Reducing image artefacts in concurrent TMS/fMRI by passive shimming

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Introduction: Concurrent TMS/MRI is a promising tool for neuroscience because it allows simultaneous stimulation and measurement of human brain activity with high spatial resolution [2].
However the concurrent application of TMS and MRI is technically challenging because of the sensitivity of MRI (particularly FMRI) to inhomogeneities in the magnetic field of an MR-scanner. One particular problem are the artefacts caused by the non-zero magnetic susceptibility of a TMS-coil, which is positioned very close to the head of a participant [1]. The image distortion and signal dropout occurs primarily directly under the TMS coil – often the area of most interest for a TMS/MRI experiment.
This abstract demonstrates that it is possible to use thin ferromagnetic shims to reduce these inhomogeneities and to significantly reduce the signal dropout in EPI.

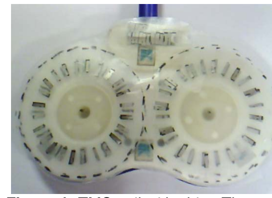

Figure 1: TMS-coil with shim. The steel for the shim was distributed as follows: Evenly along two rings around each side of the TMS-coil with a mean diameter of 70mm and a width of 10mm (each ring: 1080 mm^2 foil or 0.21 g steel), on the entrance point of the lead about 0.14 g of steel

Setup: Experiments were carried out with a GE 3T HDx. An MR-compatible 70mm figure-of-8 TMS-coil from the Magstim Company was used. The passive shim consisted of austenitic stainless steel foil (type 302) with a thickness of 0.025 mm. This foil was cut into 3x10 mm^2 pieces, which were distributed over the back of the TMS-coil as shown in Figure 1.

Methods: The inhomogeneity introduced by the TMS coil was passively shimmed by iteratively minimizing the peak-to-peak B_0 field variation measured by B_0field maps.

Field maps: The TMS coil was positioned flat, either superior or anterior to a plain flat side of a 40x20x20 cm^3 cubic gel phantom. Field maps were calculated from the phase information of two 3D FSPGR images (FOV 350x262x135 mm^3, Resolution 2.7mm^3, TR=20ms, TE 2ms and 3ms). The active shimming was manually turned off. Phase images at each TE were calculated and unwrapped before subtraction using Prelude [4] and converted into units of μT. The field map of the baseline scan was subtracted from the field maps with the TMS-coil in place and were analysed using Matlab.

EPI: Axial EP-images (FOV 217x217x217 mm^3, Res (3.4 mm)^3, 40 slices, TR 3000 ms, TE 35ms, Phase-Encode: AP, 5 volumes, automatic shimming) were acquired on a spherical gel phantom (200mm diameter) with the TMS-coil positioned to the superior-right (radiological) of the phantom. *In vivo* EPI data were acquired with the TMS-coil on the superior-right side of the head of one participant (approximately over the sensorimotor cortex).
All data were acquired with three different configurations: 1st TMS with shim attached to the back of the coil, 2nd the shim was removed, 3rd the TMS-coil was taken away to acquire a baseline scan. The in-vivo images were co-registered using FSL Flirt, 6 degrees of freedom, to the image without the TMS-coil to correct for movement between the scans.

Results: The results from the field maps are shown in Figure 2. These figures show consistently that the B_0field inhomogeneity is reduced by between 50% and 70% by the passive shim. There are no regions in the FOV where the shim increased the field offset. The EP-images of the phantom are shown in Figure 3. The spatial perturbations and the signal drop-out under the TMS-coil are reduced. Figure 4 shows the EP-images from a human head. The artefacts are less expressed than in a phantom. The shim eliminates most of the susceptibility related artefacts.

Conclusions: This work demonstrates that passive shimming significantly reduces the inhomogeneities in B_0 caused by the TMS coil resulting in a substantial reduction in the artefacts in the EP images. The diamagnetic effects of the TMS-coil are still stronger the ferromagnetic effects of the shim, which suggests that a full optimisation can lead to further improvement in the field homogeneity. The shim is thin and easy to use and therefore a versatile solution to reduce the artefacts related to the susceptibility in concurrent TMS/fMRI.

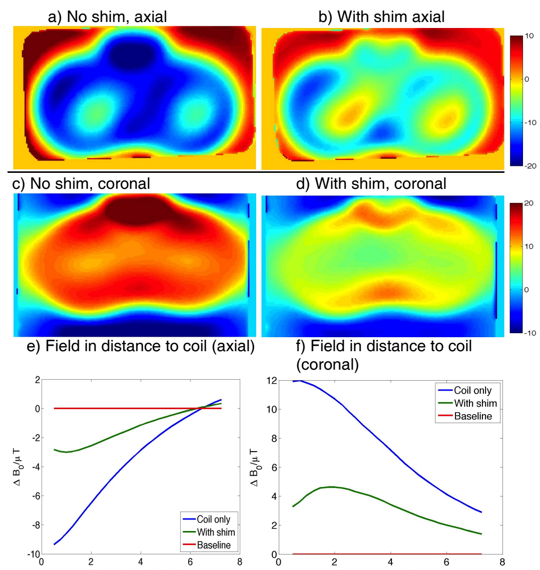

Figure 2: Field offsets (in μT) relative to baseline caused by the TMS-coil. The maps show a plane about 1cm away from the coil surface. a,b) Axial slices with the positioned superior to the phantom, in an axial orientation. c,d) Coronal slice (Superior=top), coil coronal. e,f) Plots along lines perpendicular to the coil surface through a central line where the two halves of the coil join.

References:

[1] Baudewig *J. Baudewig et al. Mag, Res. Imag 18 (2000) 479—484*
[2] Bestmann et al. *Exp Brain Res (2008) 191:383–402*
[3] Oesterbauer, *NeuroImage 29, 245-53 (2006)*
[4] Jenkinson M, MRM, 49, 193 (2003)

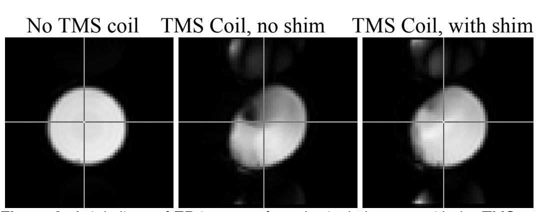

Figure 3: Axial slices of EP-images of a spherical phantom with the TMS-coil adjacent on the superior left side. Left: no TMS coil, centre: coil without shim, right: coil with shim. The spatial perturbations and a decreases in signal are significantly less pronounced in the image with the shim.

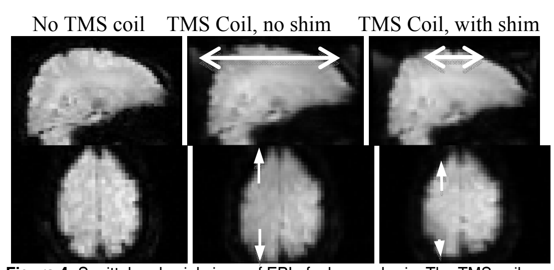

Figure 4: Sagittal and axial views of EPI of a human brain. The TMS-coil was positioned to the superior left. Left: without the TMS-coil, middle TMS-coil, no shim, right: coil with shim. The white arrows indicate the deformations in the images view. The deformations due to the TMS-coil are reduced using the shim.