Inferring Brain Activation from Spatial Modulations of fMRI BOLD Distribution

Bernard Ng[1], Rafeef Abugharbieh[1], Jean Baptiste Poline[2], Bertrand Thirion[2]
[1]Biomedical Signal and Image Computing Lab, UBC, Canada
[2]Parietal Team, INRIA Saclay, France

Introduction

The standard approach for analyzing functional magnetic resonance imaging (fMRI) data compares each brain voxel independently against an expected response to estimate the likelihood of activation [1]. The inherent spatial structure of brain activity is thus ignored. Recent studies that jointly analyze all brain voxels using pattern classification techniques suggested that task discriminant information may also be encoded by the spatial patterns of the blood oxygen dependent level (BOLD) volume [6]. To exploit such properties of brain activity, we previously proposed quantifying the regional spatial modulations of the BOLD distribution using invariant spatial descriptors to infer brain activation [3]. Our reported results were preliminary and limited to a small dataset collected during a motor experiment. In this work, we extensively explore and study the presence of such regional spatial modulations across a cohort of 65 subjects undergoing 10 experimental conditions.

Methods

fMRI data were collected from 65 normal subjects. Each subject performed 10 language, computation, and sensorimotor processing tasks [7]. Standard preprocessing, including slice timing correction, motion correction, temporal detrending, and spatial normalization, were performed using SPM8 [2]. Regions of interest (ROIs) were extracted using the AAL atlas [9]. To characterize the spatial patterns within ROIs, we employed one of our previously-proposed spatial descriptors, J_1, that measures the spatial extent of the regional BOLD distributions [3,4]. The overall analysis pipeline is summarized in Fig. 1.

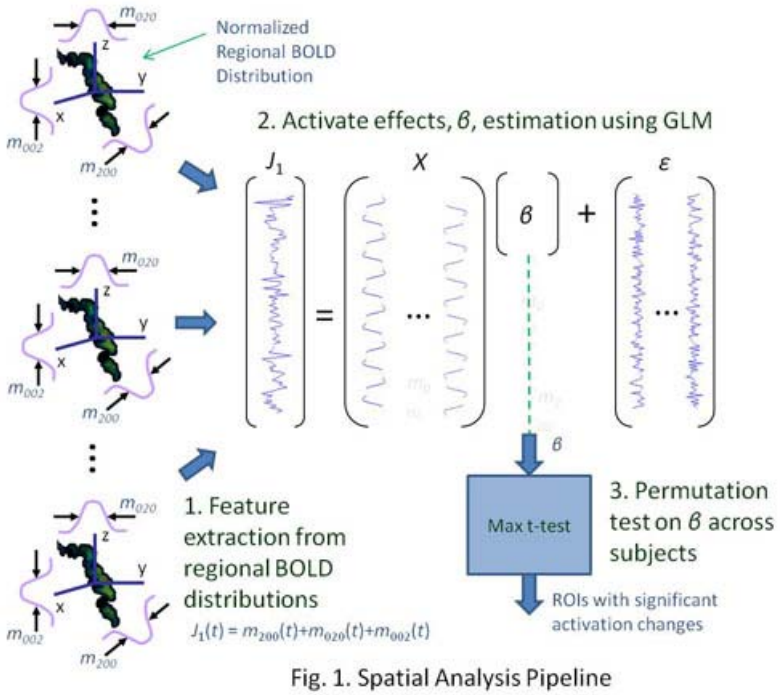

Fig. 1. Spatial Analysis Pipeline

First, the BOLD distribution within each ROI was normalized such that, at each time point, the intensity of the voxels is non-negative and sums to one. This step decouples amplitude changes from spatial changes. J_1 was then computed at each time point to generate a spatial feature time course. A general linear model [1] was employed to estimate the activation effects. To identify ROIs with significant activation changes, a non-parametric permutation test was used [5]. Statistical significance was defined at an experiment-wise error rate of 0.05. For comparison, the same analysis was performed using mean intensity within parcels as feature time courses. We employed parcel-level analysis since the mean intensity over the large AAL ROIs might be too coarse a measure for representing the ROI response. Parcels were functionally defined [8] based on resting-state data of the subjects.

Results

20 contrasts between the 10 experimental conditions were examined. Contrasts included auditory vs. visual task, language vs. computation task among others. Fig. 2 shows the percentage of AAL ROIs detected with significant activation differences using J_1.

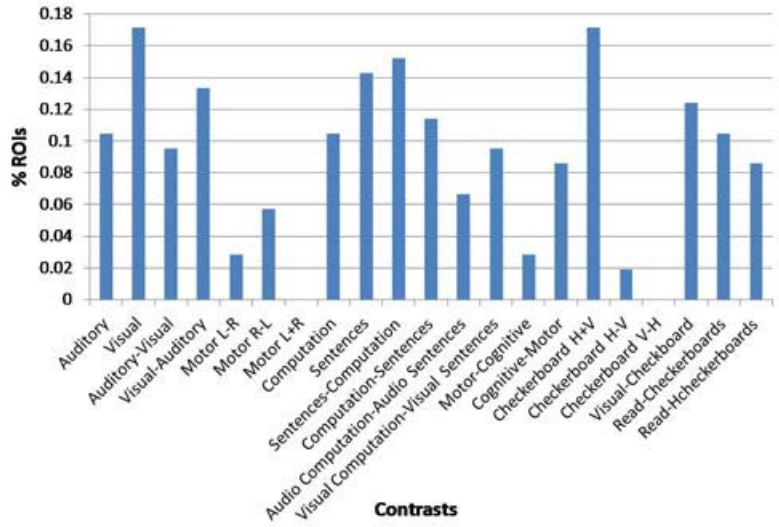

Fig. 2. Percentage of ROIs detected with significant activation differences using J_1. L = left, R = right, H = horizontal, V = vertical. Significant activation differences were detected for almost all contrasts examined.

