Reduction of susceptibility artifacts and enhancement of BOLD contrast in functional MRI using multi-band multi-echo GE-EPI

Tae Kim[1], Tiejun Zhao[2], Yoojin Lee[1], and Kyongtae Ty Bae[1]

[1]*Department of Radiology, University of Pittsburgh, Pittsburgh, PA, United States,* [2]*Siemens Medical Solution USA, Siemens MediCare USA, PA, United States*

Target Audience: Functional MRI researchers

Purpose: Intravoxel spin dephasing induced by large susceptibility differences, particularly at air-tissue interfaces, causes a substantial signal loss in gradient-echo (GE) imaging. Signal drop-out increases with TE, slice thickness, and voxel size. For fMRI studies, however, a relatively long TE is required to maximize the BOLD contrast. The dephasing effect is reduced by use of a thin slice. Thus, averaging the signal over N number of contiguous thin slices was suggested[1,2], but SNR is reduced by adding noise from all N images into one image. On the other hand, it has been demonstrated that functional BOLD sensitivity increases and susceptibility artifacts can be simultaneously reduced by the use of multi-echo (ME) EPI[3,4]. However, recovered signal from susceptibility artifacts is more weighted by shorter echo and improvement of BOLD contrast from the recovered area has not been demonstrated. The summation of contiguous thin slices improves artifacts, and then weighted ME summation enhances BOLD contrast including the recovered area and compensates the SNR loss as well. Thus, combination of thin slice summation with weighted ME improves both image artifact and BOLD sensitivity. However, long imaging time is required for whole brain and is limited for fMRI studies. Recently, a multi-band (MB) excitation imaging technique was developed to increase the speed of data acquisition[5,6]. We applied this MB technique to accelerate imaging time, and compared conventional GE-EPI, weighted ME summation, and thin slice summation with weighted ME.

Methods: Four healthy volunteers were studied on a 3-T Siemens scanner using a 32-channel head coil. Single shot GE-EPI images were acquired with a matrix size = 64×64, FOV = 23×23 cm^2, and TR = 2.5 s. In order to make the whole brain activation, 20-s of breath-holding was applied twice for each run, using a block-design paradigm (60s-(20s)-40s-(20s)-50s). Each run was averaged three times. This functional MRI study was acquired with (*A*) conventional EPI, with TE = 35 ms and slice thickness = 4 mm, (*B,C*) MB ME EPI technique, TE = 14, 44.6, and 72.2 ms, MB acceleration factor = 5, slice thickness = 4 mm (*B*)/ 1 mm (*C*). For the same slice coverage, 30 slices were acquired for methods *A* and *B*, and 120 slices were obtained for method *C*. Four contiguous 1 mm slices were summated to match the signal for the 4 mm slice thickness (method *C*). For each voxel, three-echo data were summated with the weight factor, $w(T_2^*)_n = (TE_n \cdot \exp(-TE_n/T_2^*))/(\Sigma TE_n \cdot \exp(-TE_n/T_2^*))$[3,4] for methods *B* and *C*, to generate a single time series data set (method B and C). The voxel-wise temporal-signal-to-noise (tSNR) maps for gray matter were calculated by dividing the mean of the corresponding time series by its standard deviation. The activated pixels were determined on a pixel-by-pixel basis (p-value < 0.05) using AFNI program.

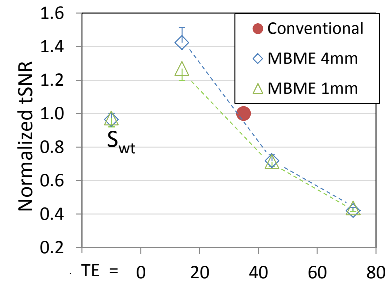

Fig. 1. The normalized tSNR to conventional EPI (circle). MB ME EPI with 4 mm slice thickness (diamonds). MB ME EPI with 1 mm slice thickness (triangles). Swt: weighted summation.

