Laminar specificity of the SE-fMRI signal in monkey striate visual cortex

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Introduction

For functional MRI to be truly useful, the physiological origin of the measured signals needs to be thoroughly understood. To relate the fMRI signal to the neural events underlying it, it is necessary to achieve a spatial resolution and specificity that permits visualization of the functional units of the cortex, such as the cortical columns or laminae. Because the spatial resolution of GE-fMRI is limited, as it is determined by the density of intracortical veins, we used SE-fMRI, which is more strongly weighted towards the capillaries [1-3] to achieve highly specific BOLD responses. The SE-EPI is also sensitive to T_2^* due to the long EPI readout times [4,5], which confers sensitivity to the venous fraction, and potentially limits spatial resolution. By decreasing the length of the EPI acquisition window, we obtained highly specific functional activation, indicating a PSF of 0.5 mm or less. The SE-BOLD signal was predominantly located in layer IV, while the contribution of the surface vessels to the signal varied with EPI-acquisition window length.

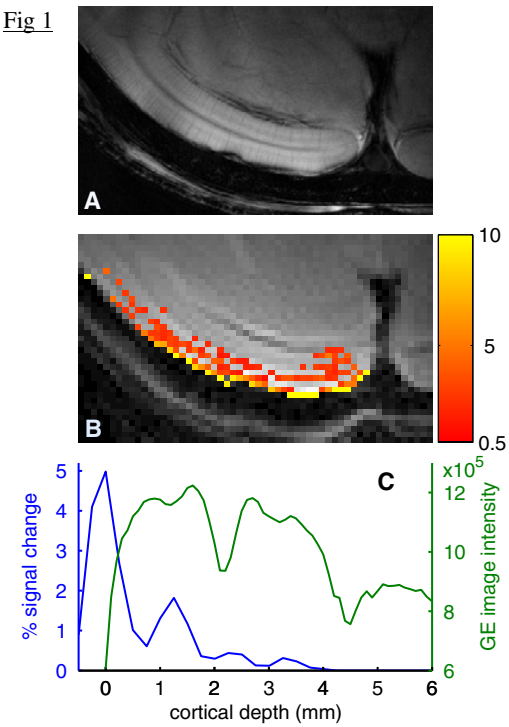
Methods

Experiments were performed in 7 healthy monkeys (*Macaca mulattta*), using an upright 4.7T scanner (Bruker BIOSPEC). The experimental setup and anesthesia were described previously [6,7]. Typical sequence parameters were: FOV 6.4x4.8 or 6.4x6.4 cm, slice thickness 2 mm; for SE-EPI, a matrix of 128 in the read direction, 96-192 in phase and 4-16 segments, yielded a spatial resolution of 250-500 µm, and EPI readout windows of 8-40 ms. TE was 46 ms and TR 2 s. For GE-EPI a 128x128 matrix was used with 8 segments, TE = 20 ms, TR = 750 ms. For anatomical images a GE was used with matrix 512x384, yielding 100-125 µm resolution, TE = 20 ms, TR = 2000 ms. The visual stimulus was a full field rotating checkerboard presented to both eyes. All data analysis was performed in MatLab (the Mathworks).

Results

Figure 1a shows a high-resolution GE image (100x100 µm) of the striate cortex showing the layering of V1, with the Gennari line at ~1.2 mm depth, which marks layer IV. Small intracortical veins and draining veins on the surface are dark, due to susceptibility gradients near veins. The BOLD activation (% change) obtained using a 4-segment SE-EPI (500x500 µm) shows activity at the cortical surface and in layer IV (Fig 1b). The profile through the cortex for the anatomical image and functional map (c) shows activity located at the surface and coincident with the Gennari line. The effect of the EPI-readout window is shown in figure 2, where the profiles for GE- and SE-EPI with different acquisition window lengths are compared. The activity for GE-EPI is located at the cortical surface, but for SE-EPI, the activity at the surface decreases with decreasing readout window. The EPI acquisition window was 31 ms for the 4-segment SE-EPI and 8 ms for the 16-segment SE-EPI. For the 16-segment acquisition, activation is located only in layer IV, as can be seen in the % change map. The T_2^* of gray matter was 40-45 ms, this suggests that the optimal readout window length is about $0.5xT_2^*$ or less. For SE-EPI the regions of maximal correlation and percentage change are the same, but for GE the maximal CC is found in deeper layers than the maximum % change.

Fig 1



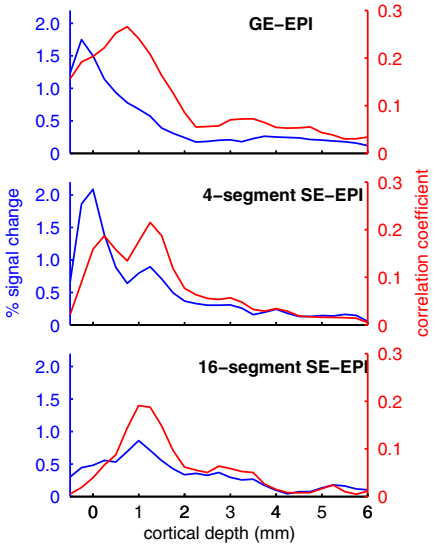
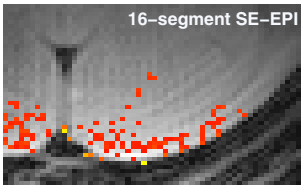


Fig 2



Conclusion

Highly specific BOLD signals can be reliably obtained using SE-fMRI, with a spatial resolution of less than 0.5 mm. Using a short EPI readout window minimized activation originating near the surface draining veins. Cortical layers could be clearly discriminated in the monkey visual cortex, with functional activation predominantly located in layer IV.

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References

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