Investigating activation dependence on cortical depth and TE using 2D FLASH

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Introduction: The increased SNR and BOLD contrast available at ultra-high field has been shown potentially to allow the detection of layer specific activity in functional studies (1-3). Spin echo (SE) imaging has been suggested as the method of choice for these measurements since the extra-vascular effects of pial veins in gradient echo (GE) data can corrupt the laminar profiles. However, SE BOLD provides a relatively low contrast to noise ratio (CNR) compared to GE-BOLD contrast. Recently it has been shown that, by using 3D FLASH to minimize distortion and blurring, GE BOLD layer specific activation can be detected (4). Here, we examine the cortical depth-related GE BOLD signal change in primary visual cortex (V1) using a very high resolution (0.35 mm in-plane) 2D FLASH sequence. In particular, we assess the strength and echo time dependence of the GE BOLD contrast as a function of cortical depth.

Methods: Scanning was performed on five subjects on a Philips 7 T Achieva scanner using a 16-channel receiver coil. Functional data sets consisted of 4 slices aligned perpendicular to the calcarine sulcus (resolution: 0.35x0.35x1.5mm^3) acquired using a flow-compensated 2D FLASH sequence. Imaging parameters were FOV:140x96mm^2 (RLxFH), SENSE factor 2 (RL), FA=32°, TR=161 ms, acquisition time per volume: 32.7 s. The functional paradigm was a block design consisting of 4 cycles of 131 s viewing of a flashing checker board alternating with 131 s of viewing a grey background. Functional scans (17 min 26 sec) were acquired at three different echo times (TE): 15, 20 and 30 ms, with a fixed bandwidth/ pixel of 16 Hz.

Data Analysis: Data were motion corrected using AFNI (http://afni.nimh.nih.gov/afni) T_2* maps were created by voxel-wise fitting to the signal decay across the data acquired at the three TE's. Anatomical ROIs were defined as bands in areas of the calcarine cortex where the stria of Gennari was visible. Five bands were drawn across the thickness of the cortical grey matter approximately parallel to the stria of Gennari (Figure 1B). Bands 1 and 5 were positioned adjacent to the WM and CSF respectively, and band 3 was located in the stria. The thickness of the bands was 1 to 2 voxels and each band contained 150-500 voxels. An additional ROI spanning adjacent surface veins was also formed. Each ROI was interrogated to determine the distribution of T_2* values and to form a time series showing signal changes at each TE. The percentage signal intensity change (ΔS/S) at each echo time was measured as (S_{ON}-S)/S, where S_{ON} and S are the average of the ON and OFF time points respectively. ΔR_2* was then calculated for each band assuming a linear relation between (ΔS/S) and TE. The percentage signal change as a fraction of the absolute signal in the OFF period extrapolated to TE=0 using the measured values of T_2^* was also calculated.

Results and Discussion: The high resolution T_2* maps allowed the stria of Gennari to be distinguished as a dark band within the cortical thickness in all subjects. Figure 1A shows representative data from one subject with the stria of Gennari indicated by the arrows in the zoomed image. A plot of the average fractional signal change (ΔS/S) across subjects versus echo time shows a linear relation for each of the cortical bands with the slope increasing from band 1 to band 5 (Figure 1C). Figure 2 shows the cortical depth-specific change in relaxation rate, ΔR_2*, calculated from the plots shown in Figure 1C. An increase in ΔR_2* is found through the cortical depth, being highest in the band adjacent to the pial surface and reducing to its lowest value in the band adjacent to white matter. In contrast to recently presented data (4), but in agreement with other studies (1-3), there is no evidence of an increase in GE BOLD contrast in band 3, corresponding to the stria of Gennari. The measured ΔR_2* value approaches the value of 1.5 ± 0.3 s^{-1} measured previously in a lower resolution study of visual cortex (5). The median of the R_2* distribution is also plotted in Fig. 2 for each band; a significant increase in R_2* can be seen in band 3 with respect to adjacent bands, indicating that the reduced T_2* value (27±2 ms) in the stria of Gennari is well resolved at the 0.35 mm in-plane resolution used here. Figure 3 shows the variation with echo time of the average across subjects of the absolute signal change on activation as a percentage of the signal extrapolated to TE =0 for each band and for the venous ROI. It shows that the absolute signal change on activation also increases across the cortical thickness moving from band 1 to 5.

