

Evaluating Field Map Reproducibility Utilizing an Open Source, Vendor Independent B0 Shimming Tool

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Impact

Our proposed shimming procedure is an open-source tool that runs on scanners of multiple vendors, and increases field map reproducibility across multiple scanning sessions.

Synopsis

Motivation: Many factors influence multi-session and multi-site MRI studies, including shimming methods and B0 homogeneity.

Goals: Harmonize the B0 shimming protocol across MRI vendors, and evaluate its impact on B0 field map reproducibility across vendors and scan sessions.

Approach: We compared our open-source, vendor-independent Julia-based shimming tool against vendors' shimming protocols. We performed human volunteer experiments involving a traveling subject on GE and Siemens scanners, head rotations, and dual-session resting-state fMRI scans.

Results: Our shim tool achieved more consistent field maps across vendors, potentially more consistent field maps across head rotations, and reduced EPI distortion in the brainstem when using a locally weighted shim.

Introduction

B0 field inhomogeneities cause image distortion and signal loss in regions with large magnetic susceptibility gradients, especially for sequences with long readouts e.g. EPI. Vendors provide built-in shimming methods that typically use second-order shim coils, but can vary in field map acquisition protocol (pulse sequence, image filtering), shim volume selection, and shim calculation algorithm. This can make it difficult to produce consistent field maps across vendors and sessions. Our open-source shim tool aims to create a consistent and transparent shimming workflow on multiple vendors. We evaluated our tool using (1) a traveling subject across a GE and Siemens scanner, (2) field maps calculated after directed head rotations to simulate different sessions, and (3) spatially weighted shimming to improve local field map homogeneity.

Methods: Shim Procedure

The proposed shim workflow¹ uses a vendor-neutral (Pulseseq^{2,3}) dual-echo GRE sequence for field mapping, and GE's Raw Data Server and the NIH data catcher on Siemens scanners to stream data directly to an external workstation.

We used MRIFieldmaps.jl⁴ to calculate regularized field maps from complex multi-coil data, and ROMEO.jl⁵ for unwrapping. ROI selection is done using FSL's brain extraction tool^{6,7} and an additional thresholding mask to exclude excess tissue. The required shim field over a region of interest (ROI) is calculated using linear least squares.

Methods: Imaging Experiments

We performed imaging experiments in volunteers on 3T GE UHP, GE MR750, and Siemens Vida scanners, each equipped with second-order spherical harmonic shim coils. Vendors' default shim (linear Autoshim on GE, Tuneup shim on Siemens) were applied before prescribing higher-order shimming methods (High Order Shim (HOS) on GE⁸; DESS std on Siemens⁹).

Experiment 1: To evaluate cross-vendor field map consistency, we scanned a traveling subject on a GE and Siemens scanner. In each session, we collected field maps following the vendor and proposed shimming protocols.

Experiment 2: To determine whether our B0 shimming protocol produces more consistent field maps across head rotations compared to a vendor shimming protocol (HOS), we performed prospective and retrospective shimming in a subject following multiple head rotations: right, left, up (extension), down (flexion). After each rotation, we shimmed using the HOS protocol and recorded a field map. After the session, additional shimming estimates were obtained retrospectively using our proposed shimming tool.

Experiment 3: To evaluate the potential impact of our shimming tool on EPI distortion and resting-state fMRI connectivity, we scanned the same subject during two separate fMRI resting-state sessions (GE MR750) using the Pulseseq SMS-EPI sequence (<https://github.com/HarmonizedMRI/functional>) with two 10-minute resting-state runs: shimming with the HOS and shimming with our proposed tool with spatially weighted ROI targeting the brainstem to improve local field homogeneity. We created the mask using SynthSeg¹⁰, followed by inflation and co-registration.

