Examination of draining vein contributions in GE- and SE-EPI BOLD across cortical depth at 7 T

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Introduction

- Functional magnetic resonance imaging (fMRI) at ultra-high magnetic field strength (≥ 7 T) bears the potential to study laminar and columnar features of the human brain in vivo. [1]
- However, gradient-echo based sequences (GE-BOLD), which are most often used for fMRI, lack spatial specificity due to their sensitivity to macrovascular contributions. [2, 3]
- Spin echo techniques (SE-BOLD) promise higher spatial specificity at the expense of sensitivity. [1, 4]
- In this study, we estimated the spatial point spread function (PSF) along the cortical sheet of high-resolution GE- and SE-BOLD at different cortical depths.

Methods

Experimental design

6 volunteers were invited to participate in 4 functional scanning sessions (2x GE-BOLD, 2x SE-BOLD) over multiple days. We estimated the modulation transfer function (MTF; Fourier transform of PSF) by inducing travelling waves in the primary visual cortex (V1) with different spatial frequencies using rotating wedge stimuli with varying number of wedges in separate runs, see Fig. 1. [5-7]

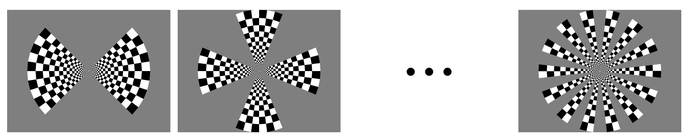
MRI data acquisition

Measurements were performed on a Siemens MAGNETOM 7 T whole-body MR scanner (Siemens, Germany) using a 32-channel RF coil (Nova Medical, USA). For fMRI, we used a single-shot 2D EPI sequence [8, 9] and scanned an oblique-coronal slab with isotropic 0.8 mm voxel size positioned over the occipital lobe (TR = 3000 ms, GE: slices = 50, SE: slices = 18-32 due to SAR limitations, FOV = 148x148 mm², GE: TE = 24 ms, SE: TE = 38 ms, partial Fourier = 6/8, GRAPPA = 3).

Analysis

Time series were slice time and motion corrected. The width of the PSF was estimated from V1 voxels by fitting an MTF model to the magnitude of the Fourier component at stimulation frequency, i.e. the response to the stimulus, in dependence of the spatial frequency of the induced traveling wave. The model assumed a Gaussian PSF and normally distributed noise in fMRI time series.

1



Visual stimuli — Subset of rotating wedge stimuli. The whole set comprised stimuli with, 2, 4, 6, 8, 10, 12 and 14 wedges. Per run, 10 rotations in counter clock-wise direction were shown (stimulation period: 48 s).

Results

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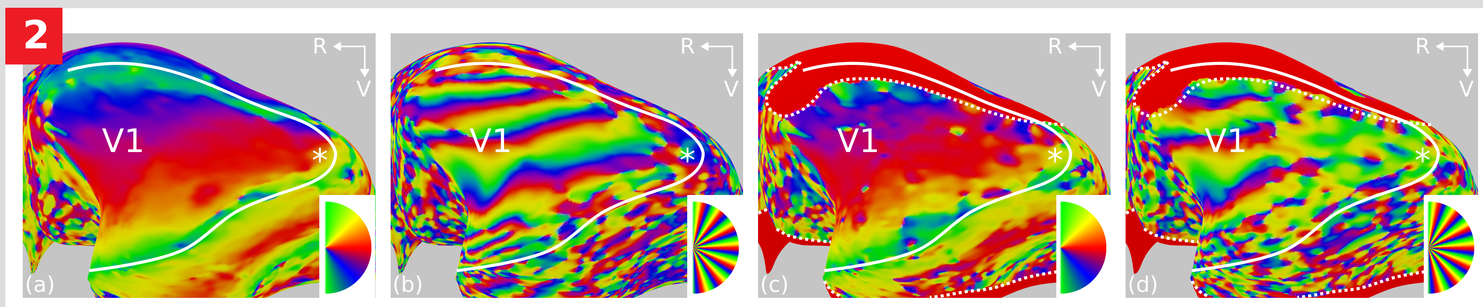
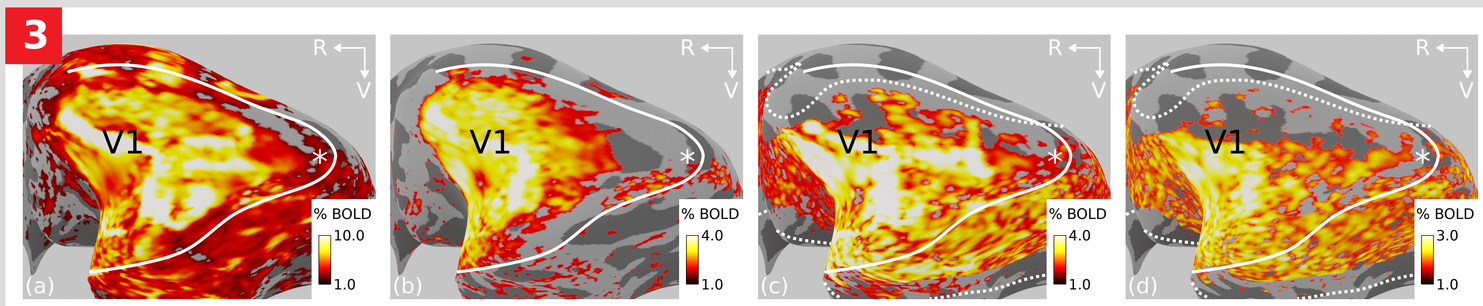