Results and conclusion Fig. 1 shows tSNRs from multi-echo data divided by that of the conventional single echo. For multi-echo images, tSNR at a shorter TE was higher than conventional EPI (TE = 35 ms), and decreased with longer TE, as expected. The tSNR of the weighted signal (S_{wt}) summated from multi-echo is comparable to the conventional EPI (Fig.1 and 2A-C). Although tSNR is higher at TE = 14 ms, the BOLD contrast is expected to be lower, while the tSNR from longer echoes is poor. Thus, we compared tSNR and activation maps from weighted ME summation (S_{wt}). The tSNRs was improved from the susceptibility area (indicated by white arrows in Fig. A) by the MB ME approaches (methods *B* and *C*), while other areas were similar for the three different approaches. Signal in the vicinity of the air-tissue boundary (indicated by white arrows in Fig. 2D), especially in temporal lobe, was significantly recovered in EPI images by MB ME thin slice summation (Fig. 2F). The activated pixels were also improved with the MB ME approach: 5% by MB ME (method *B*) and 12 % by MB ME thin slice summation (methods *C*), compared to the conventional EPI measurement (Fig. 2D-F). More importantly, activation was best improved in recovered areas with thin slice MB ME EPI (green circles). The multi-slice MB technique in conjunction with ME allows more slices and echoes within a given TR normally used for conventional GE-EPI of the whole brain, successfully recovered signal drop-out areas from susceptibility artifacts and increased the sensitivity of BOLD contrast. Thus, this technique can be helpful to many psychiatric and neurodegenerative studies.

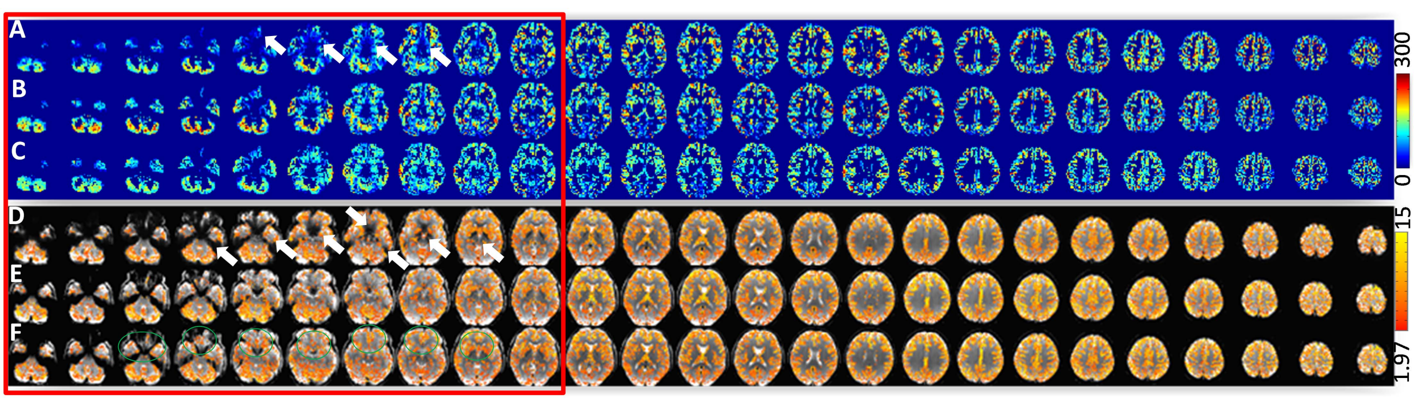

Fig. 2. tSNR (A-C) and BOLD (D-F) maps acquired with conventional EPI (A,D), MB multi-echo EPI with 4 mm thickness (B,E), and MB multi-echo EPI with 1 mm thickness (C,F). The tSNR is displayed for gray matter. Activation maps are overlaid with the corresponding EPI image. 25 out of 30 slices are displayed. Color bar: t –value (D-F)

References: **1.** Wadghiri et al., MRM 2001, **2.** Merboldt et al., JMR 2000, **3.** Posse et al., MRM 1999, **4.** Poser et al., MRM 2006, **5.** Moller et al ., MRM 2009; **6.** Setsompop et al., MRM 2012