Results

[Figure 1](#) shows increased similarity (reduced root mean square difference (RMSD): 23.2 vs 43.1 Hz) of field maps across vendors when compared to vendor shimming methods. [Figure 2](#) shows slightly improved field map similarity across multiple head rotations (mean STD 7.7 vs 9.3 Hz). [Figure 3](#) demonstrates that applying weighted shimming enhances similarity of field maps and reduces EPI distortions within the target region (RMSD: 7.5 vs 10.5 Hz), albeit with a modest trade-off in the rest of the brain (RMSD: 14.4 vs 12.0 Hz). [Figure 4](#) shows no systemic difference between shimming methods in resting-state connectivity matrices.

Discussion

Our proposed shimming procedure produced more consistent cross-vendor field maps than vendor methods ([Figure 1](#)). Since details of the vendors' protocols are unknown to us, it is unclear what aspects cause these differences; they may be due to differing shim volume selection, pulse sequences, post-processing, field map unwrapping, and/or shim calculation procedures. Our protocol explicitly controls these factors.

Our data also suggests that across (simulated) sessions on the same scanner ([Figure 2](#)), our shimming protocol may perform slightly better than the vendor HOS tool. This result may be somewhat biased since we used the same ROI for RMSD calculation to estimate shim coefficients, however it is difficult to control vendor shim volumes.

Further work is needed to assess the impact of harmonized B0 shimming on functional connectivity.

Conclusion

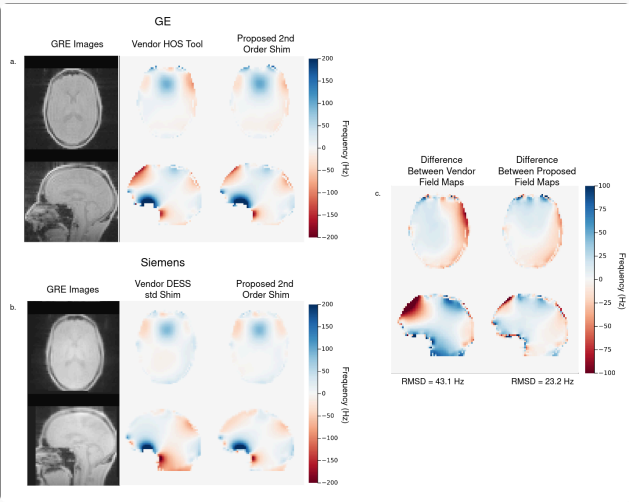
Our open-source B0 shimming tool harmonizes all aspects of the shimming step. The results presented here suggest that this makes field maps more reproducible across vendor platforms. Locally weighted shimming allows for additional control of the resulting field map and EPI distortions.

Acknowledgements

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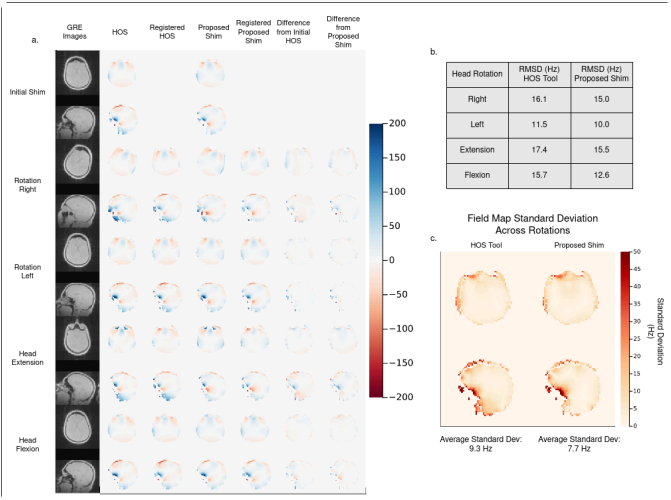
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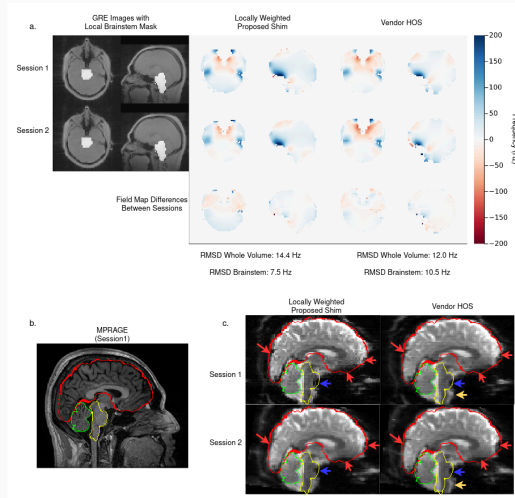
Scan for high-resolution version

