Distinguishing pial and laminar gradient-echo BOLD signals at 7 Tesla

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Introduction

With high field scanners and multi-channel coil arrays becoming more readily available, high resolution fMRI methods may be capable of detecting neural responses at the laminar level. First results in animals indicate that gradient-echo (GE) is not able to depict laminar activation [1-4] and this has been attributed to the large BOLD contribution of the pial veins corrupting the laminar activation profiles. Spin-echo (SE) studies on the other hand have been able to depict layer specific activation in animals [1-3]. At high field strengths (7T and above), the largest contribution to the SE-BOLD effect originates from the capillaries and hence SE is thought to be the method of choice for high resolution fMRI. In this study we show that GE is capable of depicting laminar activation when using a sequence with a high resolution and a high degree of anatomical trueness (i.e. no distortion). When these conditions are met, veins can be separated from the laminar response based upon their position alone and one can benefit from the superior sensitivity and reduced SAR of the GE method.

Methods

Five subjects were scanned after informed consent was given according to the guidelines of the local ethics committee. Functional scans were acquired on a 7 Tesla whole body scanner (Siemens Medical, Germany) with a 3D first order flow compensated FLASH sequence. To improve signal-to-noise near the region of interest (visual cortex) a custom 7 channel surface coil receive array (for details see: [5]) was inserted in a commercial 8 channel T/R headcoil (RAPID Biomedical, Germany). MR parameters were: voxel size 0.75x0.75x0.75 mm^3, matrix 256x256, 20 slices, TE 20 ms, TR 31 ms, FA 15°, BW 120 Hz/pixel, GRAPPA [6] was used for 4-fold acceleration. Visual stimulation consisted of a 7.5 Hz flashing checkerboard, a black screen was used as a rest condition. Both conditions included a color changing fixation cross to which subjects responded using a button box. 37 volumes (50s each) were acquired, 19 were in the rest condition. All experiments were accompanied by a T1-weighted MP-RAGE acquisition of 80 slices which had the same orientation, voxel size and FOV as the functional runs.

Results

Figure 1 shows an overview of the data from one of the subjects. In this subject, layer specific activation can even be seen in the activation map without averaging along the cortical band. The blue arrows in the mean rest image depict the stripe of Gennari. Figure 2 shows the average cortical activation profile of 5 regions of interest (taken from three subjects in whom the stripe of Gennari was visible).

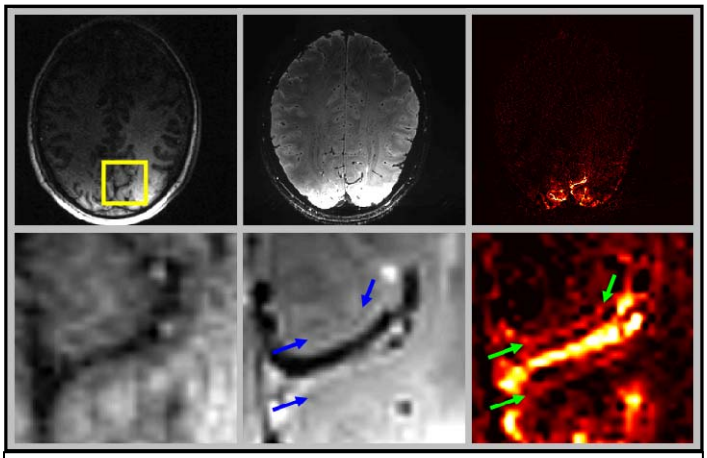

Figure 1. From left to right the MP-RAGE, the mean "rest" image and the activation maps are shown. Bottom images are zoomed sections of the region indicated by the yellow square using third-order sinc interpolation. The blue arrows show the stripe of Gennari, the green arrows show its activation.

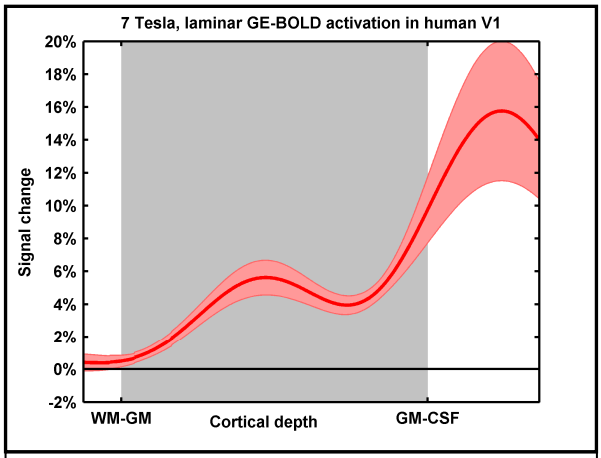

Figure 2. Signal change versus cortical depth. The gray shading depicts the approximate cortical thickness. The red shading depicts standard error of the mean.

Discussion

The results show that GE is capable of showing layer specific BOLD activation. As expected, a large signal change in the pial veins can be seen. It is however clearly separable from the layer specific increase in the stripe of Gennari. The average signal change in the pial veins was 16%, in the stripe of Gennari this was 5.6%. At 3T these values were found to be 13% and 3.5% respectively [7]. This indicates that laminar studies could potentially benefit from high fields as the intracortical signal change increases relatively more than that of the pial vein. The reason why previous GE experiments failed to depict layer specific activation may be due to the fact that these studies all used fast imaging protocols (EPI, spirals) which are affected by distortion and blurring. If these effects are large enough, the dominant pial vein contribution will corrupt the profile hence the choice of our relatively slow sequence.

Conclusion

Detecting BOLD activation at the laminar level in humans is possible using a GE sequence. When properly taking care that distortions and blurring are kept to a minimum, the pial vein contribution is spatially separable from the intracortical BOLD response. This allows benefiting from both the low SAR and high sensitivity of the GE method which are superior to that of SE.

References

[1] Goense et al., MRI 2006; [2] Harel et al., Neuroimage 2006; [3] Zhao et al., Neuroimage 2006; [4] Smirnakis et al., JCBFM 2007; [5] Orzada et al., ISMRM 2009 (submitted); [6] Griswold et al., MRM 2002; [7] Koopmans et al. (submitted);

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