Evaluation of 2D multiband EPI imaging for high resolution, whole brain fMRI studies at 3T: sensitivity and slice leakage artifacts

Nick Todd[1], Steen Moeller[2], Edward J. Auerbach[2], Essa Yacoub[2], Guillaume Flandin[1], and Nikolaus Weiskopf[1]

[1]*Wellcome Trust Centre for Neuroimaging, University College London, London, United Kingdom,* [2]*Center for Magnetic Resonance Research, University of Minnesota, Minnesota, United States*

TARGET AUDIENCE: Those interested in simultaneous multi-slice imaging techniques for functional MRI studies.

PURPOSE: 2D Multiband EPI sequences that acquire several slices simultaneously show great promise for improving imaging temporal resolution[1, 2]. Functional MRI studies requiring high spatial resolution and whole brain coverage could particularly benefit from acceleration in the slice direction to reduce long image acquisition times. The level of acceleration must be chosen based on fMRI data quality measures of sensitivity to the BOLD signal and minimization of false positive activation. This study evaluates a 2D multiband EPI sequence for high resolution, whole brain task fMRI applications at 3T in terms of BOLD sensitivity and possible false activation due to signal leakage[3] between the simultaneously excited slices.

METHODS: The study followed a 4 x 2 factorial design comparing four multiband (MB) factors and two reconstruction types. Ten healthy volunteers underwent four runs of the identical block-designed visual and motor stimulation paradigm, with a different MB factor used for each run. Scanning was done on a Siemens TIM Trio 3T scanner using Development Release R011a of the MB sequence from the Center for Magnetic Resonance Research[2, 3]. Parameters common to all MB factors were: 1.5 mm isotropic voxels; 84 slices; TE = 35 ms; GRAPPA 2 in-plane; 0.8 ms echo-spacing; transverse slices; FOV/3 CAIPI shift. The four MB factors of 1, 2, 4, and 6 gave TR values of 6.6 s, 3.3 s, 1.65 s, and 1.1 s, and resulted in 64, 128, 256, and 384 image volumes over the 7 minute experimental duration. The same data were reconstructed with two different methods: Slice-GRAPPA (SG) and Split Slice-GRAPPA (SSG)[4].

The time series data were realigned and smoothed with a 2x2x2 mm Gaussian kernel, and then fit with a general linear model that included the task onsets and durations and a high pass filter with cut off of 128 seconds[5]. Temporal autocorrelation was accounted for by pre-whitening using SPM12 for MB factors 2, 4 and 6, but not for MB factor 1 which was assumed to be serially uncorrelated. Voxel-wise T-tests were computed and significance was considered at the level of $p<0.001$, uncorrected. Sensitivity analysis considered two metrics: 1) the total number of significantly activated voxels within anatomically defined ROIs covering the visual and motor areas; 2) the mean value of the highest 1% of t-scores in all activated voxels. False positive analysis focused on the possibility of signal leakage between simultaneously excited slices by considering t-scores at known alias locations of highly activated clusters. Alias locations were determined using the MB factor, CAIPI shift, and in-plane GRAPPA factor.

RESULTS: Figure 1 shows example magnitude images from one volunteer over the four MB factors and two reconstruction types. The sensitivity results are summarized in Figure 2. MB factors 2, 4, and 6 had significantly more total number of voxels activated compared to MB 1, but no significant differences were found between MB factors 2, 4, and 6 or between reconstruction types. MB factors 4 and 6 had significantly larger t-values compared to MB 1 and 2. When using SG reconstruction, evidence of at least one instance of false positive activation due to signal leakage was found in 10%, 90%, and 90% of volunteers at MB factors 2, 4, and 6, respectively. The rates were reduced when using SSG reconstruction to 0%, 10%, and 20% for MB factors 2, 4, and 6. Figure 3 shows four example cases for MB 4 and MB 6 where false activation was observed when using SG reconstruction but not when using SSG reconstruction.

