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Effects of segmentation on population receptive field mapping in visual cortex

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Introduction

Retinotopy can be used to explore the correspondence of retinal visual input and visual cortex function in healthy subjects and various patient populations. Functional MRI scans are often restricted to visual cortex in order to improve spatial and temporal resolution. Segmentation of white and grey matter is performed to build a WM/GM surface and visualize retinotopic maps in an intuitive way. However, this procedure is typically performed on a whole-brain T1-weighted image as automatic, atlas-based segmentation fails if applied to small parts of the brain. T1-based segmentation can be problematic due to geometric distortions and misalignment of the T2*-weighted EPI data. Here we assess the effects of performing three different segmentation approaches on the resulting retinotopic maps.

Methods

A 20 channel coil at 3T (Siemens Tim Trio) was used to perform BOLD fMRI and acquire a retinotopic map of the visual cortex. We performed two runs using a CMRR multi-band accelerated EPI sequence (TE/TR = 36/1500ms, MB factor 2, voxel size = 1mm³, 10% slice gap, 28 coronal slices, 224 volumes per run). Structural images were acquired using a magnetization-prepared rapid gradient-echo (MPRAGE) sequence with TE/TR = 4/2300 ms, voxel size = 1 mm³ and 160 sagittal slices. Participants were scanned while being presented with a retinotopic visual bar stimulus. The population Receptive Field (pRF) of every voxel contained inside GM masks was modelled using a 2D Gaussian pRF model as implemented in mrVista (Stanford University, Stanford, CA) [1] for the concatenated functional runs. During preprocessing three different segmentation approaches were applied: (I) standard anatomy segmentation (STD); (II) STD with manual mask optimization; (III) transfer of STD on functional data and manual mask optimization. For approach (I) the Freesurfer image analysis suite (http://surfer.nmr.mgh.harvard.edu/) was used to segment MPRAGE datasets and create WM masks which were corrected for holes and handles. For approach (II) we overlaid the segmentation masks on the T1 images and manually adjusted these masks. In approach (III), we performed image segmentation manually on the mean single-band EPI images. The contrast of the functional T2*-weighted image was inverted to facilitate manual segmentation. After segmentation a three voxel grey matter mask was grown on the GM/WM surface using mrVista.

1)