Figure 1: Comparing the field maps produced by GE (HOS) and Siemens (std DESS) shimming methods to our proposed shimming protocol in the same subject. On the left, GRE images from each scanner with corresponding field maps (a: GE; b: Siemens). (c) Differences (GE-Siemens) between the vendors' shimmed field maps and the proposed shimmed field maps on each scanner. Our proposed shim method leads to more similar field maps (lower RMSD), possibly due to more consistent shim volume selection across sessions.



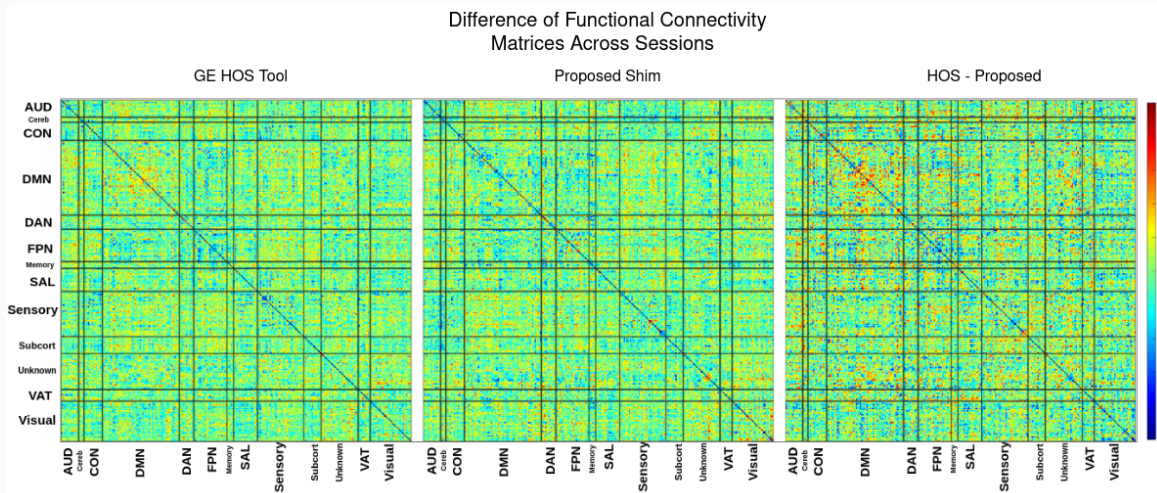
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Figure 2: Effect of head orientations on the B0 field. (a)Field maps after applying GE's HOS tool and retrospectively applying our proposed tool. Right columns show the difference between registered field maps and initial field maps. (b)Our proposed shim and GE's HOS produce comparable RMSD. Differences may be due to different shim volumes between methods.(c) Standard deviation (STD) across head rotations. The proposed shim protocol produces slightly more consistent field maps (mean STD 7.7 Hz vs 9.3 Hz).



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Figure 3: Impact of shimming methods on EPI distortion. We used the proposed tool with locally weighted shimming and GE's HOS. (a) The brainstem mask was weighted higher which led to more similar field maps in the brainstem but slightly higher RMSD globally. (b) MPRAGE image with segmentation (red: cortex; green: cerebellum; yellow: brainstem). (c) EPI images show cortex and brainstem distortion (red/yellow arrow) and signal loss (blue arrow). Brainstem distortions are reduced with proposed local weighted shim.



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Figure 4: (Left, middle) Differences between resting-state connectivity matrices in a traveling subject across two scan sessions. We used (left) GE's HOS and (middle) our proposed shimming before each resting state run to examine similarity across sessions. (right) Difference between the left and middle FC matrices. There is no systemic difference in the connectivity matrices between shimming techniques, possibly due to our limited sample size.