Laminar analysis of the BOLD effect in human visual cortex: effect of extracortical veins

P. J. Koopmans[1], M. Barth[1], and D. G. Norris[1]

[1]FC Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands

Introduction:

Neurons and their connections in the neocortex are organized in cortical laminae. The measurement of fMR signals with laminar resolution might thus provide important insight into neural computation. We performed high resolution GE BOLD fMRI to assess the laminar signal change profile. In order to obtain the signal with high accuracy we used a flow compensated 3D FLASH sequence with minimal geometric distortions. This allows for an excellent coregistration to anatomical data which is vital when analyzing the data in a laminar perspective. Extracortical veins were easily identifiable in the functional images and because they are thought to significantly influence the activation profiles [1-4], these profiles were computed before and after removal of the voxels located in these veins.

Data acquisition:

Three subjects were scanned using a flow compensated 3D Gradient Echo sequence as used in susceptibility weighted imaging. (0.75x0.75x0.75mm., 40 slices, matrix size 192x144, 4 volumes of rest, 4 volumes with subjects looking at a checkerboard flickering at 4 Hz., Tacq. ~16 min.) The acquisition time per volume is relatively long compared to conventional EPI but this technique does not suffer from geometric distortions. An MPRAGE was acquired at the same resolution for brain tissue segmentation after coregistration.

Analysis:

Realignment of the functional data and coregistration of the MPRAGE was performed with the utmost care using weighting volumes (which required the SPM coregistration algorithm to be adapted). The required transformations were calculated with high convergence criteria and by using a multiscale approach down to a scale of 0.5 mm. Vessel enhancing diffusion filtering [5-6] was applied to the average rest-volume of the functional set (fig. 1) to obtain a venous mask: occasional misclassifications were corrected manually. For each subject, an activated sulcus was located in the visual area and this sulcus was manually segmented into WM/GM/CSF using the MPRAGE data. For each GM voxel, the relative laminar position was calculated, varying from 0% for voxels at the WM-GM interface to 100% for voxels at the GM-CSF interface. We show curves averaged over voxels surviving t-value thresholds of $-\infty$, 0 and 1. Curves of the relative signal change were generated using a moving window averaging approach: the window width was $1/6^{th}$ of the cortical thickness and was moved with increments of $1/12^{th}$. For each subject the relative signal change curve was calculated. Figure 2 shows the curves averaged over subjects with and without vein removal. Figure 3 shows the difference of the curves in figure 2.

Results:

We find that the laminar GE BOLD profiles are flat in the deeper cortical layers (fig. 2). When approaching the GM-CSF boundary, the relative signal change increases by factors of 4, 2 and 1.6 for the increasing thresholds respectively. Vein removal clearly flattened the curves near the surface (relative laminar position >70% ; fig. 3).

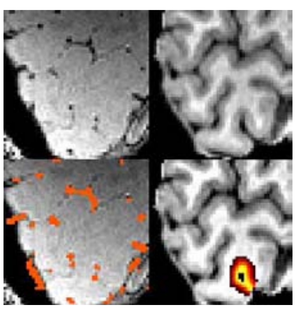

Fig 1. Top: the average functional rest volume (not suffering from image distortions as seen in EPI) and the coregistered, skull stripped MPRAGE. Bottom: the overlaid vein mask and the relative laminar positions of the voxels. (Note that only the occipital region of a single hemisphere is shown here)

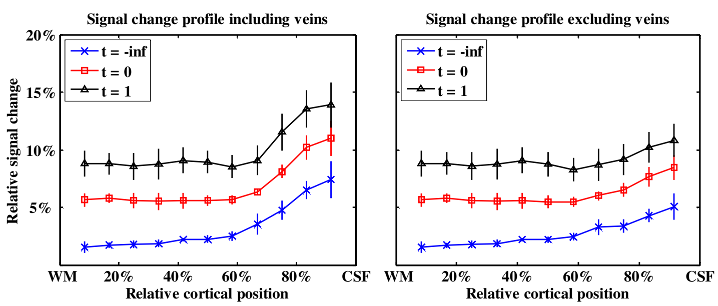

Fig 2. Left: The laminar profile of the relative signal change for different t-value thresholds without removing venous voxels. Error bars denote standard error of the mean. Right: The same curves calculated after removing voxels belonging to extracortical veins.

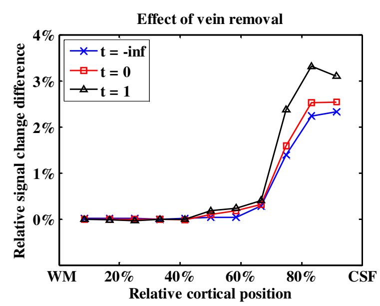

Fig 3. Effect of removing veins on the relative signal change. For layers below approx. 70% of the cortical thickness, it has little effect. Closer to the surface however, a large difference can be seen.

Discussion:

In a cat study where the partial volume effect seems negligible [1], the GE BOLD laminar profiles are very similar to the ones found here. Other studies [2-4] report profiles that were not flat in the deeper layers. We postulate that this might be caused by partial volume effects and/or EPI distortion that reduce the accuracy of the coregistration of the tissue classification. Extracortical vein removal clearly flattened the curves near the cortical surface. This confirms that the increase in the GE BOLD signal change near the cortical surface is largely caused by draining veins and that it does not reflect a local increase in neuronal activation. Extracortical vein removal has negligible effect on the curves at relative laminar positions below 70% and laminar activation profiles are flat there. This suggests that this GE technique could be used to detect layer specific activation in the deeper cortical regions provided a differential paradigm is used.

References and Acknowledgements:

[1] Zhao, Kim, Cortical layer-dependent BOLD and CBV responses measured by spin-echo and gradient-echo fMRI: Insights into hemodynamic regulation, NI 2006
[2] Goense, Logothetis, Laminar specificity in monkey V1 using high-resolution SE-fMRI, MRM 2006
[3] Harel, Yacoub, Combined imaging-histological study of cortical laminar specificity of fMRI signals, NI 2006
[4] Ress, Wandell, Laminar profiles of functional activity in the human brain, NI 2006
[5] Manniesing, Niessen, Vessel enhancing diffusion: A scale space representation of vessel structures, Med. Image Anal. 2006
[6] Koopmans, Barth, Vein segmentation from 3D high resolution MR venograms by using vessel enhancing diffusion, ESMRMB 2006

This work was supported by NWO grant ALW2PJ/04064 and FWF grant J2439-B02