Wavelet-based statistical analysis of fMRI activation images

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Objective

Analysis of an fMRI block-based visual stimulation paradigm was comparatively performed by wavelet analysis and statistical parametric mapping (SPM) [1] based on Gaussian Random Field Theory (RFT). The voxels were isotropic and the same general linear model (GLM) was employed in both SPM and the discrete wavelet transform (DWT) approach. Consequently, an equivalent spline degree for which the low-pass part of the wavelet analysis is basically equivalent to SPM was computed. The results for two biorthogonal transforms, *3D* fractional-spline wavelets and *2D+Z* fractional quincunx wavelets, are presented comparatively with spatial smoothing in SPM.

Methods

After the acquisition time correction, realignment, corregistration, and normalization of data, a spatial non-redundant DWT was computed. The fractional-spline wavelet transforms were implemented using the Fast Fourier Transform through an iterated filterbank [2] by means of two types of wavelet families: (*i*) the separable *3D* fractional-spline wavelets, and (*ii*) *2D +Z* quincunx wavelets [3]. The high frequency information was preserved in the wavelet subbands, contrarily to spatial smoothing with a Gaussian kernel in SPM. Then the GLM, which incorporates the effect of the hemodynamic response, was applied to the time series of each wavelet coefficient. The statistical coefficient map was obtained by a *t*-test in the wavelet domain. The activation pattern was spatially localized by the inverse DWT of the thresholded coefficient map and empirically compared with the activation images obtained by statistical inference in spatial domain.

Results

One healthy right-handed subject was selected for single-shot gradient-echo MR EPI scanning at 1.5 T magnetic field while performing a block-based visual task during *12* identical sessions of *228* s each. Acquisition and reconstruction matrices were $64\times64\times35$ with voxel size $3.8\text{mm}\times3.8\text{mm}\times3.75\text{mm}$. Sessions consisted of *80* volumes acquired at $TR=3$ s and the first *8* were discarded. A flashing checkerboard was presented in blocks of *24* s followed by *24* s of fixation, starting with activation. All data were subject to some data preprocessing: (*i*) acquisition time correction, (*ii*) realignment and (*iii*) coregistration in SPM. In both spatial and wavelet domain analysis, the same GLM was employed for time courses of spatial activation and wavelet coefficients modeling. DWT and processing in the wavelet domain were run within WSPM toolbox [4]. Finally, the statistical parametric maps were obtained by inference in the spatial domain using SPM. The statistical approach of the wavelet method with false detection rate (FDR) error correction for multiple testing lead to similar activation patterns as SPM based on RFT family wise error (FWE) control. For each subject, we identified a set of cortical regions activated during visual stimulation measured with the same statistical threshold. We found bilateral activation within a network of visual responsive regions, including the inferior occipital gyrus, fusiform gyrus, superior temporal sulcus, amygdala, inferior frontal gyrus, and orbitofrontal cortex.

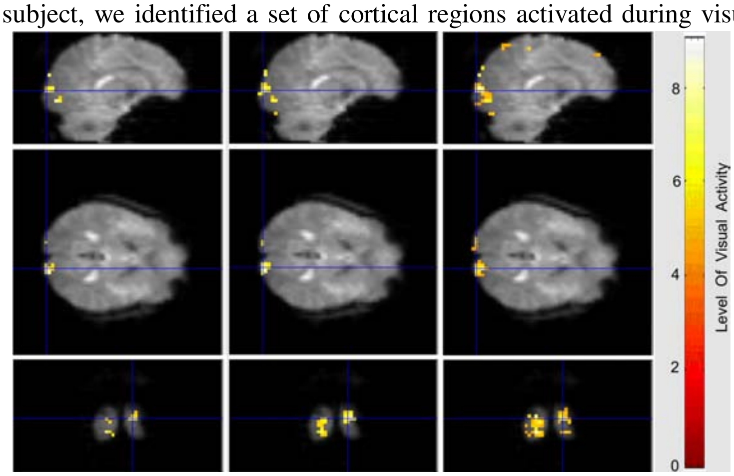

Fig. 1 – *Statistical analysis in spatial domain: no Gaussian smoothing (left), with Gaussian smoothing (mid), and in wavelet domain (right).*

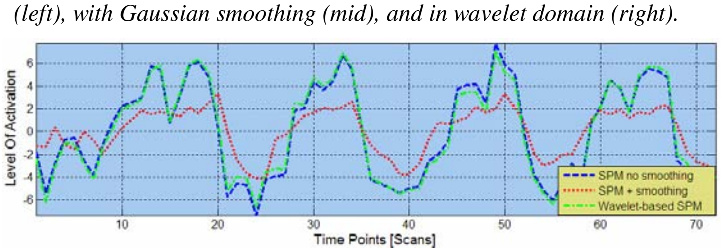

Fig. 2 – *Time courses of activation.*

Conclusion

Instead of controlling the chance of *false positives* (as Bonferroni), FDR controls the expected proportion of false positives (i.e., type I errors) among suprathreshold voxels (i.e., rejected null hypotheses). A rather *ad-hoc* threshold was required in the wavelet domain after reconstruction of the coefficient map in order to distinguish between activated and non-activated voxels. By mapping back in the spatial domain, the results were deployed of a precise statistical meaning. Yet the wavelet approach yielded activation maps of higher resolution when using the coefficients from the high-pass subband too. Wavelet-based methods for denoising brain activation maps offer a naturally multiresolution alternative to single scale Gaussian spatial smoothing as used in SPM.

References

[1] SPM2 software available at www.fil.ion.ucl.ac.uk/spm/;
[2] S. Mallat, *IEEE Trans. Pattern Anal. Mach Intell.*, 11:674-693, 1989; [3] D. Van De Ville *et al.*, *NeuroImage*, 23(4):1472-1485, 2004; [4] WSPM toolbox at http://bigwww.epfl.ch/wspm