Artificial scotoma size estimation on high-resolution 7T retinotopy data

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Introduction

Applying population receptive field (pRF) mapping methods [Dumoulin 2008] at ultra-high field MRI scanners yield the possibility for detecting visual field losses due to retinal pathologies. However, various artefacts including magnetic field inhomogeneities, subject compliance or the influence of dural venous sinuses, negatively influence the quality of analysis results. While it was previously shown that artificial scotoma sizes could be estimated by pRF analysis data at 3T [Hummer 2018], it is unclear to what extent BOLD sensitivity benefits at ultra-high field translate to scotoma detection accuracy. Here we apply two different pRF stimulation paradigms at 7T to assess and compare coverage map quality and scotoma estimation performance.

Methods

The experiment was performed on a 7T Siemens MAGNETOM scanner, using a 32-channel head coil. 18 subjects (age: 25.6±3.8; 9 female) were included in the study. Beforehand, the subjects were attested for good sight at the local ophthalmology department and had no history of eye diseases. EPI data was acquired with 1mm isotropic resolution using the CMRR multi-band sequence (TR/TE=2000/25.2ms, flip angle=70°, slice gap=0.1mm, LR phase-encoding direction). As usual in retinotopic studies, the acquisition is limited to the occipital lobe (32 slices). Additionally, to the functional runs, two short EPI sequences were measured for distortion correction as well as a full-brain, T1-weighted MPRAGE image for the white matter segmentation.
Inside the scanner, stimuli of reversing checkerboards were presented to the subjects using a projection screen fixed at the end of the patient table. The two different stimulation paradigms were (1) bars moving through the visual field in eight different directions and (2) a combination of rotating wedges and expanding and contracting rings [Engel 1994; Dumoulin 2008]. These stimuli were used for two runs of 356s each. In order to simulate central vision losses the stimuli were modified by a blank, unstimulated circle in the centre with a radius of 2° visual angle.
Processing of functional data included slice-timing, realignment and distortion correction. Functional images and white matter segmentation data derived from the anatomical image were used as input for the pRF analysis suite mrVista. As the analysis input stimulus, the unmodified stimulus without artificial scotoma was used. For the combined results, bar/wedges and rings runs were concatenated.

Results

Visualisation of the visual field coverage maps as well as the visual cortex overlayed with the retinotopic maps were obtained in mrVista (Figure 1). Note the lack of statistically significant voxels in the foveal, non-stimulated visual field. In Figure 2, pRF centres from the coverage maps were integrated over the polar angle, a Kerned Density Estimation (KDE) was performed and the result plotted over the eccentricity for each stimulus type respectively. Further, figure 3 shows the first derivative of the estimated KDEs and the eccentricity value at their maximum. There maxima are suitable for the prediction of the scotoma border and yield the following results: (1) bar: 1.86°; (2) wedge and ring: 1.76°; (3) combination: 1.88°.
It is shown, that the combination of both stimuli provides the highest peak in the derivative plot and therefor the most considerable pRF centre difference at the scotoma border. Hence, it is advantageous to combine the two stimuli in order to get profound scotoma size estimations from pRF mapping.

