increase greater than 200%. This is consistent with non-uniform g-factor noise amplification. The increase in temporal fluctuations is offset by the gain in coverage justifying the use of multi-band excitation for fMRI studies. Functional activation maps from a 150 sec (30 s on/30s off) finger-tapping motor task with 8 Hz flashing-light visual stimulation are shown in Figure 3. The experiment was performed with and without the use of quad-band excitation; in both cases a total of 28 slices were acquired. Figure 3 shows activation maps for a subset of 6 coronal slices from both, covering the primary visual and motor areas. The quad-band acquisition exhibited lower t-scores overall, but similar robust, statistically-significant activation was observed for both acquisitions. The maximal aliasing was A_M=3 and A_M=12 for the single and quad band experiments respectively. We have found that multi-band excitation enables the extension of traditional multi-slice GE-EPI to cover the whole brain with reduced T_R. The combination of 2 orthogonal reduction directions and increased SNR from separate excitations, makes an effective undersampling factor of 16 feasible.

References: [1] Pruessmann, MRM 1999. [2] Kyriakos, NMR Biomed 2006. [3] Larkman, JMRI 2001. [4] Paley, MRM 2006. [5] Breuer, MRM 2006. [6] Moeller, MRM 2006, [7] Blaimer, MRM 2006. [8] Adriany, ISMRM2005, 2005.

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