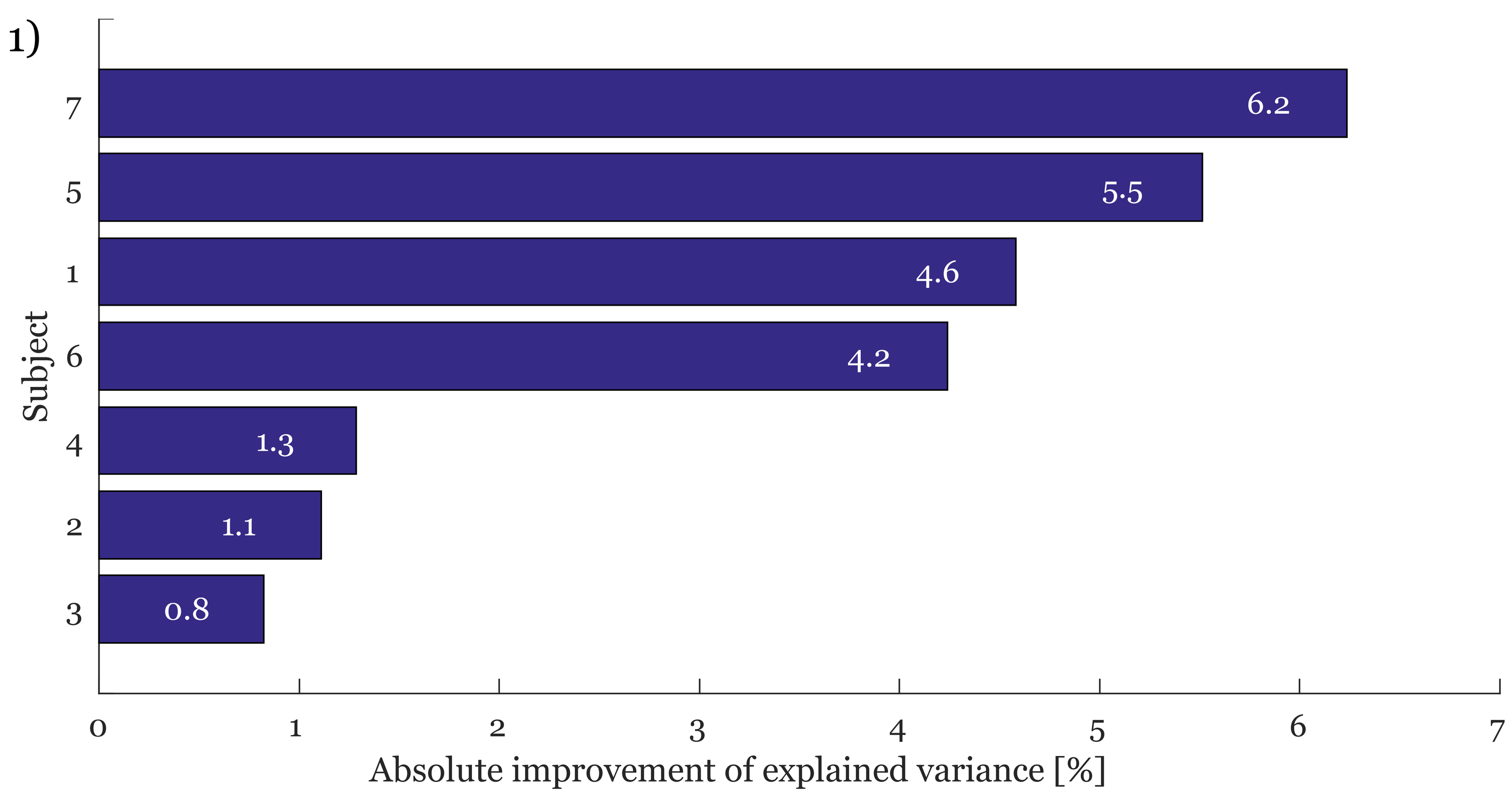


Figure 1) Change of mean variance explained in visual cortex regions V1-V3 after manual WM segmentation based on EPI images is compared to STD for all subjects. Explained variance improved for all subjects suggesting that due to manual segmentation more GM voxels were classified correctly.

Results

To study the effects of the different segmentation approaches different pRF mapping parameters were compared. In Fig. 1) absolute mean explained variance changes in regions V1-V3 are depicted for each subject. On average, explained variance increases by 3.4% (which corresponds to a relative increase of 20%) when comparing EPI-based segmentation to STD. Fig. 2) shows the WM segmentation of a single subject overlaid on the visual cortex. Using the STD approach a satisfactory WM mask can be generated. After transferring the mask to functional space, labeling errors are apparent. Manual optimization improves the segmentation in anatomical space, but mismatches are still grave in functional space unless segmentation is optimized with the help of EPI images. Fig. 3) shows consequences of the different methods on pRF maps of the same subject. EPI-based segmentation leads to reduced artifacts and therefore smoother retinotopic maps.

References

[1] Dumoulin, S. O. and B. A. Wandell (2008). "Population receptive field estimates in human visual cortex." Neuroimage 39(2): 647-660.

[2] Fracasso, A., N. Petridou and S. O. Dumoulin (2016). "Systematic variation of population receptive field properties across cortical depth in human visual cortex." NeuroImage 139: 427-438.

Conclusions

By segmenting T2*-weighted EPI images, errors from geometric distortions, misalignment and interpolation due to coregistration can be avoided. Poor WM/GM contrast in EPI data makes direct segmentation of functional images a tedious, labour-intensive process. The manual effort could be minimized by using the coregistered, eroded T1 segmentation as prior in functional space and apply active contour models to obtain a starting point. Our results show that manual segmentation optimization not only enhances pRF specificity [2], but enhances the quality of retinotopic maps as they become smoother and more reliable.

2)