On average, significant activation differences were found in 9% of the AAL ROIs across contrasts. Thus, task-related spatial modulations of the BOLD distribution appeared to be present for various tasks, and not specific to only motor tasks. Also, a moderate number of ROIs detected with J_1 were different from those found using mean intensity, as shown in Figs. 3 and 4. This observation suggests that spatial characterization of the regional BOLD response can potentially play a complementary role to traditional intensity-based analysis.

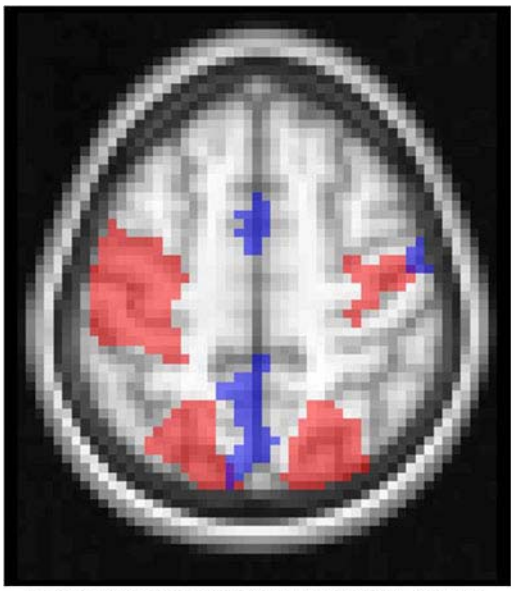

Fig. 3. Contrast map of auditory vs. visual task. Red area detected by J_1. Blue area detected by mean intensity.

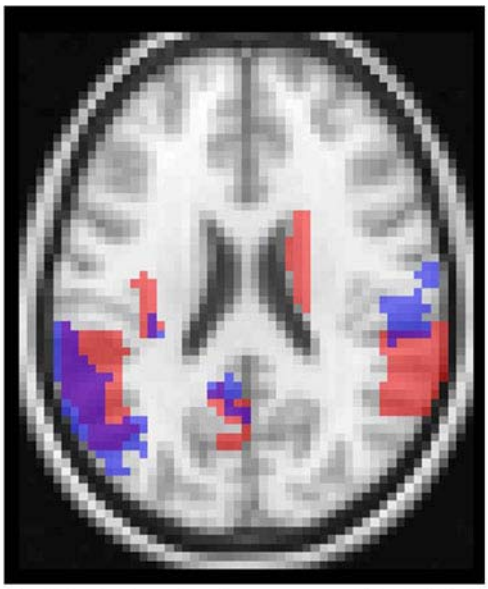

Fig. 4. Contrast map of sentence vs. computation task. Red area detected by J_1. Blue area detected by mean intensity.

Conclusions

In this study, we showed that task-related spatial modulations of the regional BOLD response are generally present in a wide range of tasks. Also, some of the ROIs found with significant activation differences with our proposed spatial feature were undetected with mean intensity. Analyzing the BOLD distribution from a spatial perspective using our approach might thus elucidate brain properties that are neglected by examining intensity modulations alone. Inferring brain activation from the spatial modulations of regional BOLD response hence appears to be a promising direction to explore.

References

[1] Friston, K.J. (1995), 'Statistical Parametric Maps in Functional Imaging: A General Linear Approach', Human Brain Mapping, vol. 2, pp. 189-210.

[2] http://www.fil.ion.ucl.ac.uk/spm/

[3] Ng, B. (2007), 'Characterizing Task-Related Temporal Dynamics of Spatial Activation Distributions in fMRI BOLD Signals', in Proc. Medical Image Computing and Computer Assisted Intervention, LNCS 4791, pp. 767-774.

[4] Ng, B. (2009), 'Spatial Characterization of fMRI Activation Maps Using Invariant 3D Moment Descriptors', IEEE Transaction on Medical Imaging, vol. 28, pp. 261-268.

[5] Nichols, T. (2002), 'Nonparametric Permutation Tests for Functional Neuroimaging: A Primer with Examples', Human Brain Mapping, vol. 15, pp. 1-25.

[6] Norman, K.A. (2006), 'Beyond Mindreading: Multi-voxel Pattern Analysis of fMRI Data' Trends in Cognitive Sciences, vol. 10, pp. 424-430.

[7] Pinel, P. (2007), 'Fast Reproducible Identification and Large-scale Databasing of Individual Functional Cognitive Networks', BioMed Central Neuroscience, vol. 8, p. 91.

[8] Thirion, B. (2006), 'Dealing with the Shortcomings of Spatial Normalization: Multi-subject Parcellation of fMRI Datasets', Human Brain Mapping, vol. 27, pp. 678-693.

[9] Tzourio-Mazoyer, N. (2002), 'Automated Anatomical Labeling of Activations in SPM using a Macroscopic Anatomical Parcellation of the MNI MRI Single Subject Brain', NeuroImage, vol. 15, pp. 273-289.