

5242

The clinical relevance of correcting susceptibility-related distortions in presurgical fMRI at 7 T

Pedro Lima Cardoso¹, Barbara Dymerska¹, Beáta Bachratá¹, Florian Ph.S. Fischmeister^{1,2}, Nina Mahr^{1,2}, Eva Matt^{1,2}, Siegfried Trattnig¹, Roland Beisteiner^{1,2}, and Simon Daniel Robinson¹

¹High Field Magnetic Resonance Centre, Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Vienna, Austria, ²Study Group Clinical fMRI, Department of Neurology, Medical University of Vienna, Vienna, Austria

Synopsis

The clinical relevance of correcting susceptibility-related distortions using a recently-developed dynamic distortion correction (DDC) approach is assessed. This was applied in fMRI data acquired from a group of 12 patients with a range of neuropathologies at 7 T. Despite the presence of pathologies, time series of artifact-free field maps were generated. If distortion correction was neglected, substantial displacements, both in EPI geometry and activation, were observed. Two cases with potential clinical implications were identified. The DDC was able to accurately correct distortions in all cases and is shown to be effective and clinically relevant in presurgical planning at 7 T.

Purpose/Introduction

In presurgical planning, susceptibility-related distortion of fMRI results can lead to clinically relevant mislocalization of activation and affect decisions concerning optimal therapeutic approach.¹ Acquisition at UHF (7 T) with the associated increase in time-series SNR and BOLD sensitivity²⁻⁴ allows higher resolution and/or shorter measurement time, which is valuable in preoperative planning. However, field inhomogeneities increase with B_0 , increasing image distortion. We assess distortion-related shifts in activation and their potential clinical relevance in twelve patients with a range of neuropathologies and the effectiveness of a novel method for Dynamic Distortion Correction (DDC)⁵ in removing distortions.

Subjects and Methods

Twelve patients with brain tumors and arteriovenous malformations volunteered to participate in this study, which simulates presurgical fMRI localization of the primary motor cortex (M1) at 7 T. One patient was excluded due to excessive motion. Ten runs (of 56 volumes each) of a motor task were presented in block design. EPI time-series were acquired with $1.7 \times 1.7 \times 3.0$ mm³ voxels, matrix size $128 \times 128 \times 40$, TE/TR = 22/2500 ms, GRAPPA 2, RBW = 1447 Hz/px. Additionally, multi-echo GE data (TE = [5.0, 10.0, 16.0] ms) were acquired before and after the fMRI runs. Data were preprocessed and analyzed with SPM12. Analysis pipelines are illustrated in Figure 1. The analysis for no distortion correction (noDC) and DDC differs only in the unwarping of individual time points (TPs). DDC uses the GE pre-scan to identify the contribution to the phase that does not originate from B_0 . This contribution is subtracted from the phase of each single-echo EPI time point to generate a series of field maps from the fMRI data itself. These are converted into voxel shift maps (VSMs), which are then used to bring the fMRI runs into a distortion-free space.

Results

Comparison of DDC and noDC EPI runs with reference GE images indicated that warps seen in noDC data were effectively removed by DDC in all patients. Figure 2 illustrates two cases in which susceptibility-related geometric distortion resulted in clinically relevant shifts in activation. In P3, a large region of susceptibility-related distortion was visible in M1 in the mean noDC EPI. Here, voxel shifts up to 5.1 mm (see "mean VSM") were found. The std VSM showed relatively larger values (~1 mm) in the vicinity of the pathology for this patient. In P4, a shift in M1 of ~3.4 mm and low std VSM were observed. These shifts were corrected accurately by DDC as demonstrated by the good correspondence to the distortion-free GE reference. Smaller shifts of ~2 mm were present in four patients and to a negligible extent in the remaining four.

Shifts in activation of ~3.4 mm were observed in three patients, reaching over 5.1 mm in more lateral areas of M1 in P3 (Figure 3). These shifts were smaller (~1.7 mm) in five patients, and negligible in two. Two cases with clinically relevant shifts in activation were found (P3 and P4, Figure 3). In P3, activation may wrongly be judged to originate from the strong susceptibility-related artifact. With DDC, however, the activation perfectly overlays M1. In P4, with noDC, the most statistically significant activation appeared to be in the middle part of the precentral gyrus, hindering unique identification of the central sulcus. The activation could be interpreted as reflecting viable primary motor cortex. Following DDC, activation was shifted into the post-central gyrus, a correction which was established as being accurate (see P4, Figure 2). In this case, DDC is likely to change the clinician's interpretation to suggest that, in fact, primary motor cortex is compromised and function has been reallocated to the post-central gyrus.

Discussion

A dynamic approach to correcting for distortions was used in this study, as "static" approaches do not account for changes in B_0 originating from unintentional or task-related motion,⁷ respiration⁸⁻¹⁰ or hardware heating.¹¹ The higher standard deviation values observed in VSMs close to pathologies reveal the dynamic nature of distortion in these regions. Measurable activation displacements of 1.7 up to 5.1 mm (1-3 voxels) were observed in M1. These dislocations were accurately corrected with the DDC approach. The shifts observed in both EPI geometry and functional results are consistent with prior investigations involving neurological patients at 7 T, which report distortions of ~4 mm or even larger, pointing to a possible misidentification of the central sulcus.^{1,12}

Conclusion

If neglected, EPI distortions may lead to misinterpretation and/or mislocalization of activation, particularly in presurgical fMRI, where significantly altered morphology and contrast are present due to pathology. Hence, we propose fMRI data to be unwarped into a distortion-free space using a dynamic approach before drawing conclusions for presurgical planning.