Exemplary phase responses — The phase of the BOLD signal at stimulation frequency is shown for one exemplary participant (left hemisphere). (a) and (b) illustrate responses from GE-BOLD measurements for runs with 2 and 14 wedges, respectively. (c) and (d) show the corresponding responses from SE-BOLD measurements. Data was sampled at mid-cortical depth and averaged across two sessions. Responses are visualized on an inflated cortical surface mesh of the occipital lobe. Solid white lines indicate the V1/V2 border which was based on a separate retinotopy session. Dotted lines illustrate the edges of the SE-BOLD imaging volume. White asterisks indicate the foveal region. R: rostral, V: ventral.

3



Exemplary % BOLD signal changes — For the same participant as in Fig. 2, the corresponding amplitudes at stimulation frequency are shown. These signal amplitudes were used in combination with the spatial frequencies of induced traveling waves (see Fig. 4) to model the MTF from which the width of the PSF was computed. Other details as in Fig. 2.

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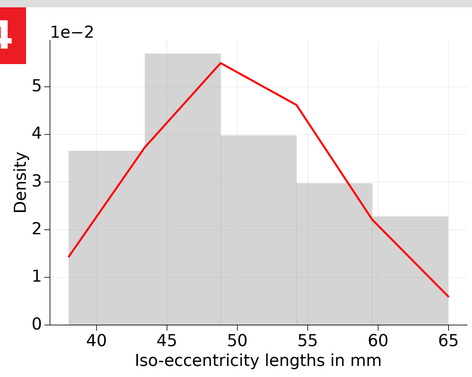

Cortical distances in V1 — To yield an estimate of the PSF in mm, the spatial frequencies of induced traveling waves in cycles/mm have to be known. Therefore, we determined the distance between dorsal and ventral borders for all V1 voxels along iso-eccentricity lines. The histogram shows the distribution of cortical distances at mid-cortical depth across all participants and hemispheres. The red line shows the fit with the probability density function of the standard normal distribution.

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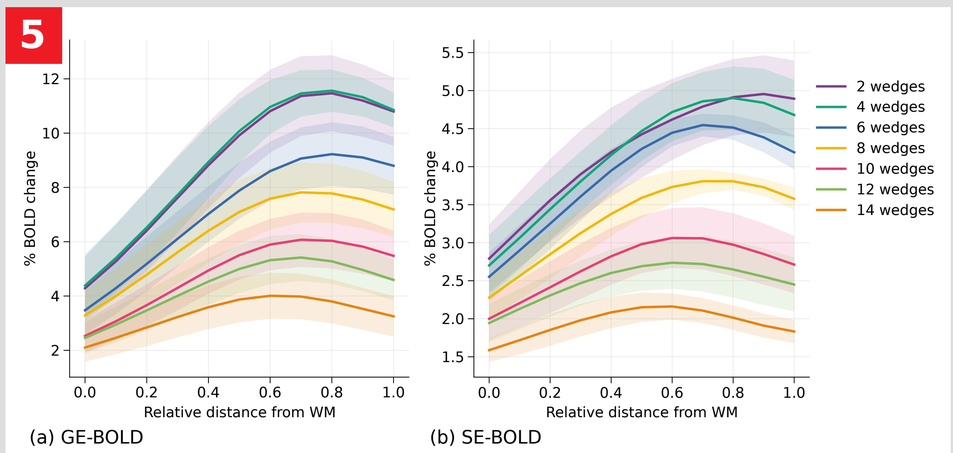

