Evaluation of Multi-band EPI in resting state and task fMRI studies

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Target audience: MR physicists and neuroscientist in neuronal MR imaging field, especially fMRI

Purpose: Two dimensional (2D) single-shot echo planar imaging (EPI) is a popular acquisition for functional MRI (fMRI) and resting state fMRI (rs-fMRI). To accelerate the 2D EPI, various methods have been proposed. One such promising method--simultaneous excitation of multiple slices using multi-band (MB) radio-frequency (RF) excitation--has caught the attention of many researchers because the number of simultaneously excited slices (the MB factor) accelerates the acquisition's possible temporal resolution by the MB factor [1-2]. While the MB technique is expected to be beneficial for (rs-)fMRI studies, it has not be thoroughly evaluated yet. We hypothesize that the kernel size choice have a non-negligible effect on MB-accelerated EPI image reconstruction, affecting the results of rs-fMRI and fMRI studies. In this study, we evaluate rs-fMRI and fMRI analysis, and investigate the kernel size sensitivity of MB reconstruction in the simulation. Finally, we demonstrate rs-fMRI and fMRI analysis using MB EPI scans.

Methods: We acquired conventional EPI and MB EPI scans during both rs-fMRI and block-design (motor) fMRI paradigms over 3 healthy subjects in 3T scanner using 32 ch headcoil. All the scan data were collected in raw Siemens (Erlangen, Germany) data format. For this study, we would like to compare different MB reconstruction kernels to each other, but also to a conventional EPI acquisition. In order to do this without introducing scan-to-scan variations, we simulated a MB acquisition from the conventional EPI data by combining the k-space data from multiple slices in the same manner as the MB acquisition. In this way, we can compare the same underlying brain activity with conventional and MB EPI. The following MR parameters are commonly used in all scans; FOV=24×24cm^2, matrix=96×96, voxel size 2.5×2.5×2.5mm^3, TE=29 ms, scan acquisition time 7:32. A) conventional EPI scan (TR=3.37 s, 48 slices, 133 measurements), and B) MB scan (MB=3, TR=1.17s, 16 (effective 48) slices, 394 measurements). For MB reconstruction, the Slice-GRAPPA method is used [2], varying the kernel size from 3×3 to 9×9 in readout (RO) and phasing encoding (PE) directions. No spatial smoothing was used in this study.

To determine the MB de-aliasing efficiency, we introduced the normalized temporal standard deviation of the difference (NTSDD) between a baseline and the simulated image, which indicates the temporal variation of the MB simulated signal from the truth.

$$NTSDD(i,j,k) = std(recon(i,j,k,t) - ref(i,j,k,t)) / \overline{ref}(i,j,k)$$

NTSDD map was calculated varying the kernel size (3×3, 5×5, and 7×7 in RO and PE directions) and MB factor (3, 4, and 6). Since the total slice number (=48) is fixed, the increased MB factor decreases the slice gap between the adjacent MB RF pulses. Tab.1 shows this relationship. For the reference, parallel imaging (PI) simulation was also performed with 24 reference lines and R=2 and average NTSDD in whole brain was calculated from PI simulation.

MB factor	Gap btw MB RF
3	4 cm
4	3 cm
6	2 cm

Tab1. MB factor vs the gap between the adjacent MB

Rs-fMRI analysis: Nine-voxels were chosen in left/right M1for seed ROIs, and seeded connectivity Pearson correlation coefficients (CC) maps were calculated from the left M1 seed ROI, for each of the kernel sizes after low pass filtering. Calculated CC values were converted to t-score.

Task fMRI: The voxel-wise time series of signal intensity in the reconstructed images were fitted in a simple block design paradigm (44.8 sec ON & OFF, 5 repetitions). A corrected p value (=.001) were used to calculate the number of activated voxels in the motor cortex area. For the demonstration purpose, uncorrected p value (=.001) was used to define the activation.

MB factor	Kernel size (RO×PE) in MB 3x3	5x5	7x7	9x9
3	1.94	1.84	1.84	1.84
4	3.64	3.93	4.09	4.07
6	4.72	5.69	6.30	6.70
PI	1.16	2.13	0.98	1.04

Tab2. Average NTSDD (%) varying MB factor and the kernel size over 3 subjects. NTSDD values in PI recon. varying the kernel size are also shown.

Results & Discussion: Sensitivity of NTSDD to the kernel is increaesed as the MB factor is increased or as the gap between adjacent MB RF pulses is decreased. NTSDD values in Tab1. show the increasing tendency of 12% with MB factor 4 and 42% with MB factor 6, from 3×3 to 9×9 kernel size while NTSDD with MB factor 3 is essentially unchanged except for a small increase at 3×3 kernel size. The comparison of t-score between the left and right M1 seeds and the number of the task-activated voxels demonstrate the relatively small kernel size senstivity within the same MB factor while the results of rs- and task-fMRI and task t-score are dependent on MB factor, as shown in Tab2 and 3. From the simulation result in rs- and task-fMRI analysis, MB factor 3 (the MB RF gap = 4 cm) would be the preferred MB strategy. Note that this MB simulation does not employ the blipped-CAIPININHA paradigm, which is known to increase the efficiency of MB de-aliasing [2].

Figure 1 demonstrates the result of rs-fMRI and task fMRI using MB (=3) scans with 5×5 kernel over 3 subjects. MB scan is beneficial to rs-fMRI due to the temporal resolution, but does result in some degradation of statistical power in fMRI because of 1) lower SNR in MB than in a conv. EPI, which compensates the gain of increased degree of freedom, 2) fitting a signal into a simple block design, not considering a hemodynamic response function, and 3) increased high-frequency noise (i.e. physiological artifact due to respiration and heart beat).

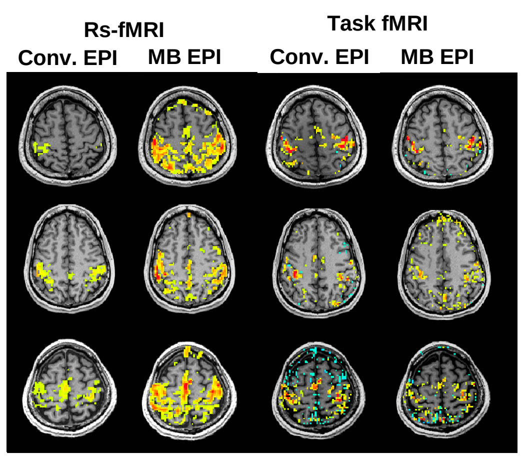

Fig 1. Activation t-score maps of rs-fMRI (uncorrected p<.01) and fMRI (uncorrected p < .001). Note that MB result is *not simulated, but acquired* from a separate scan.

MB factor	Kernel size (RO×PE) in MB 3x3	5x5	7x7	9x9
3	12.44	13.23	13.02	12.53
4	9.60	9.48	9.88	9.83
6	6.09	6.56	6.37	5.75
PI	13.60	10.11	14.33	14.32

Tab3. Average t-score between the right and left M1 seed ROIs over 3 subjects. Note that average t-score from a conv. EPI is 13.97

MB factor	Kernel size (RO×PE) in MB 3x3	5x5	7x7	9x9
3	1081	1070	1064	1052
4	638	577	551	527
6	287	244	192	178
PI	1244	780	1483	1462

Tab4. Average number of task activated voxels (corrected p < 0.001) in motor cortex over 3 subjects. Note that average number of task activated voxels from a conv. EPI is 1564

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Reference

1. Moeller et al., MRM, 2010;63(5):1144-1153.
2. Setsompop et al.,MRM, 2012;67(5):1210-24.