Acknowledgements

This study was funded by the Austrian Science Fund (KL264). BD was additionally supported by a DOC fellowship of the Austrian Academy of Sciences.

References

- Dymerska B, Fischmeister F, Geissler A, et al. Clinical Relevance of EPI distortion Correction in Presurgical fMRI at 7 Tesla. Proceedings of the Twenty-third Annual Meeting of the ISMRM, Milan 2014; #1416.
- Beisteiner R, Robinson S, Wurnig M, et al. Clinical fMRI: Evidence for a 7T benefit over 3T. *Neuroimage* 2011; 57(3):1015-21.
- Triantafyllou C, Hoge RD, Krueger G, et al. Comparison of physiological noise at 1.5 T, 3 T and 7 T and optimization of fMRI acquisition parameters. *NeuroImage* 2005; 26(1):243-50.
- van der Zwaag W, Francis S, Head K, et al. fMRI at 1.5, 3 and 7 T: characterising BOLD signal changes. *Neuroimage* 2009; 47(4):1425-34.
- Dymerska B, Poser BA, Barth M, et al. A method for the dynamic correction of B0-related distortions in single-echo EPI at 7T. *NeuroImage* 2016; doi: 10.1016/j.neuroimage.2016.07.009.
- Andersson JL, Hutton C, Ashburner J, et al. Modeling geometric deformations in EPI time series. *Neuroimage* 2001; 13(5):903-19.
- Jezzard P, Clare S. Sources of Distortions in Functional MRI Data. *Human Brain Mapping* 1999; 8:80-85.
- Dymerska B, Poser BA, Bogner W, et al. Correcting dynamic distortions in 7T echo planar imaging using a jittered echo time sequence. *Magn Reson Med* 2016; 76(5):1388-99.
- Zahneisen B, Asslander J, LeVan P, et al. Quantification and correction of respiration induced dynamic field map changes in fMRI using 3D single shot techniques. *Magn Reson Med* 2014; 71(3):1093-102.
- Zeller M, Kraus P, Muller A, et al. Respiration impacts phase difference-based field maps in echo planar imaging. *Magn Reson Med* 2014; 72(2):446-51.
- Foerster BU, Tomasi D, Caparelli EC. Magnetic field shift due to mechanical vibration in functional magnetic resonance imaging. *Magnetic Resonance in Medicine* 2005; 54(5):1261-67.
- Robinson S, Geissler A, Trattnig S, et al. Correcting for EPI distortion at very high field using the fieldmap method with multi-channel coils: effectiveness in presurgical planning fMRI at 7 T. Proceedings of the Eighteenth Annual Meeting of the ISMRM 2010; #2302.

Figures

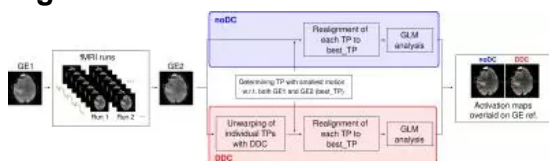


Figure 1 Schematic overview of the steps applied in the analysis of patient data, from acquisition to final activation maps. For each patient, the one time point (“best_TP”) was identified from all the EPI time-series that showed least rotational motion (determined by rigid body realignment) with respect to one of the GE images. Rotational motion has been shown to be the most relevant in introducing susceptibility-induced distortion by movement.⁶ The GE image with the smallest displacement relative to the “best_TP” (“GE reference”) was used as the distortion-free reference image.

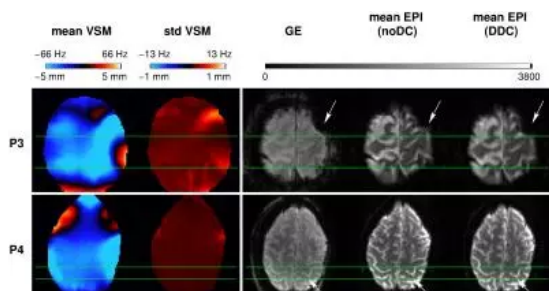


Figure 2 *Left column:* Temporal mean (*left*) and standard deviation (*right*) across all runs of the VSMS for the two patients with potential clinically relevant shifts in activation. In this slice, the highest statistically significant motor activation was detected. *Right column:* GE distortion-free reference (*left*), and temporal mean EPI images for noDC (*middle*) and DDC (*right*) in the same slice. *Green lines* delimit the primary motor hand area of the affected side (at *white arrows*).

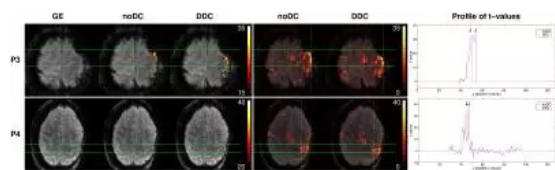


Figure 3 Comparison of noDC and DDC for the two patients with potential clinically relevant shifts in activation. *Left column:* GE reference (*left*) and thresholded activation maps obtained from noDC (*middle*) and DDC (*right*) analyzes. *Middle column:* Unthresholded positive t-values for noDC (*left*) and DDC (*right*) (25% transparency). Activation maps are overlaid on the GE reference. *Green lines* aid visualization of shifts in activation. *Right column:* Profile plots of t-values obtained from the activation along the *white dashed lines*.