COLUMNAR ORGANIZATION OR NOISE? OPTIMIZATION AND VALIDATION OF FMRI AT THE RESOLUTION OF COLUMNS

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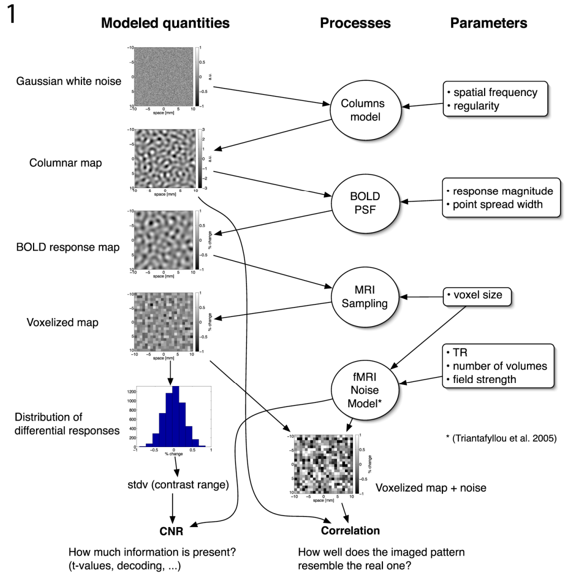
Introduction

With the advent of high-field fMRI it has become possible to image cortical columnar organizations. Resolving the true underlying columnar organization depends on several factors, e.g. the spatial scale of the columnar pattern, Blood Oxygenation Level Dependent (BOLD) point spread, voxel size and the noise level. It is not obvious which parameter values are optimal for obtaining functional maps and whether a certain voxel size is sufficiently small for resolving patterns of known and unknown columnar organizations. To better understand the role of each factor, and to guide the selection of optimal parameters, we developed a mathematical model of imaging cortical columns.

Methods

We quantified the expected differential functional contrast relative to noise and the expected similarity between the imaged pattern and the true neuronal columnar organization as a function of parameters of interest. Firstly, a generic isotropic pattern of cortical columns was modeled that allows varying the spatial frequency and degree of regularity (Rojer and Schwarz, 1990). Secondly, fMR imaging data acquisition of this simulated cortical map was modeled, while considering the hemodynamic point spread function, voxel size and the expected level of noise (Triantafyllou et al. 2005). In a third step, the data generated from the acquisition simulations were used to calculate (I) the differential functional contrast relative to noise, and (II) the correlation to the original neuronal response pattern. Measures (I) and (II) evaluated our capacity to detect cortical maps and the accuracy with which we reconstructed them, respectively. (Fig 1)

1



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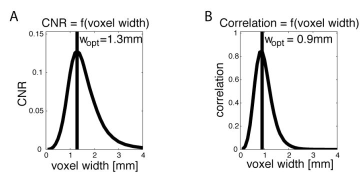

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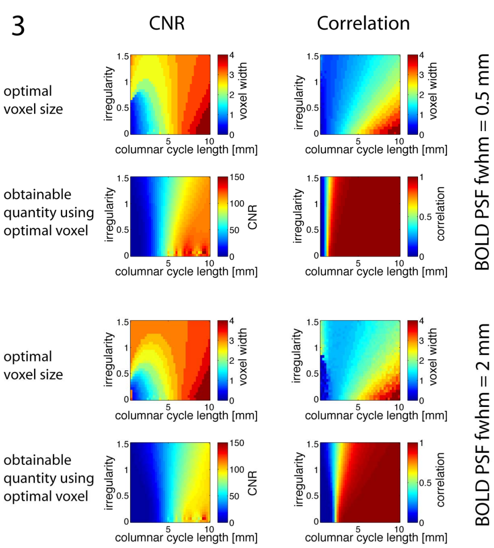

Results

We first investigated the interplay between functional contrast and noise while varying the voxel size. With increasing voxel width SNR increases while functional contrast decreases. The voxel width that optimizes differential contrast (Fig 2A) is larger than the one that optimizes accuracy of imaged pattern (Fig 2B). Both measures depend on the number of averaged volumes. However, only the voxel size that optimizes the accuracy of the imaged cortical pattern changes as a function of number of averaged volumes. In a second step we estimated how optimal voxel sizes for functional contrast (CNR) and accuracy (correlation) depend on the spatial organization of the pattern and the width of the BOLD point spread function (Fig 3). The results show that whether a columnar pattern can be imaged accurately depends mostly on whether the columns are large enough relative to the BOLD point-spread width. The functional contrast that can be obtained, on the other hand, depends more gradually on the spatial scale of the organization. For high irregularity and high spatial frequency large voxels can become optimal for obtaining CNR, relying only on low spatial frequency contributions that were not affected by the point spread. To address the question of resolvability of a columnar pattern we attempted to reconstruct the spatial frequency spectrum of the columnar pattern by applying the inverse MTF of the BOLD point spread to simulated data. When voxel size is adequate (Fig 4B), a peak in the spectrum is visible and the power falls off gradually in the range below the highest sampled MRI frequency. When voxel size is too large (Fig 4C), the spectrum is cut off abruptly due to the spatial frequency limit of MRI sampling. Assuming a unimodal spectrum and the knowledge of the point spread function this effect can be used to indicate whether the imaged pattern reflects the true pattern.

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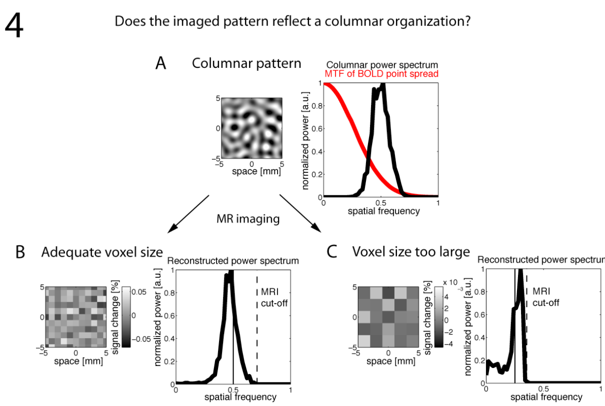

Conclusions

For a simulated columnar organization with a cycle length of 2 mm and a moderate degree of irregularity, and assuming a point spread width of 1mm of Spin-Echo fMRI at 7T, we found that 1.28 mm-wide voxels maximized functional contrast. The correlation to the pattern of the underlying neuronal columnar organization was maximized when using 0.9 mm-wide voxels. We further showed that assuming a unimodal spectrum and the knowledge of the point spread function, the power spectrum of the imaged pattern can be used to confirm that the observed pattern reflects the true columnar organization.

References

Triantafyllou, C., Hoge, R. D., Krueger, G., Wiggins, C. J., Potthast, A., Wiggins, G. C., & Wald, L. L. (2005). Neuroimage, 26(1)

Rojer, A., & Schwartz, E. (1990). Biological Cybernetics, 62(5)

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