Motion immune diffusion imaging using augmented MUSE (AMUSE) for high-resolution multi-shot EPI

Shayan Guhaniyogi[1], Mei-Lan Chu[1], Hing-Chiu Chang[1], Allen Song[1], and Nan-Kuei Chen[1]
[1]*Brain Imaging and Analysis Center, Duke University, Durham, NC, United States*

TARGET AUDIENCE: The aim of this work will benefit researchers and clinicians whose investigations require high-resolution diffusion-tensor imaging (DTI) data free of corruption from motion.

PURPOSE: DTI data acquired with multishot EPI sequences have several advantages over data acquired with single-shot EPI, including reduced geometric distortions and improved spatial resolution[1]. However, multishot acquisitions have amplified sensitivity to motion from one shot to another. Specifically, miniscule motion during the application of diffusion gradients results in phase errors among shots, causing ghosting artifacts, and macroscopic motion results in pixel misregistrations among shots, causing blurring. It has been previously demonstrated that ghosting artifacts can be correcting using the MUSE procedure[2], but blurring from macroscopic motion was not addressed with MUSE. Furthermore, macroscopic rotations also cause each shot to experience a different diffusion-encoding direction. Therefore it is not sufficient to only correct the phase errors and pixel misregistrations among shots in DTI data. The altered diffusion-encoding among shots due to macroscopic rotations must also be corrected, since neglecting these effects will produce inaccurate estimations of diffusion tensors. Here we present a new method, named Augmented MUSE (AMUSE), to correct motion-corrupted diffusion-encoding in multishot DTI, thereby allowing reliable high-resolution diffusion images and accurate diffusion tensor information even in the presence of macroscopic subject motion.

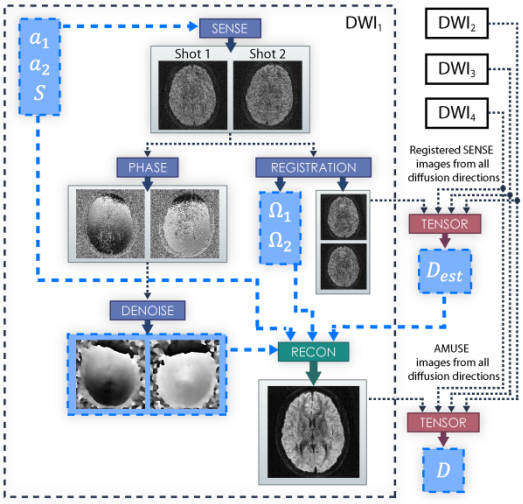

Figure 1: Flowchart of the proposed method

METHODS: Figure 1 shows a flowchart of AMUSE for a 2-shot example. First, each interleaf is FFTed to an aliased image (a_1, a_2) and then used with coil sensitivity profiles (S) to perform a SENSE reconstruction[3]. From these initial SENSE images we estimate the phase differences arising from miniscule motion, and also the motion parameters (i.e. rotations and translations, Ω) describing the macroscopic motion using a registration procedure. Furthermore, the registered SENSE images from all acquired diffusion directions are used to estimate initial values of diffusion tensors (D_{est}) via multivariate regression. The purpose of D_{est} is to estimate the effects of altered diffusion-encoding. Finally, all of the attained information (a_1, a_2, S, phase error, Ω, D_{est}) are combined in a multiplexed reconstruction, resulting in an image without ghosting artifacts, pixel misregistrations, or altered diffusion contrast. A new set of diffusion tensors (D) can then be calculated from these images. The performance of this technique was evaluated on the following data. Axial T2-weighted images and diffusion-tensor data (15 directions) were acquired on a 3T system (General Electric MR750, Waukesha, WI) using a 4-shot interleaved EPI sequence with an 8-channel head coil (In-plane resolution = 0.75 x 0.75 mm^2, Slice Thickness = 4.0 mm, TR = 6 s, TE = 71 ms, b-value = 800 s/mm^2). Two datasets were acquired: a stationary dataset used as a gold-standard, and a dataset in which a volunteer was asked to rotate his head continually during the course of the scan. The reconstruction was performed on the motion-corrupted dataset and two quantitative tensor error metrics were calculated: 1) angular deviation between the primary eigenvectors (V_1) of the reconstructed dataset and the gold-standard dataset, 2) percent error in fractional anisotropy (FA) between the reconstructed dataset and the gold-standard dataset. All processing was performed in Matlab (The MathWorks, Natick MA) on a Linux machine (2.30 GHz CPU, 16 GB RAM).

