Spatiotemporal Response Patterns in Sensory-Motor Cortex Using Surface-Based Smoothing of fMRI Data

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Introduction: Recently, a functional magnetic resonance imaging (fMRI) analysis approach involving surface-based (2D) smoothing of hand-segmented brain slices has been developed (see companion poster, Kilias et al.). Unlike traditional volume-based (3D) filtering, which uses euclidean distances to determine neighborship relations between voxels in the brain volume, the new method's smoothing algorithm determines geodesic distances to account for local brain topography and real distance relationships between points on a manually segmented cortical surface. Combined with image acquisition under high field strengths, yielding high-resolution surface data, this method permits functional data analysis of unprecedented accuracy.
Applying this new smoothing method to the human sensory-motor cortex, we investigated spatiotemporal hemodynamic responses following finger movements at different filter widths. A comparison between this new surface-based filtering and the volumetric filtering method was performed.

Methods: High-resolution fMRI data sets were obtained with 3 and 7 Tesla (T) scanners, letting six subjects perform simple visuomotor tasks that involved right index finger movement in response to visual stimuli at fixed intervals of 24 seconds. Superficial pre- and postcentral cortical voxel layers on both sides of the central sulcus, representing primary motor and sensory areas, were segmented manually and directly on the raw brain volume data. The marked voxel layers were then triangulated to obtain surface meshes, and geodesic distances between the voxels on the meshes were calculated.
Subsequently, for discrete time points out of a time window 7.5 seconds before to 22.5 seconds after movement onset, each surface voxel's BOLD (blood oxygen level dependent) responses were extracted out of the fMRI time series and spatial smoothing of the responses was performed. Gaussian smoothing kernels with filter widths from 2 mm to 16 mm full width to half maximum (FWHM) were applied, using the geodesic distances for computation. For comparison and as an alternative, the entire brain volume was conventionally (3D) smoothed using the SPM8 toolbox, and relevant volume-filtered responses were afterwards projected onto the segmented surfaces.
Surface activation maps of each subject's motor and sensory cortices were then generated, allowing in-depth visualization of spatiotemporal hemodynamic response patterns resulting from finger movement. These activation patterns along the cortical surface could be directly displayed and compared for defined time points.

Results: The 2D surface-based filtering approach yielded relatively high BOLD responses in sharply defined activation clusters at small (3-4 mm FWHM) filter widths. For instance, stripe-like patterns of activation could be distinguished perpendicular to the central sulcus in the surface maps of the contralateral motor cortex (see Figure 1). Generally speaking, responses were found to be more spatially restricted and stronger than those obtained by conventional volume-based analysis, which tended to produce more diffuse activation and lower responses even at relatively low filter widths (see Figure 2). At higher filter widths, 2D-filtered responses started to get fainter and more diffuse, but not to the same extent as 3D-filtered ones. Moreover, volume-based filtering led to the integration of BOLD responses from anatomically separated areas and false positive results, respectively. Activation clusters observed in the contralateral and ipsilateral sensory and motor cortices were found to be considerably influenced by hemodynamic responses of the sulcal veins and even cortical areas on the opposing side of the central sulcus. Due to the nature of the surface-based filtering, this effect was not present in the 2D-filtered results.

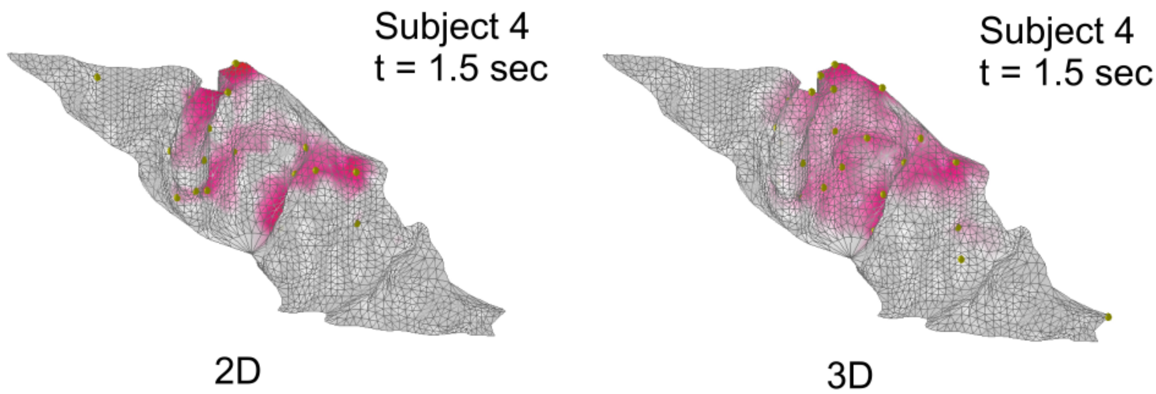

Figure 1: Activation in the contralateral motor cortex of subject 4 at 1.5 seconds after finger movement onset. Application of a surface-based (2D) filter of 4 mm FWHM (left) yields stronger responses and clearer activation boundaries as compared to a volume-based (3D) filter of the same size (right). Activation peaks are shown in yellow.

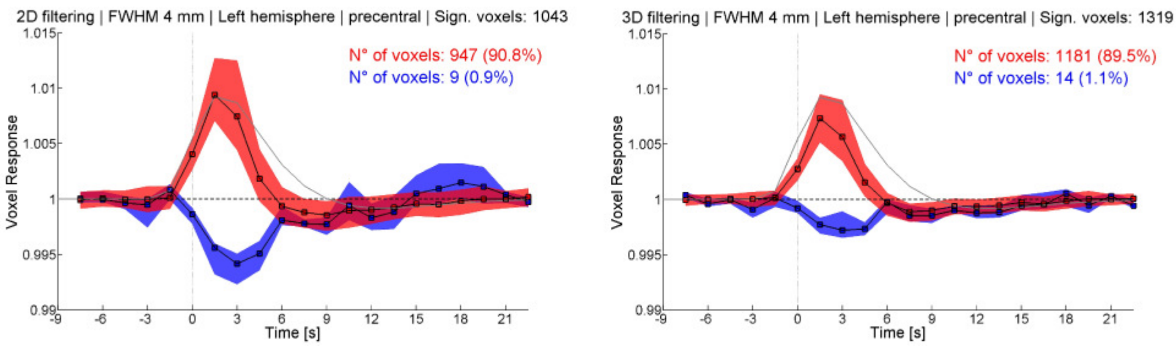

Figure 2: Median BOLD response time courses of motor cortex voxels exhibiting a significant positive (red) or negative (blue) response during a time window of 22.5 seconds after finger movement onset. Responses of 2D-filtered (left record) and 3D-filtered data (right record) are opposed. Lower and upper boundaries mark 25th and 75th percentiles, respectively.

Conclusions: Our results clearly state that an fMRI analysis based on our new segmentation and filtering approach is generally possible. Moreover, due to its superior accuracy in estimating the shape of the hemodynamic response and higher detection power it is clearly recommended. Regarding sensory-motor tasks, the new method's strengths can permit new insights in how different digits and movement types are represented spatially in the cortex. Furthermore, it allows the study of temporal activation patterns like the negative BOLD undershoot and the determination of its extent as a measure of square (cm^2).
Thus, due to the restrictions of traditional 3D filtering methods, which tend to ignore brain topography and thus impair the informative value of results, this technique is clearly to be favored and, in conjunction with high-resolution fMRI data, provides superior accuracy when interpreting fMRI results.

References:

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