Statistical Inference for Wavelet-denoised Statistical Parametric Maps

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Introduction

A new wavelet based hypothesis testing procedure for statistical parametric maps (SPM) is proposed. The current wavelet based methods [1] apply statistical testing in the wavelet domain wherein the coefficients are thresholded to achieve a specified false rate control. An inverse wavelet transform is then applied to the thresholded wavelet coefficients which results in smoothed SPMs. This necessitates another thresholding in the spatial domain to delineate activated regions from the non-activated regions. This choice of threshold is made arbitrarily and does not guarantee the required false positive rate. In this work, a method is proposed wherein a rejection region (threshold) is fixed and the false discovery rate (FDR) achieved for this threshold is estimated using various FDR estimation methods. This procedure is validated both on simulated and in-vivo fMRI data.

Materials and Methods

The statistical testing of SPMs requires corrections for multiple comparisons. This is achieved using methods based on measures such as family wise error (FWE) rate or FDRs. Recently, methods based on FDR have been gaining popularity owing to their superior power in statistical testing compared to methods based on FWE. The Benjamini-Hochberg (BH) step up approach [2] is one of the most popular methods used for testing SPMs. This method assumes the statistics at each voxel to be independent of each other or that they are related by a specific kind of correlation (the positive regression dependency). A different approach proposed by Yekutieli and Benjamini (YB) [3] is based on resampling and incorporates the correlation structure in the data. This is very important because the voxels in SPMs from neuroimaging data are inherently correlated and this correlation increases with wavelet denoising.

Statistical parametric maps generated by the SPM99 package were denoised using the wavelet Bayesian shrinkage method. In our proposed method, these denoised SPMs were thresholded using a fixed threshold and then the FDR control achieved at this threshold was estimated using the B-H and Y-B methods. This threshold was altered until the estimated FDR was below the required rate (0.05).

The YB method, which is based on resampling, requires samples from the null distribution of SPMs. These samples were generated using wavestrapping procedures [4]. Two hundred volumes of resampled data were produced based on one SPM that was generated using resting data. Each volume of this resampled data was then subjected to wavelet denoising. The proposed method was first validated on resting data. This data was generated when the subject was not performing any cognitive task. The SPM (consisting of t-scores) was generated using SPM99. A square activation region T-score of value 4 was then added at a known location. The method was then applied to an in-vivo fMRI dataset which was acquired using the same protocol as that of the resting data, but with the addition of a simple auditory detection task during task blocks.

Results

The left and right panels of figure (1) respectively show the estimated FDR versus threshold using the BH and YB FDR estimation methods for raw and denoised resting data SPMs. The figures also show the actual (act) FDR. From this figure, it can be inferred that both BH and YB performed well when the SPM was not denoised. However, when the SPM was wavelet denoised, the YB method performed better than the BH method. Although YB performs better than BH in the denoised case, the estimated FDRs are below the actual values at conventionally used FDR rates (i.e., 1% and 5% for neuroimaging). Therefore, a better bootstrapping method is required to improve the FDR estimates. Figure (2) shows the result of our proposed method when applied on in-vivo fMRI data. The top and bottom rows show the activation map obtained by applying the YB method on raw and denoised SPMs, respectively. In the case of the raw SPM, a threshold 60% of absolute maximum of the SPM gave about 5% FDR control (top row). In the case of the denoised SPM, a threshold of 25% resulted in an FDR of 7% and a threshold of 30% resulted in an FDR of 0.6% (bottom row).

Conclusions

An approach for thresholding wavelet-denoised SPMs is proposed. In the case where denoising was not applied, both BH and YB methods gave good estimates of FDR. For the case of wavelet denoised SPMs, the YB method performed better than the BH method.

References

1. Fadili, M et al. A comparative evaluation of wavelet-based methods for hypothesis testing of brain activation maps, NeuroImage, 2004, 23, pp.1112-1128.

2. Benjamini Y., Hochberg Y, 1995, Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing, Journal of the Royal Statistical Society, 57,1, 289-300

3. Yekutieli, D et al. Resampling based false discovery rate controlling multiple test procedures for correlated test statistics, Journal .of statistical planning and inference, 1999, pp.171-196.

4. Breakspear, M et al. Spatiotemporal wavelet resampling for functional neuroimaging data, Human Brain Mapping, 2004, 23, pp.1-25.

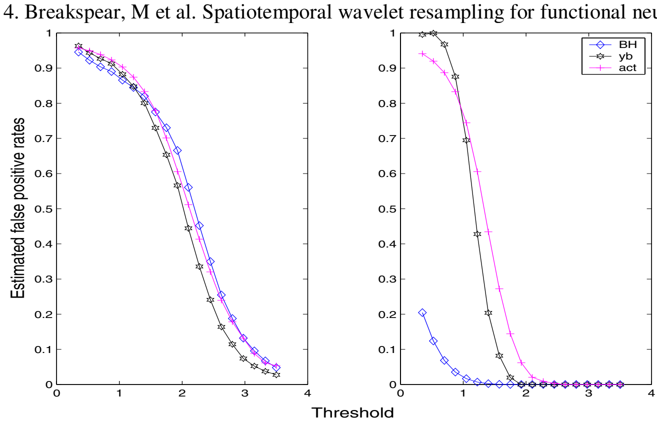

Figure 1. Estimated FDR versus threshold for raw SPM (left panel) and denoised SPM (right panel)

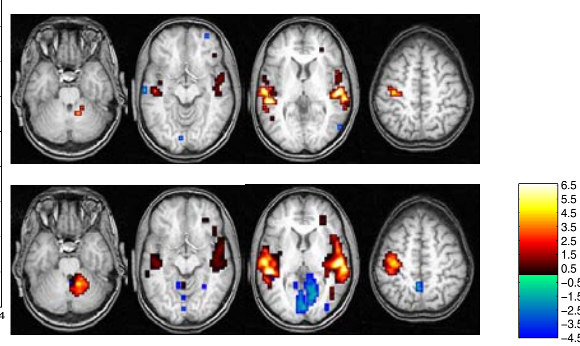

Figure 2. Activation maps for raw (top row) and denoised SPMs (bottom row).