Conclusion: High resolution 2D FLASH imaging has allowed assessment of the variation of GE BOLD contrast across the cortical thickness, with the results indicating a monotonic increase in contrast on moving from the WM boundary to the pial surface.

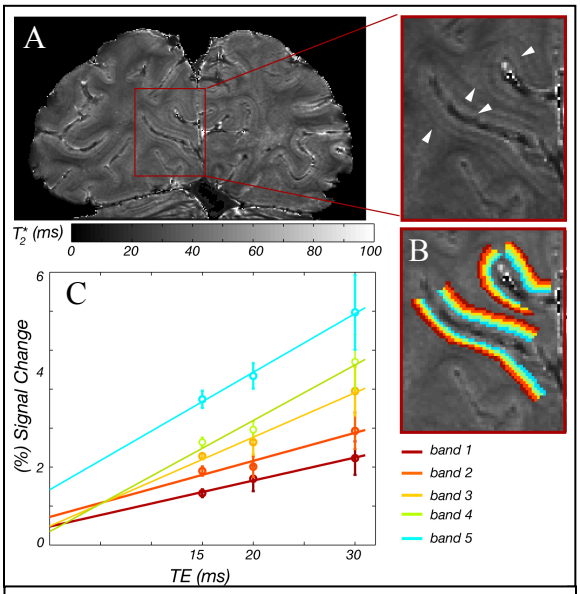

Figure 1: T_2* map, zoomed image and cortical bands overlaid onto image for one subject. Linear regression of ΔS/S versus TE for data averaged across subjects for each band. Error bars represent the standard error across subjects.

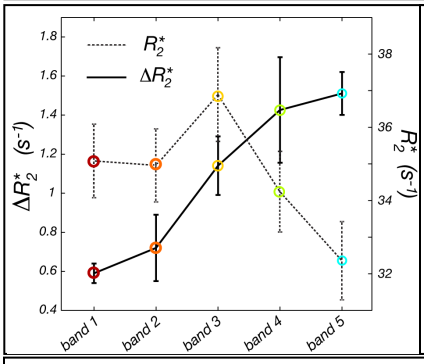

Figure 2: R_2* values (dashed line) and ΔR_2* (solid line) for each cortical band. Band 1 corresponds to the margin of white matter and band 5 to the pial surface. Error bars: sterr across subjects.

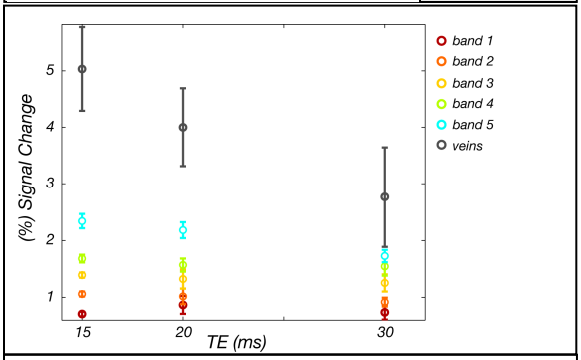

Figure 3: Signal change ΔS as a percentage of the absolute signal at TE=0 for each band and veins. Error bars: standard error across subjects.

References: (1) Goense et al., MRI: 381-92, 2006, (2) Harel et al., 2007, Neuroimage: 879-87, 2006, (3) Zaho et al., Neuroimage: 1149-60 2006. (4) Koopmans et al., Proc ISMRM:1558, 2008. (5) Yacoub et al, MRM: 588-94, 2001.