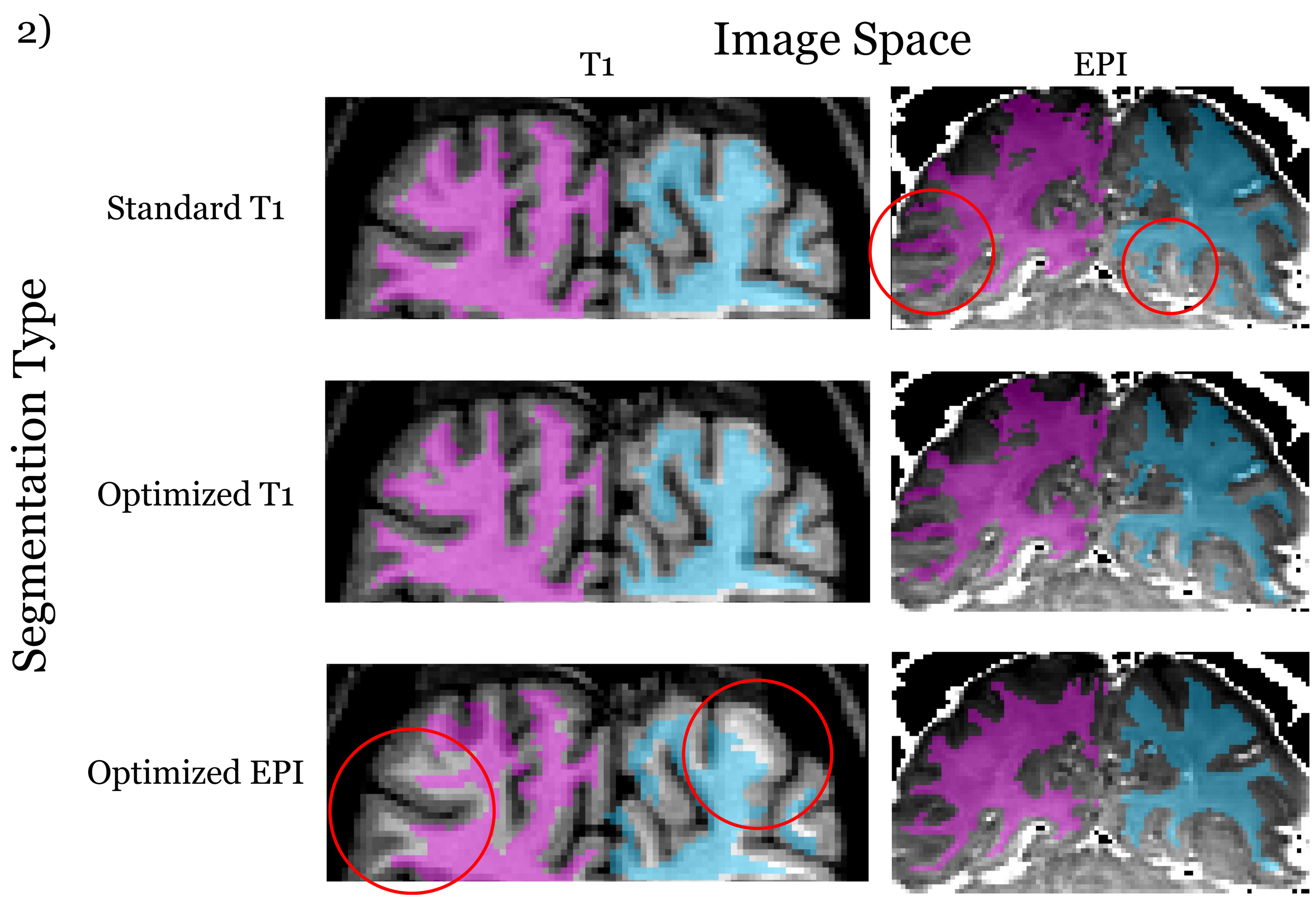
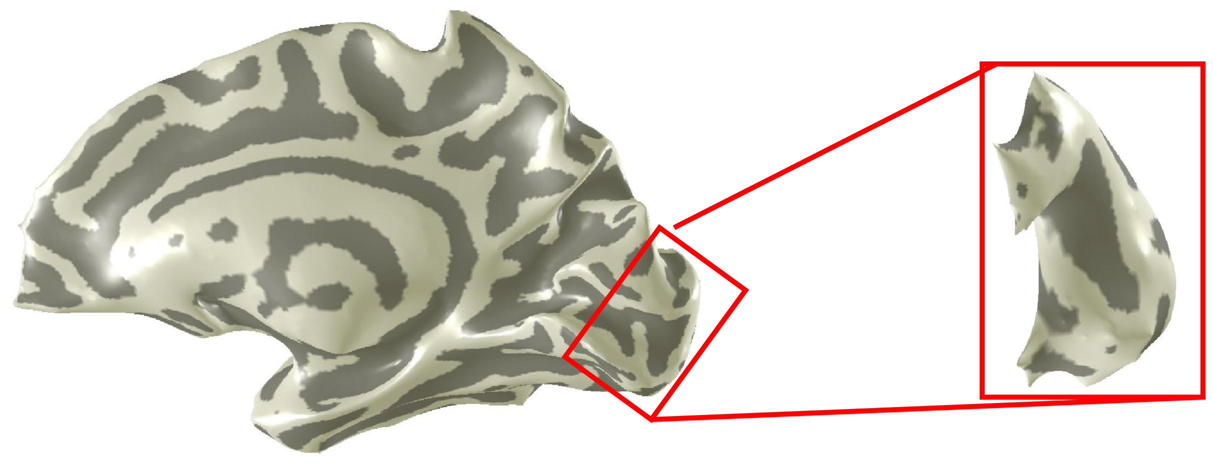


Figure 2) Results of different WM segmentation approaches with mismatches encircled in red. Segmentation errors are primarily located in lateral regions. To correct these errors in functional space manual segmentation based on EPI images is necessary. When coregistering the EPI-based segmentation back to the anatomical image space segmentation errors are visible once again.

