Functional MRI Incorporating Information on Voxel-Wise Tissue Volume Fractions

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Introduction

A majority of functional MRI techniques use fast image acquisition schemes (EPI and spiral) to achieve better temporal resolution and larger spatial coverage. The spatial resolution in fMRI is usually 2-4 mm for an image matrix size of 64×64 or 128×128. Due to the irregular arrangement of brain tissue, partial volume of tissue content inevitably exists in these image voxels. Typically, a voxel is considered as "activated" based on statistical analysis, regardless of the voxel tissue content. In this case, partial volume effects may have significant impact on the detection of fMRI signal. To address this problem, we incorporated tissue volume fraction information into fMRI data analysis. Volume fractions of gray matter (GM), white matter (WM), and cerebral spinal fluid (CSF) were obtained from a set of inversion recovery experiments acquired at the same locations as the fMRI. With the information on volume fraction in each voxel, fMRI data can be analyzed in a two dimension space, statistics and volume fraction, for enhancing the detection power.

Methods

BOLD and ASL Perfusion fMRI. BOLD and ASL images were acquired simultaneously using an inversion recovery sequence with alternated spin labeling and control. At inversion time (TI) of 1.4s, two gradient echoes were collected with TE of 7.6 and 27 ms, respectively. Difference images between labeled and control images from the first echo were used for perfusion weighting, and the sum images of the labeled and control images from the second echo were used for BOLD weighting. Experiments were done on 5 healthy volunteers on a 3T Siemens Allegra scanner. Functional data were collected on five oblique axial slice (5mm in thickness) encompassing the primary visual cortex, with a block-design visual stimulation paradigm (alternated 8-Hz flashing checkerboard and a cross). A t-test was used to compute statistics (t-scores) by comparing data collected during activation and rest states.

Tissue Volume Fraction. A set of inversion recovery data were collected in the same brain location as the fMRI, at TIs of 30, 80, 130, 180, 230, 330, 430, 530, 630, 730, 830, 1030, 1230, 1530, 1830, 2230, 2730, 3230, and 3830 ms, respectively. Volume fractions of GM, WM and CSF in each voxel were calculated from the data sets, based on reported T_1 values of these brain tissues.

Results

Representative volume fraction maps of GM, WM, and CSF of one brain slice are illustrated in Fig.1a-c. T_1-weighted image of the brain slice is also shown (Fig.1d) for comparison. The volume fraction information was incorporated into data analysis to enhance the capability of identifying activated voxels. Fig.2 shows scatter plot of t-score vs. GM volume fraction for all brain voxels of BOLD (a) and ASL images (b). The horizontal red line indicates t-score threshold ($p<0.01$), which is typically used in conventional analysis methods. A vertical yellow line is used to separate two clusters of voxels with small and large GM volume fractions. For BOLD images (Fig.2a), a significant numbers of voxels (28%) with t-scores above the threshold have small GM volume fractions (< 0.55). On the other hand, for ASL images (Fig.2b), only 10% of such voxels have small GM fractions. Since ASL perfusion imaging targets signal changes more toward capillaries and arterioles, it is reasonable to assume that voxels with large GM fractions are more closely related to neuronal activity sites, whereas voxels with small GM fractions but above the statistical threshold are likely affected by large veins as often observed in BOLD.

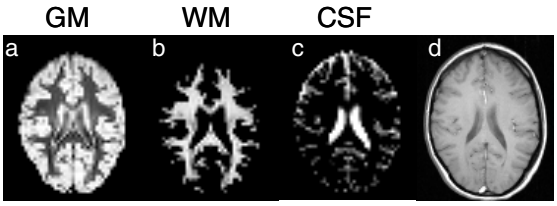

Fig.1 Volume fraction maps of GM (a), WM (b), and CSF (c), and corresponding T_1-weigted image of a brain slice (d).

Based on the above observations, fMRI data may be better analyzed based on both statistical threshold and tissue volume fraction. Fig.3 shows functional activation maps obtained with *t* statistics only (Fig.3a and 3c), and with both statistics and GM fraction (Fig.3b and 3d). For the BOLD images (Fig.3a and 3b), incorporation of GM fraction information significantly constrained activation area to gray matter, whereas ASL images were much less affected by the tissue fraction.

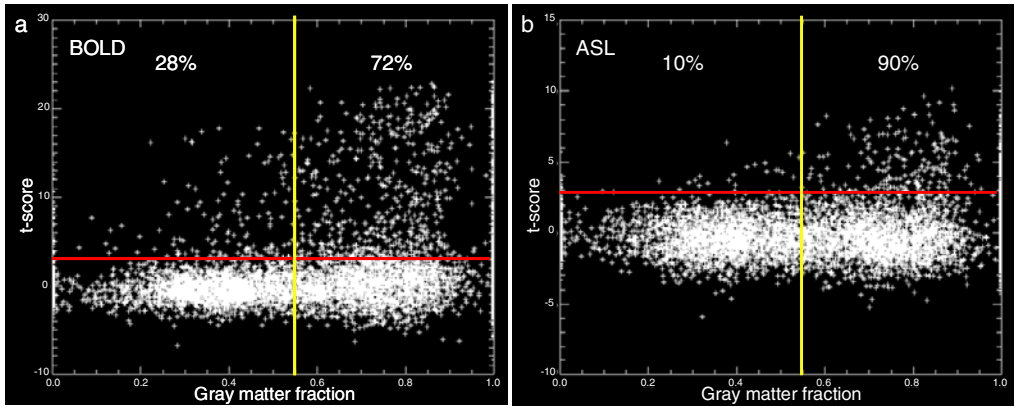

Fig.2 Scatter plot of t-score vs. GM volume fraction for all brain voxels of BOLD images (a) and ASL perfusion images (b).

Discussions

Neuronal activities are mainly located in GM. The use of voxel-wise GM volume fraction constrains brain activation in the voxels containing primarily GM. Compared to conventional fMRI analysis approaches that utilize only statistics to detect activation, the proposed method uses both statistics and tissue fraction to identify activation, and therefore may enhance spatial specificity while preserving high sensitivity.

Our study showed that the use of GM fraction is more effective for BOLD images than ASL, implying that more activated voxels detected in BOLD might be confounded by factors such as large draining veins. On the other hand, the reduced influence of the GM fraction constraint on ASL images suggests that ASL techniques have better spatial localization (primarily in GM).

It is worth noting that voxel-wise T_1 values have been used to assess fMRI data. In this study, however, tissue volume fractions in each voxel were, to the best of our knowledge, first used for fMRI analysis, which provides more accurate information on tissue components in image voxels. Further study is focusing on optimal use of the volume fraction information in fMRI.

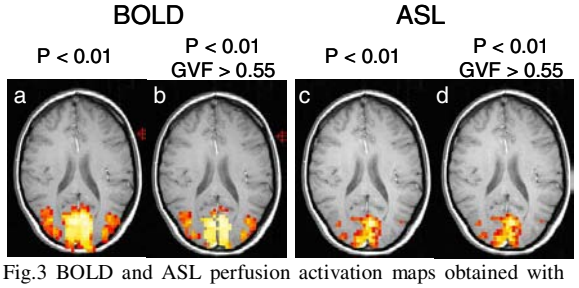

Fig.3 BOLD and ASL perfusion activation maps obtained with only statistics (a, c) and with both statistics and gray matter volume fraction (GVF) (b, d).