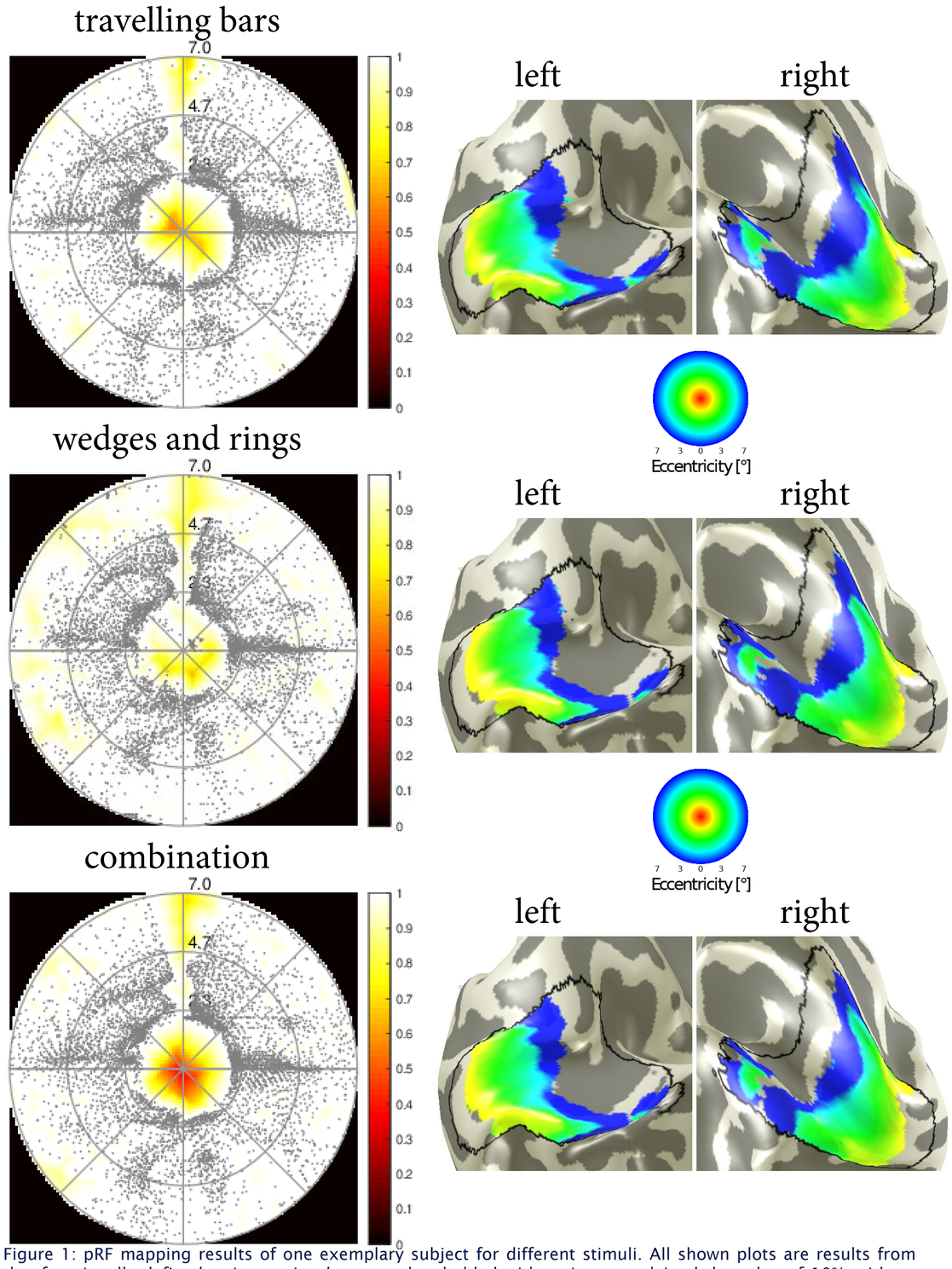

Figure 1: pRF mapping results of one exemplary subject for different stimuli. All shown plots are results from the, functionally defined, primary visual cortex, thresholded with variance explained the value of 10%, without applied data smoothing. On the right-hand side, the defined visual cortex is shown with overlayed significant voxels. The colour encodes the eccentricity parameter as seen on the circular colour bar. As expected due to the stimulation, no central voxels (red) are above threshold. On the left side, the visual field coverage maps also clearly show the stimulated scotoma in the centre. The simulated scotoma is visible through different stimuli. However, the combination of bar and wedge stimulus yields to the most clearly delimited scotoma.

Conclusion

When using retinotopic mapping at ultra-high fields, it has been shown, that the scotoma size estimation yields significant values for both stimulation paradigms. However, the most distinct raise at the artificial scotoma borders can be measured when combining the two stimuli. With the choice of the right stimulation paradigm, retinotopic mapping can complement the possibility of scotoma estimations in patients beyond the conventional ophthalmologic methods, as microperimetry.

