ITERATIVE SEGMENTATION OPTIMIZATION FOR MODEL-BASED DETECTION OF FMRI ACTIVATION

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Introduction

Analysis of functional magnetic resonance imaging (fMRI) data has been performed using both model-driven (parametric) methods and data-driven methods. An advantage of model-driven methods is incorporation of prior knowledge of spatial and temporal properties of the hemodynamic response (HDR). A procedure has been developed that uses an iterative segmentation-based optimization algorithm to group voxels into clusters based on estimations of HDR model parameters. This approach results in enhancement of both selectivity and sensitivity over conventional fMRI analysis procedures.

Methods

Human data: Experiments were conducted at the Indiana University School of Medicine (Indianapolis, IN) using a 1.5T GE Signa LX Horizon. A visual surface coil (Nova Medical, Inc., Wilmington, MA) was used to obtain 135 images of each of 10 slices (3.8mm thick), perpendicular to the Calcarine fissure. A spiral echo-planar imaging (EPI) sequence (TR/TE=1s/40ms; FOV=24cm^2; matrix= 64×64; flip angle=90^o) was used. Preprocessing of all data comprised rigid-body motion correction and 2nd order detrending. A flashing checkerboard was presented to the left or right visual hemifield in an alternating fashion. Two experiments (one blocked with 30s on/off cycle; one event-related with 1s stimulus duration and ISI=15s) were conducted on each of two subjects.

Synthetic data: Artificial images were generated as a uniform 96x96 image to which was added a noise matrix modeled by an autoregressive integrated moving average (ARIMA) process.[1] Nine 8x8 blocks of activation were created within the image, each containing slightly different additive "activation." Activations were generated to mimic the experiments conducted on human subjects. The time-averaged contrast-to-noise ratio (CNRavg; signal power divided by noise variance) was varied from 0.5-4.0.

Analysis procedure: An initial spatial segmentation of the fMRI data is generated through agglomerative clustering of voxels based on a weighted distance metric, which combines both time course similarity and physical distance. HDR parameters are fitted to each individual voxel and cluster (average signal over included voxels). By evaluating the reference waveforms of each voxel and its neighbor clusters, the best-fit cluster index is assigned to the voxel. Revision of the segmentation continues until the difference between successive segmentations falls below a threshold criterion (e.g., less than 1% reassignment) and the final segmentation is passed with the original data through a general linear model test to yield a statistical parametric map. The proposed algorithm (CLU) was compared to conventional fMRI analysis procedures: principal component analysis (PCA), independent component analysis[2] (ICA; preprocessed using the first 20 principal components), k-means clustering (KCL; k=100), and a standard univariate t-test (STD).

Results

Human data: Detected activation for the left hemifield event-related visual stimulation in Subjects 1 and 2 is presented in Figs 1a and b, respectively. Corresponding STD analysis of the block paradigm experiment are shown in Figs 1c and d.

Synthetic data: Receiver operating characteristics are shown (Fig 2) for blocked (left) and event-related (right) synthetic activations.

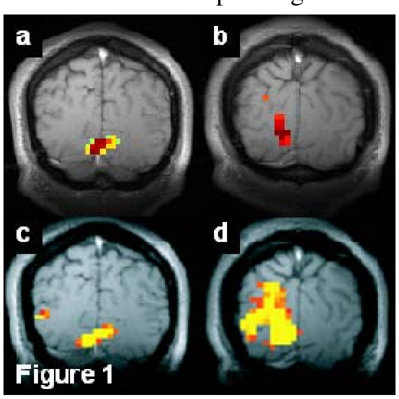

Figure 1

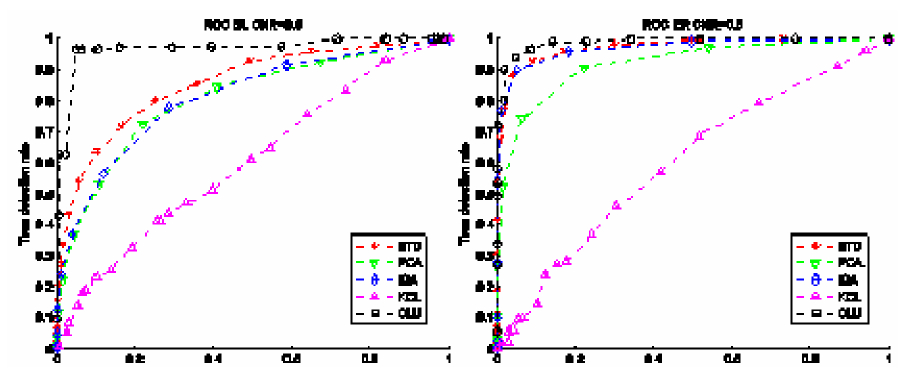

Figure 2

Discussion and Conclusion

In both subjects, event-related detections are consistent with the "gold standard" blocked analysis, which has more statistical detection power than conventional event-related analysis. From evaluation of synthetic data, the proposed procedure is shown to be more sensitive and selective than conventional methods in identification of active regions. The development of an analytical procedure that focuses on generating multi-voxel regions of interest and is based on properties of HDR models will enhance usefulness of fMRI in furthering our understanding of cortical activity under both normal and disordered conditions. Refinement of this new procedure is expected to reduce both false positive and negative rates, without resorting to filtering that can reduce the effective spatial resolution.

References

[1] Wei, WWS, *Time series analysis: univariate and multivariate methods, 2nd edition*, Pearson, Addison Wesley, Boston, 2006.

[2] http://www.sccn.ucsd.edu/fmrilab