Multiband Multiecho 2D-EPI: Maximizing BOLD CNR for fMRI at 3T

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TARGET AUDIENCE: Researchers interested in multiband (MB) and multiecho (ME) 2D-EPI sequences for fMRI studies.

INTRODUCTION: Multiband[1] Multiecho 2D-EPI with blipped-CAIPI[2] is an MR imaging sequence that allows the acquisition of multiple slices simultaneously – thus dramatically reducing acquisition time and repetition time (TR) – and of multiple echoes with different TEs after a single RF excitation, improving BOLD sensitivity in fMRI studies[3]. Nonetheless, crafting protocols which maximize the tSNR of MB accelerated experiments is not a straightforward task[4]. **In this contribution we compared the BOLD CNR of various MB-ME 2D-EPI protocols - different in their MB factors** (number of slices excited simultaneously), **in-plane acceleration factors** (referred to as GRAPPA[5] throughout this contribution) **and/or CAIPI factors** (2 for FOV/2, 3 for FOV/3, etc.) - under three constraints: 1. Equal number of volumes for all acquisitions, 2. As many echoes as possible using minimum TEs and TRs available, without violating the conditions TE_{max}=100ms and TR_{max}= 2000ms, and 3. Total acceleration = MB*GRAPPA < 10.

MATERIALS AND METHODS: MB-ME EPI data was acquired with a 32-channel head coil on a 3T Siemens Skyra MR scanner from N=3 subjects after written consent. For all acquisitions the following parameters were kept fixed: FA 65, BW 2030 Hz/px, voxel size 2.5mm^3, in-plane resolution 88 x 88, 36 slices, slice distance factor 0, and number of volumes =100. Acquisitions varied with respect to the multiband factor (MB), the GRAPPA factor, the CAIPI shift (CAIPI), measurement time (Time), TR, TE, echo spacing (ES) and number of echoes (Ec), as shown in table 1. Images were reconstructed online with the slice-GRAPPA[2] and GRAPPA algorithms. Echoes were combined offline by weighted summation, using as weighting factors the relative BOLD contrast[3] of each echo, resulting in a single time series. An effective tSNR map of each scheme was computed as the mean over the standard deviation of the weighted time series, divided by the square root of its respective TR. Finally, for each subject, the effective tSNR of voxels inside of a grey matter mask (extracted with FSL FAST, http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FAST) were averaged, yielding a relative BOLD (weighting) CNR value used as metric to compare different schemes. Masking is important for a fair comparison, to avoid influence from the difference in CSF/WM/GM contrast. This difference in contrast between acquisitions can be seen in Figure 1.

Table 1. Acquisition parameters for all tested MB-ME protocols.

	MB	GRAPPA	CAIPI	Time	TR	TE1	ES	Ec
1	2	2	1	3:33	1900	18	26	3
2	2	3	1	2:52	1460	15	19	3
3	2	3	2	2:52	1460	15	19	3
4	3	2	1	3:11	1630	19	26	4
5	3	2	3	3:11	1630	19	26	4
6	3	3	1	2:59	1440	15	19	5
7	3	3	2	2:59	1440	15	19	5
8	4	2	1	2:07	956	18	26	3
9	4	2	3	2:12	998	20	29	3

RESULTS: The relative BOLD CNR decreased with MB factor for all subjects, independent of the CAIPI and GRAPPA factors. For MB 2 and MB 3, higher relative BOLD CNR was obtained with GRAPPA 3, even though the total acceleration increased with respect to GRAPPA 2. For MB 4, results improved drastically by using the blipped-CAIPI technique. Figure 2 shows the relative BOLD CNR of all acceleration schemes tested.

DISCUSSION: The decrease in relative BOLD CNR for higher MB factors is partly attributable to the lower steady state signal intensity due to shorter TR, and the increase in the standard deviation of the time series arising as consequence of the reconstruction noise amplification (g-factor). Since the blipped-CAIPI technique reduces g-factor by reducing the degree to which the reconstruction relies on coil sensitivity encoding along the slice direction alone, it reduces artifactual variations in signal intensity thus improving the relative BOLD CNR. The better performance with GRAPPA factor 3 is likely to be caused by the shortening of the echo train length and the ES, reducing TEs and (for MB3) increasing the number of echoes acquired. These benefits seem to outweigh the reconstruction SNR g-factor penalty. The apparent outperformance of schemes 2 and 3 (MB2/PE3) will be further investigated, as it might be a consequence of the discrete character of the experiment.

CONCLUSION: For a MB-ME 2D-EPI acquisition, with same amount of measurements, and within boundaries of achievable total acceleration factors for a given coil, **the relative BOLD CNR decreases with MB factor,** though blipped-CAIPI ameliorates this drawback substantially, **and the benefits of GRAPPA 3 outweigh g-factor losses when compared to GRAPPA 2.**

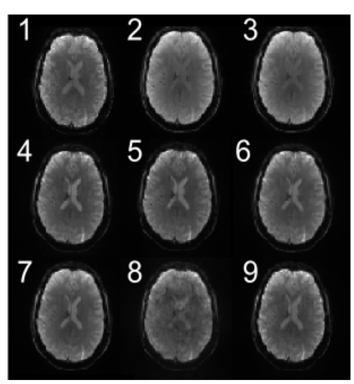

Figure 1. Central slice of the first volume of the weighted series.

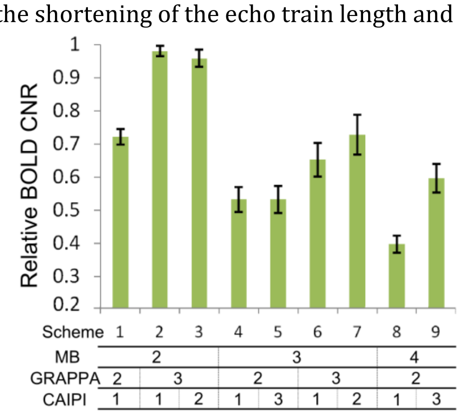

Figure 2. Relative BOLD CNR, averaged over all subjects. Error bars indicate standard deviation.

References: [1] Nunes et al., 2006. *Proc. Intl. Soc. Mag. Reson. 14.* p. 293 [2] Setsompop K. et al., 2012. *Magn. Reson. Med.* 67:1210-1224 [3] Poser B. et al., 2006. *Magn. Reson. Med.* 55:1227-1235 [4] Chen L. et al., 2014. *Neuroimage*. In Press. [5] Griswold M. et al., 2002. *Magn. Reson. Med.* 47:1202-1210