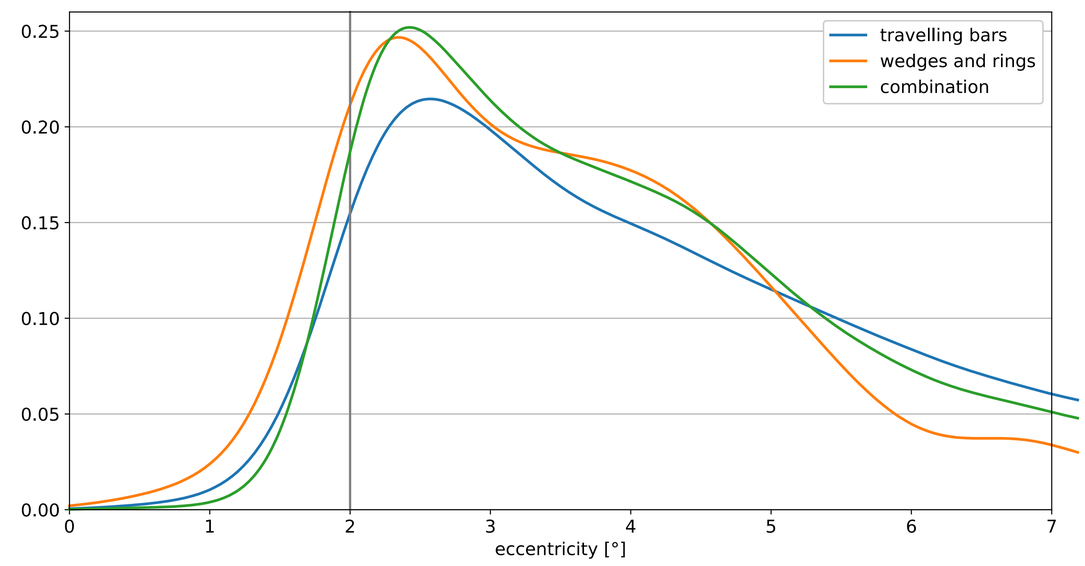

Figure 2: Kernel Density Estimation of the pRF centers, over all subjects and integrated over the polar angle. So this KDE estimate the density of pRF centers over the eccentricity, for three stimulus variants respectively.

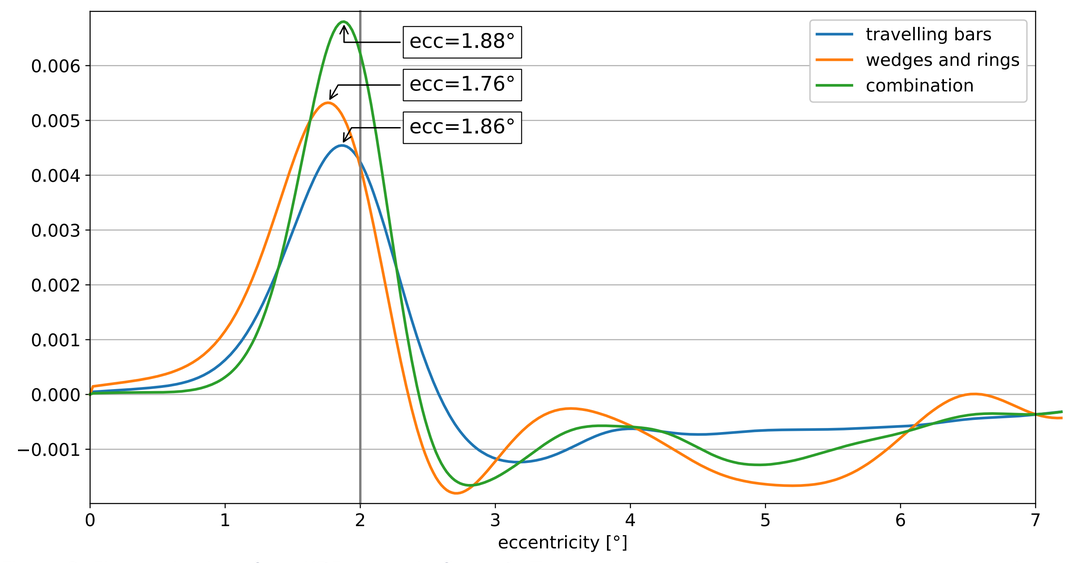

Figure 3: First derivative of the KDE curves in figure 1. The maximum corresponds to the point with the highest gradient and therefore the biggest difference in pRF centers. This area is associated with the artificial scotoma border.

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