Multiband spin- and gradient-echo (SAGE) fMRI

Heiko Schmiedeskamp[1], Eric Peterson[1], Julian Maclaren[1], Rafael O'Halloran[1], Thomas Christen[1], Samantha J Holdsworth[1], Eric Aboussouan[1], William A Grissom[2], and Roland Bammer[1]

[1]*Department of Radiology, Stanford University, Stanford, CA, United States,* [2]*Biomedical Engineering, Vanderbilt University, Nashville, TN, United States*

TARGET AUDIENCE – Neuroscientists with an interest in whole-brain spin- and gradient-echo (SAGE) acquisitions for functional MRI.

PURPOSE – The simultaneous excitation of multiple slices using multiband RF excitation[1] has found widespread application in fMRI, particularly in conjunction with the Human Connectome Project.[2] A major advantage of the multiband method in comparison to conventional single-slice techniques is a reduction in TR without compromising whole-brain coverage. Whole-brain coverage is of particular concern in EPI-based multi-echo gradient-echo (GE) fMRI[3] or simultaneous GE and spin-echo (SE) fMRI.[4] In order to accommodate additional echo readouts, these methods require prolonged acquisition times pre slice compared to conventional single-echo GE measurements, resulting in poor temporal resolution. Nevertheless, it has been shown to be advantageous to acquire multiple echoes simultaneously to improve the overall detection of functional activity.[5,6] Moreover, the combined acquisition of GE and SE fMRI signals facilitates the differentiation between simultaneously acquired BOLD signal changes with distinct contrast mechanisms: GE signal changes are dominated by large-vessel effects, while SE signals – in particular at higher magnetic fields – are dominated by microvasculature effects,[7] providing more localized mapping of functional activity.[8] To facilitate combined GE and SE fMRI while maintaining whole-brain coverage without prolonging TR, we propose utilizing multiband RF excitation in simultaneous multi-echo SAGE EPI acquisitions and present preliminary results using a breath-hold task as proof-of-principle for stimulus-based multiband SAGE fMRI experiments.

METHODS – The SAGE EPI[9] pulse sequence was applied to fMRI at 3T using a breath-hold stimulus: 15 s of breathing was followed by a 15 s breath-hold period, repeated 6 times with a total acquisition time of 3 min, stimulus/rest periods were indicated via a screen projected onto a mirror mounted on top of a 32-channel receive-only head coil. Image acquisition was performed using a 5-echo SAGE EPI acquisition to generate 5 images per excitation with varying contrast (see Fig. 1A). The echo times were chosen as follows: TE_1-TE_5 = 10 ms, 27 ms, 68 ms, 84 ms, and 100 ms. The first 2 echoes followed a multiband 90° excitation pulse[10] to generate GE contrast, while the remaining 3 echoes were acquired following a 180° PINS refocusing pulse,[11] creating 2 asymmetric spin-echoes (ASE) and one Hahn SE. The repetition time, TR, was set to 1.5 s. In-plane parallel imaging acceleration was set to 3 and a two-fold slice acceleration was used, with a matrix size of 84 x 84 x 24 voxels. In-plane field-of-view (FOV) was 24 cm, and z-FOV was 14.3 cm. A slice-matched calibration scan was acquired prior to the fMRI data, facilitating ghost correction and parallel imaging calibration. Image reconstruction was performed using a SENSE-GRAPPA reconstruction method.[12] Functional analysis was performed by voxel-wise correlation of fMRI signals to a sinusoid function,[13] with correlation coefficients $r \geq 0.3$ shown in the plots in Fig. 1D.

