Non-linearity in diffusion-gradient induced eddy-current fields in a head only 3T scanner

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Introduction

Diffusion-weighting gradients produce eddy-currents that result in transient magnetic fields during acquisition, and lead to image distortion and artifacts in diffusion-weighted MRI. Recently, Chen *et al*. demonstrated a simple distortion correction scheme to correct for the eddy-current induced direction-dependent distortions for DTI [1]. This method requires collecting magnetic field maps for each of the diffusion gradient directions and *b*-values, a time consuming process. Subsequently, the same group demonstrated that the eddy-current induced fields behave linearly in the diffusion gradient amplitude [2], allowing for a much simpler calibration procedure.

In this work, we investigated the applicability of this approach to our head-only 3T scanner. We find that the short-time eddy-current induced fields indeed scale with the amplitude of the diffusion gradients, but the long-time eddy-current induced fields do not.

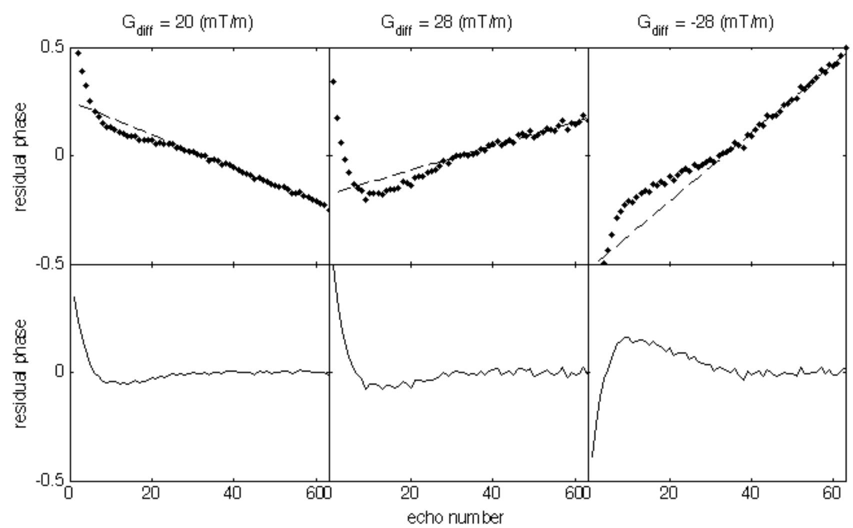
Methods

Data from a spherical doped-water phantom were collected using a twice-refocused spin-echo diffusion-weighted EPI sequence [3] on a 3T head-only scanner (Siemens Allegra) with a custom birdcage coil (Nova Medical). The sequence was modified as follows: 1) EPI blips were removed, and 2) conventional y-phase encoding gradient was added before the EPI readout. This allowed for the acquisition of distortion-free images sampled at progressing echo times [1]. Images were collected with diffusion gradients along the 3 cardinal axes using three different diffusion-encoding gradient amplitudes (G_{diff} = 20, 28 and –28 mT/m, corresponding to *b*-values of 500 and 1000 mm/s^2). Imaging parameters: resolution = 3.5x3.5x3.5 mm^3, TE = 81 ms, echo-spacing = 380 μs, ETL = 64.

The signal from an off-center region of interest was analyzed: 1) The mean of the complex image was computed for each echo-time and diffusion *b*-value and direction. 2) The signal evolution under B_0 and the EPI readout gradients was removed from the $b \neq 0$ data by subtracting the phase of the $b = 0$ (no diffusion) image point-wise. 3) The long-time behavior of the eddy-current induced field was characterized by fitting the second half of the data to a straight line. 4) The short-time behavior was characterized by the residual after the linear fit in step 3.

Results

Results from a representative ROI (x = 40, y = 46, z = -32 mm, V = 1 cm^3) are shown in the figure below, for the diffusion-weighting gradients along x, for three different gradient amplitudes. The top row shows the mean phase in the ROI after correcting for B_0 and EPI readout gradients effects (black points), together with the linear estimation for the long-time eddy-current induced field effect (dotted line). The bottom row shows the short-time behavior, i.e. the difference between the actual phase and the linear fit.



Note that, as expected, the short-term behavior of the eddy-current induced field scales roughly linearly with the gradient amplitude, reversing when the gradient changes sign.

On the other hand, we found that in our head-only system the long-term behavior differs significantly from what was described in [2]. The slope is not linear in the gradient amplitude. Specifically, the long-term behavior for G_{diff} = -28 mT/m cannot be predicted by extrapolating a linear fit of the slopes for G_{diff} = 20 and 28 mT/m.

Discussion & Conclusions

The diffusion-weighting induced eddy-currents in our system cannot be calibrated simply by acquiring only two G amplitudes for each of the cardinal axes and assuming linearity as in [2], even for the eddy-current compensated twice-refocused pulse sequence. It seems that a fuller spatio-temporal characterization of the eddy-current induced fields (as described in [1]) will be needed for optimal image quality on our head only scanner.

References:

1. Chen *et al*. NeuroImage **30**, 121 (2006).
2. Chen & Song, Proc. ISMRM **15**, 3520 (2007).
3. Reese *et al*. MRM **49**, 177 (2003).