CONCLUSIONS: The combination of in-plane GRAPPA and MB acceleration can lead to false positive activation when signal from highly activated areas leaks into simultaneously excited slices. For a 1.5mm high resolution, whole brain protocol at 3T as presented here, we recommend using SSG reconstruction with in-plane GRAPPA 2 and MB factor 2. MB acceleration factors beyond 2 should be carefully tested before use.

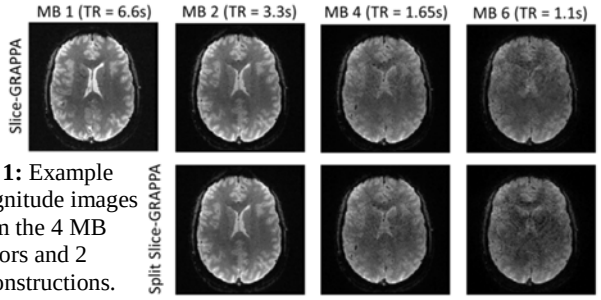

Fig 1: Example magnitude images from the 4 MB factors and 2 reconstructions.

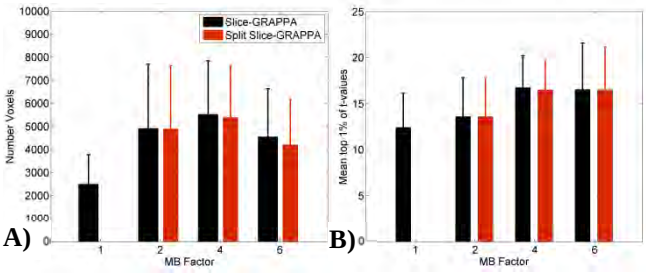

Fig 2: Sensitivity analysis across MB factors and reconstructions. A) Number of activated voxels, mean and sd over volunteers. B) Mean of the highest 1% of t-score values, mean and sd over volunteers.

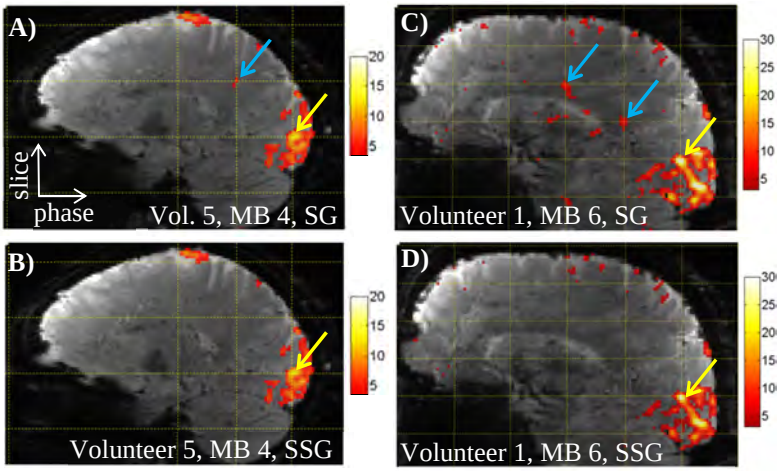

Fig 3: Examples of false positive activation. Yellow arrows point to a voxel in an area of high, expected, activation. Dashed yellow lines indicate simultaneously excited slices and phase encode locations where signal aliasing may occur. Blue arrows point to false activation arising from yellow arrow voxels. False activations were seen in most volunteers at MB 4 and MB 6 using the SG recon, examples in A) and C). Use of the SSG recon suppressed these false activations in most, but not all, cases, B) and D).

REFERENCES: 1. Setsompop et al. MRM 2012. 2. Moeller et al. MRM 2010. 3. Xu et al Neuroimage 2013. 4. Cauley et al. MRM 2014. 5. SPM12 framework, Wellcome Trust Centre for Neuroimaging, London (http://www.fil.ion.ucl.ac.uk/spm/).

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