Cortical profiles of % BOLD signal changes — Mean amplitudes across participants with associated standard errors are shown for (a) GE- and (b) SE-BOLD sessions. Two participants were excluded due to inconsistent responses between sessions. The typical increase towards the pial surface can be seen. Furthermore, the signal decreases with increasing number of wedges (increasing spatial frequency). This behavior was exploited to estimate the BOLD PSF.

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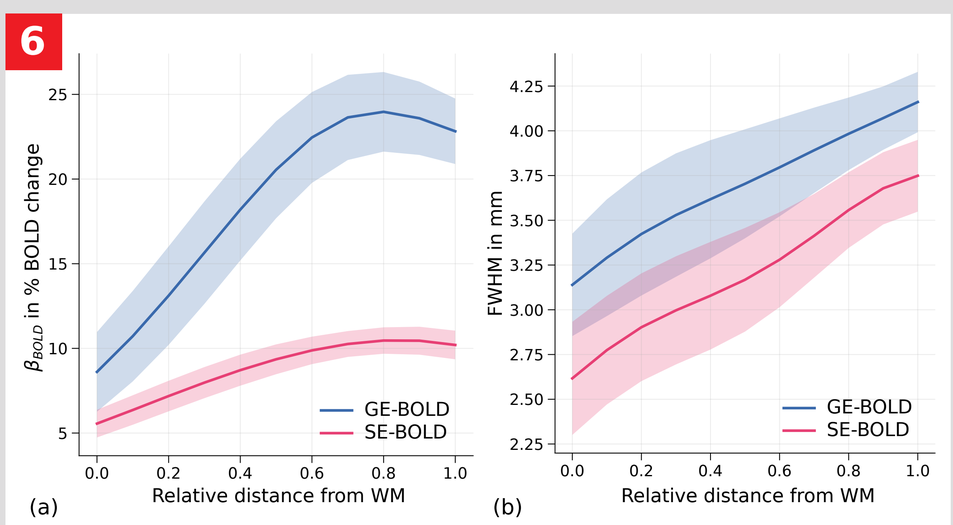

Model parameters across cortical depth — Mean MTF amplitudes (a) and FWHMs (b) across participants with associated standard errors are shown across cortical depth. Here, time series noise was neglected, i.e., the presented fitting parameters show the "best-case scenario". In (b), it can be appreciated that both GE- and SE-BOLD show an incrase of the PSF towards the pial surface which is interpreted as remaining macrovascular contributions in both imaging modalities. Note that adding noise to the model will change the absolute values of the PSF but not their overall trend, see e.g. [10].

Discussion

- In this study, we estimated the tangential physiological PSF of GE- and SE-BOLD across cortical depth by exploiting the retinotopical arragement of early visual cortex.
- A recent study quantified the increase of the PSF for GE-BOLD across cortical depth from the arrangement of stripes in extrastriate visual cortex V2. [11]
- Here, we show that the same trend holds true for SE-BOLD.
- These results indicate that SE-BOLD suffers from similar unspecific macrovascular contributions which lowers its effective spatial resolution towards the pial surface.
- While we expect that more advanced SE-BOLD acquisition schemes will improve the signal specificity, in standard acquisitions using a 2D single-shot EPI approach, disadvantages of SE-BOLD (low sensitivity, low coverage, high SAR) outweigh its anticipated advantages.
- To the best of our knowledge, this is the first study which studies the cortical depth dependence of the physiological point spread function of the spin-echo BOLD signal.

References

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