Layer specific BOLD activation in human V1 at 3 Tesla

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Introduction

Detection of neural responses at the laminar level in humans would significantly increase the scope and power of fMRI. To date this goal has proven elusive. In this study we demonstrate for the first time layer specific activation in humans, specifically in layer IV of V1. On the basis of this result and known blood-vessel distribution within V1 we conclude that for examinations perpendicular to the cortical surface the intrinsic spatial resolution of the BOLD-fMRI signal is in the sub-millimeter range. Furthermore we show that in human V1 the intracortical BOLD response to simple visual checkerboard stimulation is dominated by that of layer IV.

Methods

Seven subjects were scanned after informed consent was given according to the guidelines of the local ethics committee. Functional scans were acquired on a 3T Siemens Magnetom Trio system with a 3D first order flow compensated FLASH sequence using a custom 8 channel occipital phased array coil [1]. Voxel size was 0.75x0.75x0.75 mm^3, matrix 256x256, 20 slices, TR 35 ms, FA 15°, BW 120 Hz/pixel, GRAPPA [2] was used for 4-fold acceleration. TE was 28 ms, chosen such that vein visibility was optimal [3,4]. 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. 33 volumes (1 minute each) were acquired, 17 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

The analysis procedure is shown for a single subject in fig 1. In six subjects the stripe of Gennari was visible in the average functional volume. In these subjects a ROI was defined surrounding the stripe and lines were drawn tangential to the cortical surface (fig 1b). These lines were copied to the neighboring (sagittal) slices. Within a slice, image intensity profiles along the lines were plotted next to each other effectively "unfolding" the cortex. Each column in fig 1c corresponds to a slice, showing from top to bottom the MP-RAGE, the average rest volume and the activation respectively. The slices were realigned and averaged to create a single image (fig 1d). Fig 2 shows the results of all subjects along with the cortical profiles. The signal change profiles shown in fig 2 of all subjects were normalized (in terms of cortical thickness) and averaged (fig 3). As not all subjects showed the stripe on both banks of the sulcus and because some banks were severely affected by the coil bias field and/or the RF slab profile, a single sided average profile was calculated after mirroring the right-hand side profiles of fig 2.

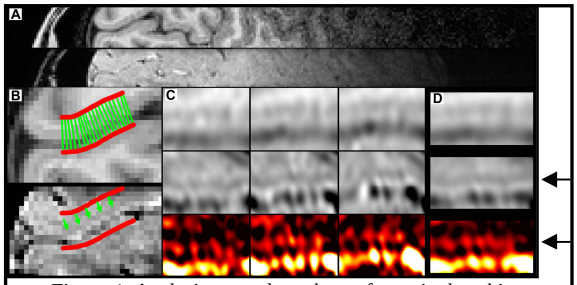

Figure 1. Analysis procedure shown for a single subject

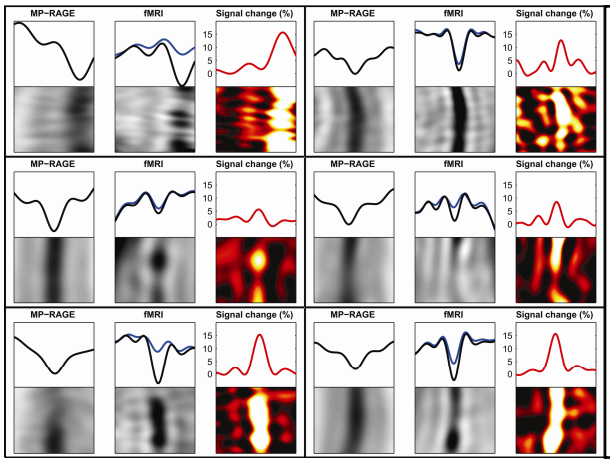

Figure 2. Each panel shows data from a single subject. The bottom row of each panel shows - from left to right - the coregistered MP-RAGE image, the mean functional rest volume, and the mean activation image. The top row shows the results of the bottom row projected along the cortical band resulting in laminar profiles. In the profiles of the functional scan, the blue line corresponds to the stimulated state, the black line to the rest condition. The activation is shown as a relative signal change with respect to the GM intensity averaged across the entire cortical thickness in order to avoid biasing the profiles towards regions that are darker in the rest image (e.g., the stripe of Gennari).

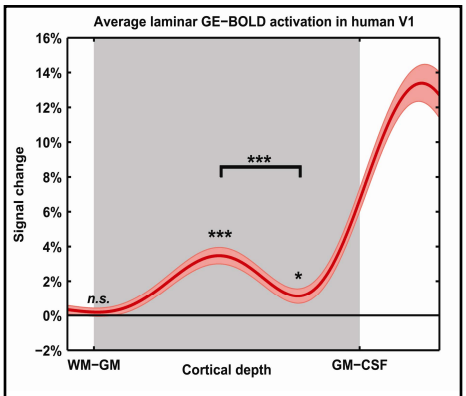

Figure 3. Average laminar activation profile. (*): p<0.05; (***): p<0.001

Discussion

The results show the well known signal increase in the superficial draining veins previously shown in animals [5-8] and humans [1,9]. However, the *intracortical* GE-BOLD response peaks in layer IV of human V1 in response to checkerboard stimulation. This corresponds very well to results found in monkeys using SE [5]. The FWHM of the peak is 0.8 mm which is impossible to explain in terms of the 3.9 mm GE-BOLD PSF reported in literature [10]. We think this is explained by the laminar organization of the intracortical vasculature. As shown in [11], capillaries and the smaller draining veins drain parallel to the surface before reaching bigger intracortical draining veins which drain outwards, perpendicular to the cortex. So although the *tangential* (classical) PSF may be in the order of the diameter of a vascular unit (0.75-4 mm [11,12]) or larger (due to pial veins), the *radial* PSF may be in the order of 100 µm (estimated from taking twice the mean capillary length [12]). On the basis of the results we conclude that the intrinsic spatial resolution of the GE-BOLD-fMRI signal is in the sub-millimeter range. Human laminar fMRI is a significant development which may improve our understanding of intracortical activation patterns and of the way in which different cortical regions interact.

References

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