T2 weighted high-resolution fMRI in human visual cortex at 9.4 T using 3D-GRASE

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Target Audience. Researchers interested in human ultra-high field and high-resolution fMRI

Purpose. Ultra-high field magnetic fields (>3 T, i.e. 7 T or 9.4 T) offer increased spatial resolution and increased signal strength in functional MRI (fMRI) as compared to lower field strength. The spatial specificity of BOLD imaging can be improved using T2 weighted fMRI pulse sequences, which also have sufficient sensitivity for sub-millimeter applications at these high fields. However, static and radio-frequency (RF) field inhomogeneity are more pronounced at higher field strength hampering T2 weighted fMRI applications. In this work, we demonstrate the feasibility of isotropic 0.8 mm and 0.6 mm resolution T2 weighted human fMRI with a visual paradigm at 9.4 T using a zoomed inner-volume 3D gradient and spin echo (3D-GRASE[1]) sequence.

Methods. Measurements were performed on a Siemens 9.4 T scanner equipped with a head-only gradient coil. A healthy volunteer was scanned in compliance with the local ethical board. A half volume RF coil (24 channel receive, 8 channel transmit; Life Services, Minneapolis, MN, USA) was used with a static B1+ phase shim (no amplitude modulation) optimized for efficiency in early visual areas (not subject-specific). SAR supervision was managed by limiting the global SAR deposition based on simulations of the maximum local SAR given the applied B1+ shim. T2 weighted 3D-GRASE images at 0.8 mm (0.51 mm³) and 0.6 mm (0.22 mm³) isotropic nominal resolution were acquired (TE/TR = 30 ms/2000 ms, matrix size = 120×30×12, nominal flip angle = 90°/180°, echo spacing = 0.77-0.79 ms, partial Fourier = 5/8 (slice direction)). High contrast flickering checkerboards (20° visual angle) were presented in blocks of 8 s intermitted with rest periods of 12-16 s (13.2 min. per acquisition). For anatomical reference, a T1 weighted MP-RAGE was acquired (nominal isotropic resolution 0.6 mm, TE/TR/TI = 2.3 ms/3300 ms/1700 ms, nominal flip angle = 5°, matrix size = 320×320×256, GRAPPA R = 2). The resultant images were divided by a proton density weighted MP-RAGE (same parameters except TR = 1320 ms, no inversion module).[2] Results were compared to data acquired at 7T with the same subject, the same functional paradigm, and similar acquisition parameters (0.8 mm³ nominal isotropic resolution, TE/TR = 37 ms/2000 ms, matrix size = 120×30×10, echo spacing 1.02 ms). A standard GLM analysis including the task and nuisance motion regressors was performed.

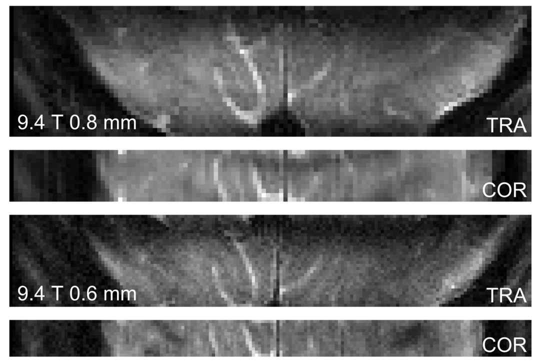

Fig. 1: Representative single 3D-GRASE images

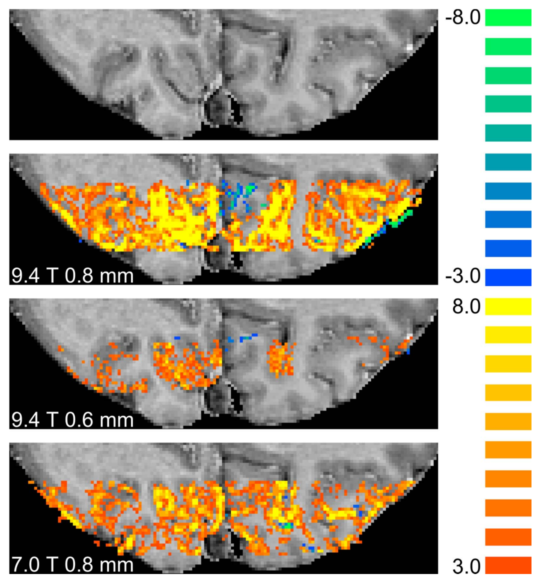

Fig. 2: Measured functional activation patterns superimposed on transversal anatomical reference slice ($p < 0.003$, uncorr.)

Results. All measurements could be performed well within the regulatory local and global SAR limits (max. 58 % local 6 min. average SAR). Fig. 1 displays transversal and coronal views of representative single acquisitions. Robust T2 weighted fMRI responses could be measured at both spatial resolutions. In Fig. 2, functional activation patterns of the different acquisitions are superimposed on an anatomical reference (t-values). The 9.4 T 0.8 mm resolution acquisition yields the most robust activation patterns. Fig. 3 displays histograms of fMRI (BOLD) signal changes of gray matter areas significant in all acquisitions ($t > 2.0$, $p < 0.05$ uncorr.) and histograms of temporal SNR of mutually covered brain areas (calculated from residuals from task GLM, no motion correction applied).

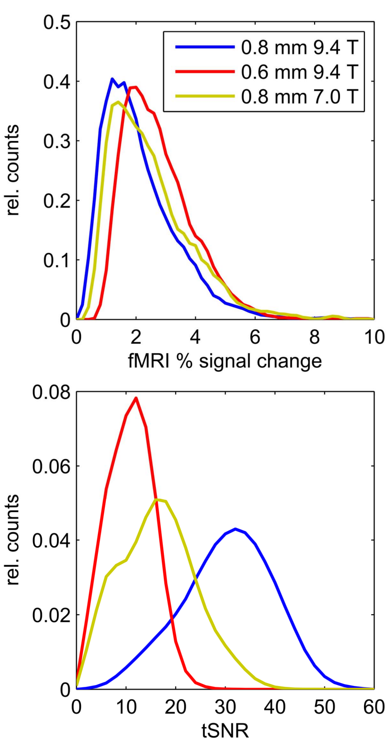

Fig. 3: Histograms of fMRI signal changes (top) and tSNR (bottom)

Discussion. The more robust activation patterns observed at 9.4 T with the 0.8 mm resolution seem not to stem from stronger signal changes but image SNR (Fig. 3).[3] In addition to the static field difference, inter-run variability and the different RF coils may affect the SNR. Slightly higher BOLD signal changes are expected at 9.4 T compared to 7 T[4], however, this effect could be over-compensated by reduced T2* contrast contribution at 9.4 T due to shorter in-plane readouts by the use of the head-gradient coil. Averaging across multiple runs is advisatory for more robust functional activation patterns at 0.6 mm resolution.

Conclusion. High-resolution T2 weighted fMRI at 9.4 T employing the zoomed 3D-GRASE sequence is feasible in conjunction with B1+ efficient surface coils. A static, non-subject-specific B1+ shim yields sufficiently strong and homogeneous B1+ fields for reduced-FoV imaging in visual areas.

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