Investigation of partial volume effects in fMRI using artificial 3D time series

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Introduction

When choosing spatial resolution for an fMRI experiment it is important to consider the effects of partial volume on functional activation. Although several studies regarding the impact of functional voxel dimensions on activation contrast and spatial localization exist, studies focusing specifically on partial volume effects (PVE) are sparse.

The purpose of this study is to investigate partial volume effects in fMRI and to simulate their impact on the resulting activation map.

Subjects and Methods

High-resolution (0.33^3 mm^3) cryosectional images of a representative female cadaver[1] were used as a basic anatomical map of the human brain. The images were segmented into white matter, gray matter and CSF-volumes by signal thresholding. The contrast in the images was altered to resemble EPI-contrast. The 3D-volume was copied in time into 48 rest and 48 active volumes creating an artificial fMRI time series. The activated state was created as a signal increase (2, 2.5, 3, 4, and 5 % respectively) of the gray matter in selected ellipsoid-shaped regions. Time series with different spatial resolutions were then generated by mean value sampling of the high-resolution images into coarser voxel resolutions (cubic). Adequate thermal[2] and temporal physiological[3] noise was added taking into account effects of the sampled voxel size. The artificial time series were analysed in SPM5 (Statistical Parametric Mapping[4]) at a threshold of $p<0.05$ corrected and compared to "true" activation.

Results

Activation patterns and significance levels depend on activation contrast and the choice of functional resolution (figure 1). This applies as well to the area of true positive (TP), false positive (FP) and false negative (FN) activation. A plot of the ratio TP/(FP+FN) shows that the optimal functional resolution depends on the specific activation contrast (figure 2). At high resolution, the resulting activation volume is quite sparse due to the large quantity of thermal noise. Increasing the voxel size results in overall higher activation significance although the PVE is more evident, mainly due to increased FP-activation. At some specific voxel size, the benefit from high temporal SNR is neutralized by the escalating PVE (figure 2).

Discussion

It is of great benefit to visualize activation patterns at different functional resolutions and activation contrasts. The access to "true" activation maps in this study, make it possible to quantitatively investigate the amount of TP-, FP- and FN-activation change in different fMRI-experiments. Several studies in fMRI leave the effects of partial volume unaccounted for. This study shows that the impact of PVE is important to consider, even though the activation map in a real case of course depends on several other parameters as well. Furthermore it would be interesting to investigate PVE in different regions of the brain, as it is likely to vary due to inherent differences in the gray matter surface-to-volume ratios. In studies requiring localization and quantification of small activation clusters, knowledge of PVE will be of extra value when choosing functional resolution. This model may also be attractive when investigate the effects of smoothing and other vital concepts in fMRI post processing. In conclusion, this study introduces a way to optimise functional resolution with respect to partial volume effects in fMRI.

References

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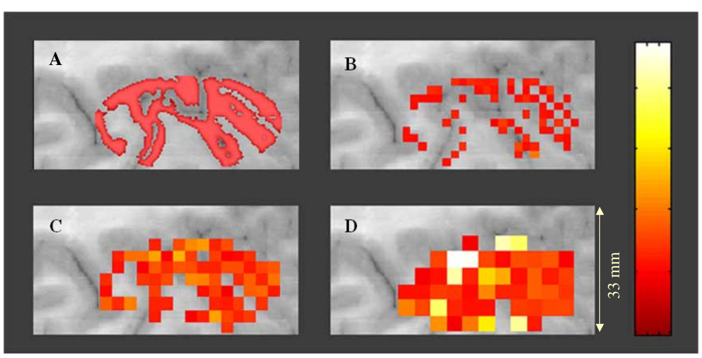

Figure 1. Activation patterns (3 % activation contrast) in a sagital view of prefrontal cortex at different functional resolutions. A) "True" high-resolution ellipsoid activation, B) 2^3 mm^3, C) 3^3 mm^3 and D) 4^3 mm^3.

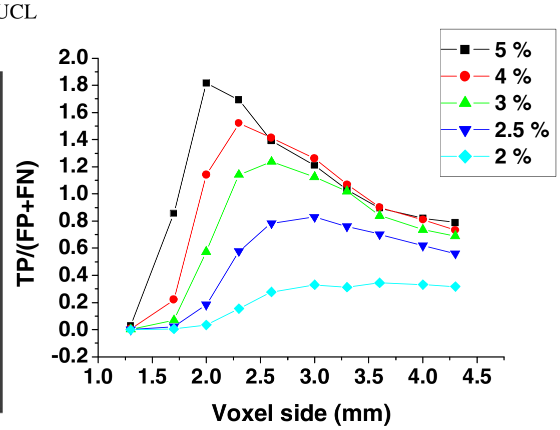

Figure 2. Plot of optimal functional resolution for several activation contrasts