The correlation of spatial resolution of fMRI with column structure in visual cortex

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1. Purpose
   The univariate analyses based on the GLM have been traditionally used for fMRI data analysis. Such approaches, however, cannot distinguish each brain states. Therefore, multivariate approaches are increasingly used by taking into account the full spatial pattern of brain activity. These approaches make it possible to predict brain state by classifying each brain responses.

Therefore, we aim to understand the decoding mechanism how the voxels encodes the brain activities. As one of this process, we simulated to find proper spatial resolution of fMRI by using the cortical columnar structures.

2. Methods
   2.1 Generate orientation column map
   The synthetic orientation map is generated by band-pass filtered white noise. Because the generated orientation map should have orientation selectivity, it is represented by complex function, and Laplacian of Gaussian function used as the band-pass filter. All possible orientations are mapped to the specified eight orientations ($0^\circ$, $22.5^\circ$, …, $157.5^\circ$).

   2.2 The intensity of BOLD signal
   Although there are several orientation columns in a voxel, each voxel has just one contrast of BOLD signal. Therefore, we defined the process through which the activated columns are encoded as intensity in a voxel. So, we represented them as proportion of density in a voxel.

   When one of eight orientation stimuli is presented to the eyes, the contiguous orientation columns related with the stimulated column are also activated by the stimulus. Hence, we assume that the adjacent columns related with the stimulated column are activated according to Gaussian distribution.

   Depending on Gaussian distribution, the intensity can be obtained by the sum of activated orientation columns with activity of neighboring columns.

   2.3 Decoding the orientation selectivity
   We assume that Field of View in which we are interested is $60 \times 60$ (mm). The simulation is implemented by increasing the voxel size in the same orientation map. The data contain white noises and jitter noises caused by head motion. The maximum jitter is 1mm.

   Using multi-voxel pattern analysis based on Support Vector Machine (SVM), the orientation-related information encoded in these spatial patterns can be classified, despite the lack of spatial resolution of fMRI.

3. Results
   The result obtained from the simulation shows that when the spatial resolution of fMRI decreases, the difference between the distributions of orientation columns increases, which, in turn, enhances decoding accuracy to classify the brain activity patterns in columnar level of visual cortex. The point beyond which the increasing rate of the accuracy slows down suggests the proper level of resolution for decoding the activity patterns. When the voxel size is decreasing consistently, it can investigate the cortical columnar structure of visual cortex. However, if the spatial resolution is getting better, the noise strongly affects the decoding performance.

4. Conclusion
   The orientation column in early visual cortex is arguably the most fundamental brain feature. Although fMRI has lack of resolution to demonstrate the structure of orientation column, it is possible to classify which orientation column is activated by stimulus.

   As one of the process to understand the brain decoding mechanism, the result of our simulation suggests the optimal point to decode the brain activity patterns and which spatial resolution is necessary to investigate the functional brain properties.