Simultaneous Multi-Slab Echo Volume Imaging: comparison in sub-second fMRI

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Introduction: Echo volume imaging (EVI) is closely related to EPI and utilizes phase encoding pulses on two gradient axes to readout a complete 3D k-space from each echo train. The limitation of EVI has been that it requires much longer echo train than EPI and therefore greater T_2* decay of signal as well as accumulative off-resonance phase errors in the echo train lead to greater image distortions, susceptibility signal loss and blurring. Certainly parallel imaging on two axes has greatly mitigated these deleterious effects by shortening the echo train without reducing spatial resolution. Also, the inclusion of multi-slice technique so as to acquire multiple-slab EVI is useful in reducing the echo train length, simply by reducing the slice encoding number in each restricted slab region yet acquiring adjacent additional slabs with the TR to in effect cover the same volume with several shorter EVI echo trains. This multi-slab EVI technique has additional image artifacts at adjacency regions where imperfect slab-selectivity profiles, T_1 saturation effects from slab tail regions and Fourier leakage due to smaller slice encoding number all contribute to signal loss at slab interfaces in whole brain imaging. Recent work combining multi-slab and parallel imaging have generated interest in fMRI performed in sub-second TRs with high sensitivity [1]. Here we incorporate multiband rf pulses (MB) into multi-slab EVI to further reduce scan time by acquiring slabs simultaneously without lengthening the echo train. Further, we evaluate this new simultaneous multi-volume (SMS)) EVI to previous multi-slab EVI as well as multiplexed-EPI (M-EPI) [2] with similar parameters in fMRI experiments to assess differences in sensitivity and utility.

Methods: SMS-EVI, multi-slab EVI, and M-EPI data were acquired in 4 normal volunteers on a 3T Siemens Trio scanner with 32 channel head coil. The acquisition parameters were as below: FOV = 200 x 200 mm^2, image matrix = 64 x 64, slice thickness=3.0 mm and slab distance factor=0. For both SMS-EVI and EVI, 6 slices per slab, 33.3% oversampling, echo spacing=0.52ms, in-plane undersampling factor of 4 and slice/phase partial Fourier factor of 6/8 were used. SMS-EVI were run with TE=30ms, flip angle=20-30º and multiband factor of 3; two SMS-EVI including single-shot 3 slab (TR=100ms) and interleaved two-shot 6 slab (TR=200ms) were used. EVI were run with TR=480ms, TE=30ms and flip angle=35º. M-EPI were run with TR=200ms, TE=36ms, flip angle=30º, slice number=36, SIR factor=2, multiband factor=9 and control aliasing factor of FOV/4. A simple visual paradigm with a 15s on 15s off 4Hz flickering checker board pattern was used for fMRI activation of primary visual areas. The t-test (degrees freedom=16) was used to generate the activation map. Different methods were compared based on the mean t-value and the number of voxels with t-value above 1.5 ($p<0.01$, uncorrected). In addition to checkerboard experiment, 30 TR under resting state scan was used for temporal SNR (tSNR) evaluation.
To evaluate the T_1 saturation effects, single-shot 3 slab SMS-EVI was performed with gap of 0, 2%, 25% and 100%.

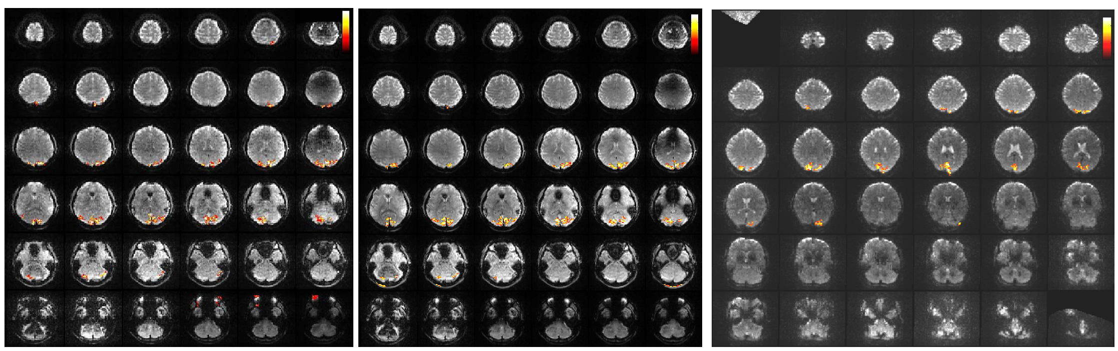

Fig 1 (**Left**) Simultaneous multi-slab EVI, TR/200ms (**Middle**) multi-slab EVI, TR/480ms (**Right**) Multiplexed EPI with parameters:SIR/2, MB/9 and TR/200ms

Results: **Fig 1** shows the comparison of 200ms two-shot SMS-EVI and multi-slab EVI. In general, the image quality of SMS-EVI had identical distortions, blurring and susceptibility loss regions as multi-slab EVI. The signal loss in slices at slab edges was the same, indicating their primary source is from slice profile and Fourier leakage. The T_1 saturation effect between slabs does not occur with simultaneous excitation, and there was no measurable worsened signal loss with contiguous slabs at 0% gap compared to 2%, 25% or 50% gap spacing. The tSNR (**Fig 2**) and the t-value statistical results. (**Fig 3-4**) were shown to compare SMS-EVI (two-shot), EVI and M-EPI. The single-shot SMS-EVI showed lower BOLD signal than the others.

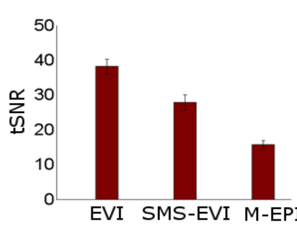

Fig 2. t-SNR comparison (3 subjects)

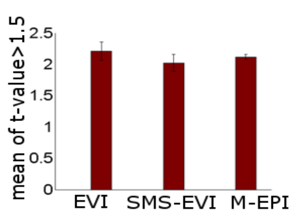

Fig 3. The mean t-value >1.5 threshold.

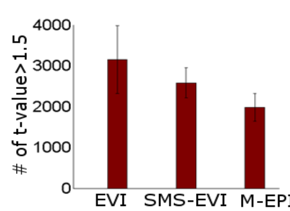

Fig 4. Number of voxels > threshold.

Discussion: The absence of additional signal loss when the slabs are simultaneously excited with 0% gap can be explained by the absence of T_1 saturation effects between slabs that would normally occur when slab excitation is time sequential in as in standard multi-slab techniques. EVI show the higher sensitivity than the other two fast sequences in this comparison utilizing a shorter TR in SMS-EVI. Incorporating controlled aliasing techniques [3] could greatly reduce the g-factor which may benefit the SMS-EVI.

References: [1] Posse S et al, NeuroImage 61,115-130, 2012 [2] Feinberg DA, et al, Plos One 5, e15710 2010 [3] Setsompop K et al MRM 2012;66, 1210-24 Acknowledge:NIH R44 NS073417, 5R44NS63537 (first 2 authors made equal contribution)