The impact of background removal techniques on the quantification of magnetic susceptibility in the human cortex

Diana Khabipova[1] and José P. Marques[1]
[1]*CIBM, Lausanne, Vaud, Switzerland*

TARGET AUDIENCE: researchers interested in cortical surface maps for quantitative susceptibility mapping

PURPOSE: The sensitivity of magnetic susceptibility, χ, to iron and myelin content has made quantitative susceptibility mapping (QSM) a very active field of research. However, many pre-processing steps need to be performed before QSM maps can be retrieved and used. One essential step is the background field removal. Many methods have been suggested [1,2,3,4,5], with their performance being evaluated mostly regarding their impact in the quantification of the susceptibility of deep gray matter structures. This study compares the performance and quality of some of the state of art background removal techniques in the estimated susceptibility of the brain cortex.

THEORY: Local tissue magnetic sources generate small magnetic field variations which are overlaid by the strong background fields due to surrounding tissue-air interfaces as well as imperfect shimming. In order to remove such background field from the measured field, a mask that defines the region of the local effects of interest and the background has to be defined. All methods presented in litterature will either end up eroding the mask (losing relevant information) or giving values close to the boundary that are unreliable. Three of the methods that are expected to have smaller effects in the boundary region were compared:

- EAHF[5] (Efficient and Automatic Harmonic Field Pre-Filtering): solves the Laplacian equation (Laplacian of radius 1) iteratively with boundary conditions;
- ReSharp[6]: based on Sharp[1] method and introduces additionally a Tikhonov regularization to enhance the small norm feature of the residual local field after background field removal;
- PDF[2,3] (projection onto dipole fields): uses the knowledge that the background field inside a ROI is composed by fields generated by dipoles outside the ROI

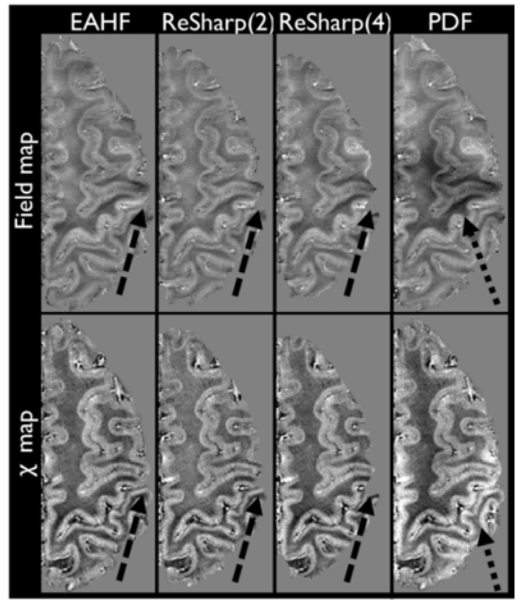

Figure 1 shows on first, second, third and fourth column the field map after background removal (first row) and the resulting reconstructed susceptibility maps (second row) using the background field methodologies i) EAHF, ii) ReSharp with radius 2, iii) ReSharp with radius 4 and iv) PDF, dashed arrow points differences in keeping the brain cortex, dotted arrow points to introduces bias field.

METHODS: Data from one subject was acquired on a 7T scanner (Siemens) according to a protocol accepted by the local ethics committee using the following sequences:

- T1w imaging MP2RAGE: res= 0.6mm isotropic, Tacq=10min 25sec
- B1 map Sa2RAGE: res= 2.2x2.2x2.0mm, Tacq=1min 55sec
- T2*w imageing 3D GRE: TR/TE1/TE5=42/4.97/37.77ms, res= 0.66mm, Tacq=11 mins. The scan was repeated 4 times with the subject's head oriented along different orientations.

Quantitative R_1 maps were calculated using the MP2RAGE and Sa2RAGE data and the processing protocol as described in [7]. Field maps were computed as in [8] and the background field was removed using the three different techniques (EAHF[5], ReSharp[6], PDF[2,3]). χ maps were calculated with multiple orientation acquisitions (COSMOS)[9]. Cortical surfaces were computed from R_1 maps using FreeSurfer and applied to the χ maps, which were co-registered to R_1 maps using FSL-FLIRT. All maps were sampled along the normal to gray-white matter (GM-WM) surface vertex in steps of 20% of cortical thickness across the entire cortical hemisphere.

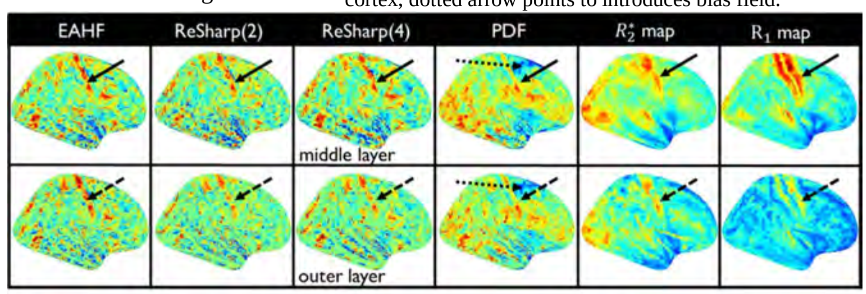

Figure 2 shows on the first, second, third and fourth column the QSM inflated cortical surface maps retrieved after using different background removal methodologies: i) EAHF, ii) ReSharp with radius 2, iii) ReSharp with radius 4 and iv) PDF. The first row row shows the midle layer between WM and CSF and the second row shows the layer closer to the CSF. Arrows point out: solid and dashed- somatosensory cortex and the middle temporal cortex (as seen in R_1 and R_2^* maps [10,11]), dotted-introduced bias field. For comparison purposes an R_1 and R_2^* surface maps are shown on the 5th and 6th column.

RESULTS: The performance of the background removal methodologies shows a similar behaviour on the resulting field maps using the EAHF and ReSharp(4), although the ReSharp method removes some of the outer cortical structure (see dashed arrows in Fig.1). Applying a radius of 2 reduces the removed cortical brain structure. The PDF method introduces a bias field (see dotted arrows in Fig.1). Comparing the cortical QSM maps the EAHF and ReSharp (other than the erosion of the cortex) show similar performance, while the PDF introduces a bias to the brain cortex which can be seen both in the volume maps (Fig.1 b) and in the cortical surface maps (Fig. 2). When looking at inner layers of the cortex (further from the edge of the brain mask) the ReSharp method performs as well as the EAHF method (see solid arrow in Fig.2), having the advantage of being computationally fast. When looking at the outer layers of the brain cortex, close to the pial surface, the EAHF method contains the most anatomical valid information (see dashed arrow in Fig.2 that points out the expected high susceptibility values of primary sensory areas similarly to what has been observed in R_1 and R_2^* cortical maps studies [10,11]).

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