Voxel-Wise Mapping of Optimal fMRI Voxel Volume.

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Introduction: To improve BOLD specificity it is desirable to obtain high spatial resolution functional maps. However, voxel size in fMRI should not be too small because of limited MRI signal to noise ratio (SNR). It is not useful to chose a voxel size that is too large either. Not only does this reduce specificity, but more significantly, there exist diminishing gains in temporal SNR (TSNR) as voxel size increases due to physiologic noise effects. This relationship has been characterized previously but has never been mapped (1,2). In this study, we clarify the definition of "optimum resolution" and construct voxel-wise maps illustrating its spatial non-uniformity. We define the optimum voxel volume (OVV) as the volume where the physiological noise contribution equals non-physiological (thermal+MRI scanner) system noise (Figure 1). TSNR is defined here as ratio of the average voxel time course signal over time course standard deviation. At the OVV as shown on Figure 1, as the voxel volume increase further, increases in SNR translate less and less into proportional increases in TSNR. If the voxel volume is reduced relative to the OVV, the SNR and TSNR are reduced in direct proportion.

Methods: Imaging hardware: 3T General Electric VH/3 MRI scanner (3T/90cm, whole body gradient inset 40mT/m, slew rate 150 T/m/s, whole body RF coil) equipped with home built 16 channel MRI digital receiver (3); standard T/R head coil and 16-channel receive-only array (4); single shot full k-space gradient echo EPI with matrix size 128x96. "Resting fMRI" experiments were performed on human subjects (n=3). Imaging parameters: Axial plane, 8 slices, FOV/slice 22cm/4mm, TR=3sec, TE=45ms, flip angles (90,70,45,20,1,0 degrees), number of volumes 70. For segmentation purpose the T1 maps were computed from ratio of the first EPI time course image (infinite TR, flip angle=90) over an average steady state image. To compute the optimal voxel volume maps we collect high-resolution (voxel volume 12mm^3) single shot EPI resting state fMRI runs as a function of flip angle. For each flip angle TSNR maps were calculated. Next on pixel-wise basis we fitted TSNR versus SNR data to physiological model equation introduced by Krueger et al. (1,2) to find the optimum TSNR/SNR (Figure 1). From the optimum SNR value and assumption that a MRI signal is proportional to a voxel volume, we computed the optimum fMRI voxel volume map.

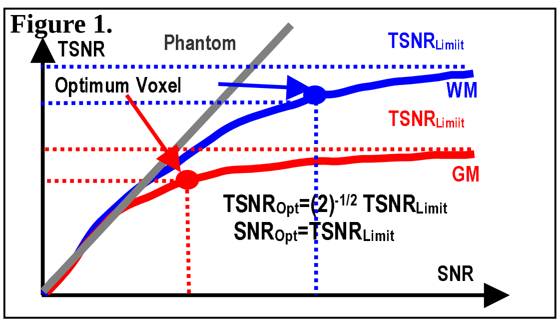


Figure 1.

Figure 3. OVV maps. Display range 0-24 mm^3.

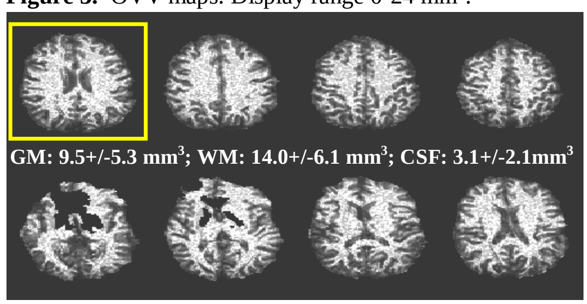


Figure 2. T1 map (a) and GM (b),WM (c),CSF masks (d).

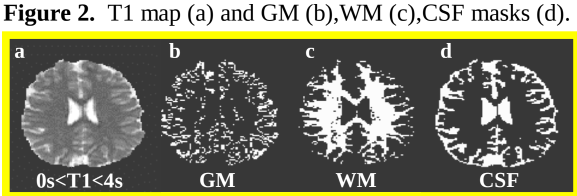
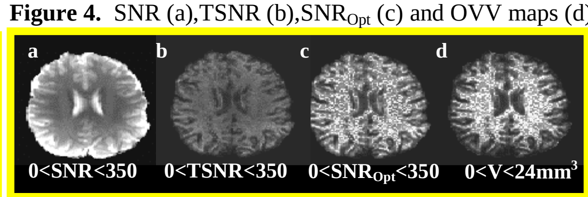


Figure 4. SNR (a),TSNR (b),SNR_{Opt} (c) and OVV maps (d).



Result and discussion: Figures 2-4 show a representative single subject data. Figure 2 shows a T1 map and different brain tissue mask obtained from image segmentation. Figure 3 shows OVV maps for all slices. Figure 4 shows a comparison for a single slice: SNR (a) and TSNR (b) maps both acquired with 90 degree flip angle, with optimum SNR_{Opt} (c) computed from corresponding OVV map (d). Group data from all 3 subjects, based on large number of voxels within tissue masks, provides the following mean cubical voxel size: GM (33789 voxels) 1.78+/-0.4 mm, WM (55262 voxels) 2.1+/-0.4 mm and CSF (26296 voxels) 1.36+/-0.31 mm. Specific values for OVV can be the function of various degrees of partial volume averaging of different tissue types. However interestingly (1.8mm)^3 cubical voxel for GM matches closely restraints from cerebral cortex anatomy (5) and corresponds well with experimental observation of Hyde et al (6).

Conclusion: The optimum voxel volume for BOLD imaging was defined as the voxel volume where physiological noise contribution equals to system plus thermal noise. We have computed the optimum voxel volume on pixel-wise basis at 3 Tesla. We have found that for GM, WM and CSF brain compartments the optimal cubical voxel volume is: (1.8mm)^3, (2.1mm)^3 and (1.4mm)^3 respectively. The optimum GM (1.8mm)^3 cubical voxel reflects cortex anatomy (5) and agrees well with previous experimental observation that was obtained under different criteria and definition for OVV (6).

References: (1)Krueger et al., Magn Reson Med 2001:45:595;(2)Krueger et al., Magn Reson Med 2001:46:631;(3) Bodurka et al. Magn Reson Med 2004:51:165;(4)de Zwart et al. Magn Reson Med 2004:51:22.;(5) Duvernoy et al., Brain Res Bull 1981:7:519;(6)Hyde et al., Magn Reson Med 2001:46:114.