Analysis of Population Receptive Field Estimation Technique in Neuroimaging

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Abstract

We introduce novel analysis methods for designing fMRI experiments of population receptive field (pRF) estimation in human visual cortex using computational techniques.

The pRF estimation of visual cortex plays an important role in understanding and quantifying the visual system. The pRF estimates give single positions in the visual field that has the largest respond in the visual cortex (i.e., visual field map) in addition to neuronal population parameters such as receptive field sizes, laterality and surround suppression.

The pRF estimation method (using fMRI experiment) that is used for analysis is a linear spatio-temporal parametric (i.e., model-based) method that is shown to give more accurate visual field map and pRF sizes that agree well with EEG predictions in V1V3 compared to conventional non-parametric ways (Dumoulin & Wandell,2008). In addition, the model-based nature of the method allows for more meaningful interpretations which we have used this to our advantage to simulate this method with computational techniques.

This simulation approach to analysis of the pRF estimation method allows us evaluate the precision of the method under different conditions and assumptions. For example, using this method, we can find the optimal stimulus parameters in order to get the maximal signal to noise ratio which results in more accurate estimates. In addition, the various pRF method's assumptions could be put to test using this analysis technique which is one of the main focus of the study.

In particular, the pRF estimation method assumes a linear temporal model of fMRI which means that the underlying Hemodynamic Response Function (HRF) is a linear function of neuronal activity with a given impulse response. Although this assumption is shown to hold in most areas of the visual cortex, there might be some nonlinearities. The question is whether the pRF estimation method is able to work with non-linear HRF models.

In order to simulate the BOLD response from the stimulus frames, we have first modeled the pRF sizes in V1 (Wandell, Dumoulin, & Brewer,2007) using a log-polar function. Then we continued to sample the visual field using a Multivariate Gaussian function and applied the HRF function to obtain a 30x30 grid where each pixel corresponds to fMRI BOLD signal of a voxel in the primary visual cortex.

Here we used our simulation technique using moving bar stimulus to test the performance of the pRF estimation method when the underlying HRF function is linear or non-linear (double Gamma function for impulse response and Friston HRF for non-linear HRF). We have simulated four different possible cases when the underlying HRF is linear or non-linear and when the assumed HRF is linear or non-linear.

From the simulation results we have observed that the orders of cases in increasing average predictions errors are; linear/linear, non-linear/non-linear, linear/non-linear and non-linear/linear. Also, we observed that there is a systematic error for pRF size estimations in the case of linear/non-linear because all the estimates were bigger than the true values.

From these observations, we concluded that this model-based pRF estimation method does not work as well with non-linear HRF models because the pRF estimation method when assumed a non-linear model gives highly biased estimates of pRF sizes. Furthermore, the pRF estimation method with a linear HRF model fails to give accurate visual mapping and pRF size estimates when the underlying Hemodynamic response is non-linear.

We have shown that using computational analysis methods to test model-based method of pRF estimates can give valuable insight regarding the limitations and optimal conditions of the method which could be used to design better experiment stimulus and validate our assumptions.

References

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