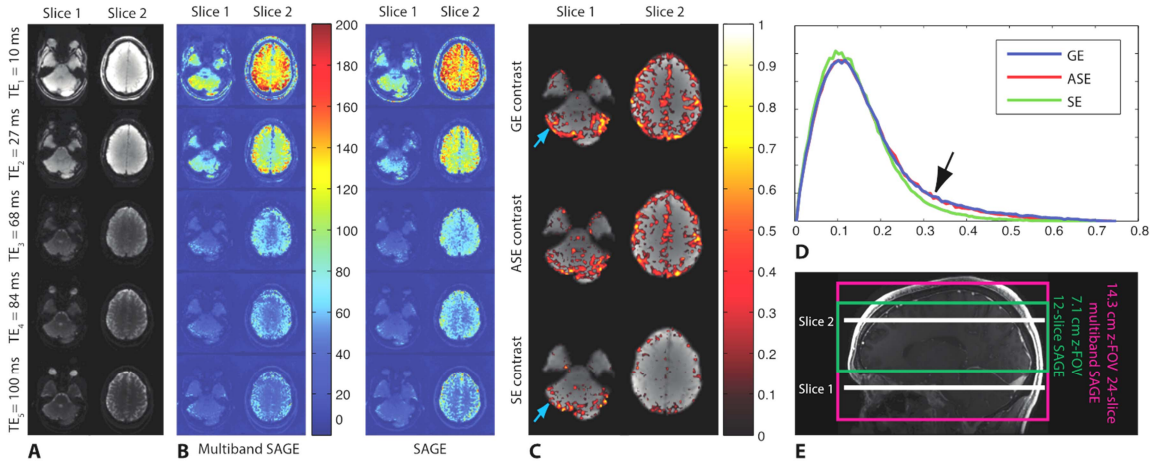

Fig. 1: A: Baseline images of 2 simultaneously acquired slices for all TEs. B: Corresponding SNR maps (left) and conventional SAGE SNR maps (right). C: Functional activity using multiband SAGE with GE, ASE, and SE contrast. D: Histograms combining the correlation coefficients across the whole brain for each contrast mechanism. E: FOV comparison between SAGE & multiband SAGE.

RESULTS – Multiband excitation with two-fold slice acceleration using the SAGE EPI pulse sequence facilitated the acquisition of 24 slices as opposed to only 12 slices when using conventional SAGE EPI (Fig. 1E), with TR of 1.5 s in both cases. The resulting raw images, signal-to-noise (SNR) maps, and fMRI activity in 2 simultaneously acquired slices using multiband SAGE EPI in one volunteer are shown in Fig.1A-C. Fig.1B shows an SNR comparison between multiband SAGE EPI and conventional SAGE EPI, which revealed comparable signal fluctuations for both acquisition schemes. For this comparison, conventional SAGE EPI data were acquired with a TR of 3 s instead of 1.5 s to preserve spatial coverage. Fig. 1C shows three different fMRI maps for each slice acquired using multiband SAGE EPI, providing GE contrast using the combined signals of the first 2 echoes, ASE contrast combining the signals from echoes 3 and 4, and SE contrast using the signals from the last echo. Overall, the analysis of the breath-hold exam revealed an increased correlation of the fMRI signals to the stimulus in areas dominated by gray matter in comparison to white matter (Fig. 1C, right column), an expected effect given hemodynamic changes induced by altering local cerebral blood oxygenation.[14] While GE and ASE fMRI signals were highly sensitive to the breath-hold task, the sensitivity of the SE signals was reduced. This effect is also seen in histograms combining the correlation coefficients across the whole brain, with comparable fMRI signals for GE and ASE data, and reduced correlation between data and task for SE data (Fig. 1D, *black arrow*). This is attributed to reduced sensitivity of SE fMRI to functional stimuli and overall reduction in SNR in later echoes. Moreover, this study confirmed decreased large-vessel blooming artifacts in SE data (Fig. 1C, left column: decrease in fMRI activity in large draining veins, *blue arrows*).

DISCUSSION – The SAGE EPI pulse sequence can be used to distinguish simultaneously acquired multiple fMRI contrast mechanisms within a single acquisition. In the past, such an acquisition was limited in spatial coverage to achieve reasonably low TR. In this study, we presented the feasibility of multiband SAGE EPI for fMRI applications, providing the capability to achieve whole-brain coverage while maintaining a relatively short TR.

REFERENCES – 1. Moeller, et al. MRM 63:1144-53 (2009), 2. Ugurbil, et al. NeuroImage 80:80-104 (2013), 3. Speck, et al. MRM 40:243-8 (1998), 4. Bandettini, et al. Proc. SMRM 1993, p169, 5. Poser, et al. MRM 55:1227-35 (2006), 6. Schmiedeskamp, et al. MRM 63:959-69 (2010), 7. Boxerman, et al. MRM 34:555-66 (1995), 8. Yacoub, et al. MRM 49:655-64 (2003), 9. Schmiedeskamp, et al. MRM 68:30-40 (2012), 10. Wong, et al. Proc. ISMRM 2012, p2209, 11. Norris, et al. MRM 66:1234-40 (2011), 12. Moeller, et al. MRM 63:1144-53 (2010), 13. Lee, et al. MRM 33:745-54 (1995), 14. Kastrup, et al. Stroke 29:2641-45 (1998).

ACKNOWLEDGEMENTS – National Institutes of Health (5R01EB002711, 5R01EB008706, 5R01EB011654, 5P41EB015891), Lucas Foundation.