RESULTS: Computation times for our reconstruction method were approximately 6 seconds per diffusion direction. Fig 2 shows the image quality of various reconstruction methods on the motion-corrupted data. The methods were FFT alone (2a), phase correction alone with MUSE (2b), and phase + macroscopic motion correction with AMUSE (2c). Fig 3 demonstrates the effects of not accounting for altered diffusion-encoding. Fig 3a shows colormaps of the tensor error metrics within a white-matter region when altered-diffusion encoding is not accounted for (3a,b), and when it is accounted for using the proposed AMUSE technique (3c,d).

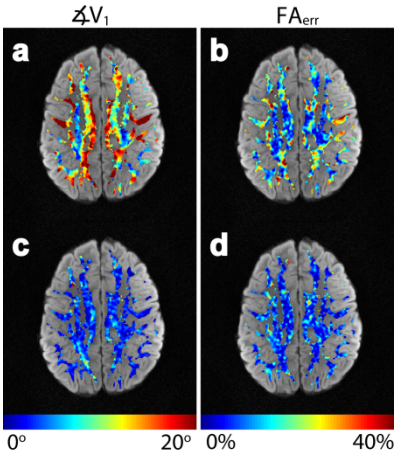

Figure 3: Tensor error metrics for *(a,b)* phase and macroscopic motion correction only, and *(c,d)* phase, macroscopic motion, and diffusion-encoding correction with AMUSE

DISCUSSION: A clear improvement in image quality is seen after phase and large-scale motion correction, compared to phase correction alone (Fig 2). However, as seen in Figs 3a-b, there remain significant errors in the calculated V_1 and FA when the alterations in diffusion-encoding are neglected. After diffusion-encoding correction using AMUSE there is a marked decrease in V_1 and FA errors (Figs 3c-d), indicating that the tensors calculated from this reconstruction are closer to the gold-standard. We demonstrate that the time spent for image reconstruction is reasonable, taking approximately 1.5 minutes for a 15 direction DTI dataset (one slice). Although this study used a 4-shot EPI acquisition, our technique can be generalized to a greater number of shots, making it applicable for studies requiring even higher spatial resolutions.

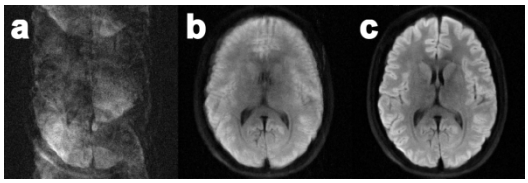

Figure 2: Motion-corrupted data reconstructed with *(a)* FFT, *(b)* MUSE, and *(c)* AMUSE

CONCLUSION: We present a technique capable of correcting motion-corrupted diffusion-encoding, in addition to motion-induced phase errors and pixel misregistrations, in multishot diffusion-weighted EPI. As a result, diffusion tensor information which would otherwise be inaccurate can be estimated more precisely. We expect that this method would be valuable for clinical and neuroscience investigations in which accurate high-resolution DTI information is needed.

REFERENCES: [1] Bammer R. European Journal of Radiology, 40:169-184 (2003), [2] Chen NK, et al. Magn Reson Med, 66:1057-1066, [3] Pruessmann KP, et al. Magn Reson Med, 42:952-962 (1999)

ACKNOWLEDGEMENT: This research was supported by NIH R01-NS074045, NIH R21-EB018419, NIH R01-NS075017, and NIH R01-EB009483.