Retrospective image correction in the presence of temporal magnetic field changes using SENSE navigator echoes

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Introduction. Spatio-temporal magnetic field changes in the brain caused by breathing or body movements can lead to image artifacts. This is especially a problem in high magnetic field T_2^*-weighted sequences [1,2]. With the acquisition of an extra echo (navigator) it is possible to measure the magnetic field change induced frequency offset for a given slice during image acquisition. However, substantial local variations do also occur within a slice. This work describes an extension of the conventional navigator technique [1] that enables the estimation of the temporally- *and* spatially- varying magnetic field distribution in the brain. This is done by combining frequency encoded signals from individual coil elements and the coil sensitivity profile of each element, termed sensitivity encoded (SENSE) navigator echoes [3,4]. To mimic artifacts as observed in Alzheimer patients [1], we asked the subjects to touch their nose (strong magnetic field fluctuations) or take deep breaths (medium fluctuations), both at an interval of approximately 30 seconds. The effect of these magnetic field variations on high resolution T_2^*-weighted sequences was investigated and the performance of the navigator corrections assessed.

Methods. Experiments were performed on a whole body 7T system (Philips Healthcare) using a quadrature transmit and 32 channel phased array head coil (Nova Medical). A navigator echo was acquired during application of a readout gradient in the anterior-posterior direction after each RF excitation prior to image acquisition. Three different methods were investigated for navigator-based field mapping. The first method consisted of a complex summation over the individual receive channels and temporal sampling points: this estimates an average *f0*-shift over the slice (the zeroth order approach). The second method consisted of a coil-sensitivity weighted summation over the channels and summation over temporal sampling points: this is termed SENSE navigator approach. The third method is similar to the second method but in addition includes the spatial information of the frequency encoding gradient in the anterior/ posterior direction: frequency encoded SENSE navigator. The latter approach results in the most accurate field estimation [4]. High resolution T_2^*-weighted images were acquired (0.4 mm in-plane resolution, 3 mm slices, $TR/TE/TE_{nav}$ = 400/20/10ms, total acquisition time 4 min) when the subject was lying still, during nose touching and during deep breathing. A retrospective reconstruction framework was implemented in Matlab using an iterative conjugate gradient solver. For each acquired k-space line the phase error caused by the corresponding spatial magnetic field is incorporated into the image encoding equation [5].

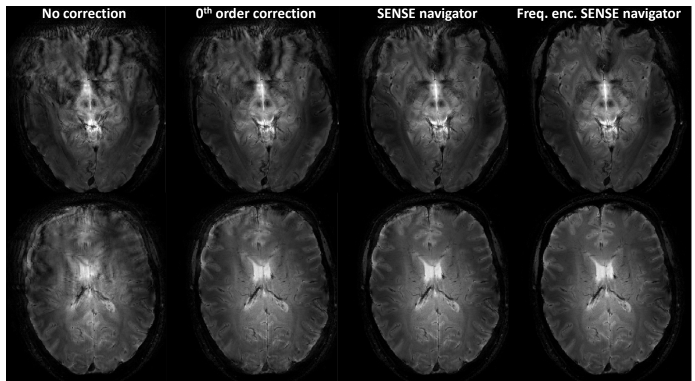

Figure 1. Images acquired during nose touching experiment. Two slices (top and bottom row) are shown for the high resolution T_2*-weighted sequence using the three navigator based field estimations.

Results. Figure 1 shows the resulting T_2^*-weighted images from a subject touching his/her nose for two slices (top and bottom row) and four different reconstruction approaches (from left to right: no correction and the three different navigator corrected reconstructions). Substantial image quality improvement can be appreciated, especially in the frontal area of the brain after correction for magnetic field variations. The best image quality was obtained for the frequency encoded SENSE navigator (rightmost column). Table 1 shows results summarized for 6 subjects in percentage artifact-reduction compared to an image acquired when subjects were at rest.

Percentage reduction in difference image (n=6)			
	0^{th} order correction	SENSE navigator	Freq. enc SENSE. nav.
Nose touching	22 ± 11% (p=0.01)†	38 ± 14% (p=0.01) †,‡	46 ± 19% (p=0.01) †,‡
Deep breathing	16 ± 18% (p=0.08)	19 ± 17% (p=0.05) †,‡	20 ± 16% (p=0.04) †,‡

Table 1. Percentage reduction in difference between images acquired when subjects were lying still and when subjects were performing nose touching or deep breathing for the different navigator correction approaches. † denotes significantly different from no correction; ‡ denotes significantly different from zeroth order correction (both p<0.05).

Discussion. The substantial magnetic field variations during acquisition of T_2^*-weighted images degrade image quality. Although in this study magnetic field variations were intentionally introduced by nose touching or deep breathing these types of field fluctuations are hypothesized to play an important role in previously observed image artifacts in Alzheimer's disease patients, where similar artifacts were observed [1].
Using the combination of coil sensitivity profiles and frequency encoded navigator echoes it is possible to estimate these fluctuating magnetic fields with a high degree of accuracy [4], which can subsequently be used for very effective image artifact correction.

References. 1. Versluis MJ. et al. NeuroImage 2010:51; **2.** Van Gelderen P. et al. MRM 2007:57; **3.** Splithoff et al. MRM 2009:62; **4.** Versluis et al ISMRM 2011 #2921; **5.** Liu C. et al. MRM 2005:54