3a)



3b)

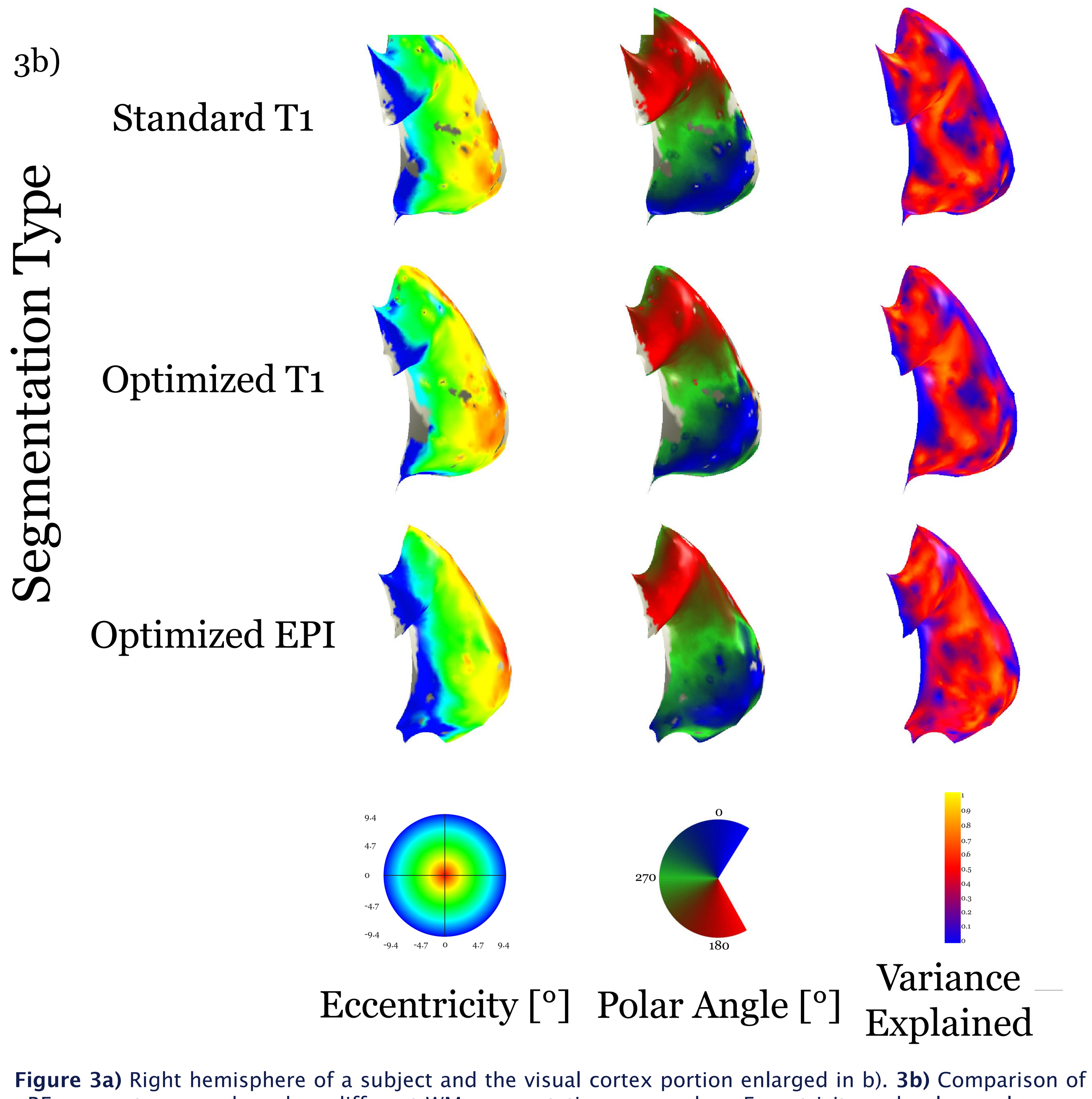


Figure 3a) Right hemisphere of a subject and the visual cortex portion enlarged in b). **3b)** Comparison of pRF parameter maps based on different WM segmentation approaches. Eccentricity and polar angle maps become smoother, while explained variance rises for manually optimized EPI-based segmentation. The threshold is set to 10% explained variance for eccentricity and polar angle maps.