Voxel-wise Tissue Segmentation and Partial Volume Quantification in Experimental EPI Space to Inform fMRI and fcMRI Analysis

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Introduction:

Tissue segmentation for functional MRI studies is normally performed with FreeSurfer, which utilizes T_1 weighted anatomical images to provide tissue separation maps (1). This can be problematic since the anatomical separation maps have a different image warping than EPI images and can lead to incorrect image registration. A different tissue separation method utilizes the accelerated gradient-echo asymmetric spin-echo (GREASE-II) sequence to produce T_1, T_2, and T_2' relaxivity maps in the same EPI space as functional studies (2). The GREASE-II sequence utilizes five echoes collected after a single excitation to produce images that are exactly registered to the original EPI image. A nonlinear fit algorithm is used to fit the signal intensity from the images to the signal equation to produce the separate relaxivity maps. The three EPI relaxivity maps can then be used to produce voxel-wise CSF, gray and white matter maps by using the individual tissue mean relaxivity value along with standard deviation. This process not only produces accurate tissue maps, but the maps can be combined to view the Partial volume effect throughout the brains gray matter.

Methods:

A healthy human subject was imaged after informed consent was obtained. An 8-channel head receiver was utilized on a 3.0 T General Electric Signa LX scanner. The scanning parameters were a TR = 2 s, ETE_{Echo1} = 11 ms, ETE_{Echo2} = 13 ms, ETE_{Echo3} = 13 ms, ETE_{Echo4} = 0 ms and ETE_{Echo5} = 26 ms. The first spin echo SE_1 = 91 ms and the second at SE_2 = 183ms. The flip angle was at 90 degrees, acquisition matrix 96 x 96, field of view 19.2 cm, slice thickness 2 mm, and 5 repetitions. Acceleration was achieved using partial Fourier acquisition with 8 overscan lines and GRAPPA with an acceleration factor of 2 and 4 ACS lines. Tissue relaxivities were found through a nonlinear fit of the GREASE-II data, which utilized all 5 echo images.

Tissue segmentation is possible, because the mean T_1, T_2, T_2^* relaxivity values vary in the three different tissue types. White matter has a T_1=800±100ms, T_2=75 ±10ms, and T_2^*=53±10 ms. Gray matter has a T_1=1350±100, T_2=105±10, and T_2^*=65±10. CSF has a T_1=4000±100, T_2=200±10, and T_2^*=400±10 (3,4,5). Knowing the mean relaxivity values and standard deviations for the different tissue types, lookup tables can be built in which each relaxivity value correlates with a certain percentage of each tissue. The Tissue separation maps are produced by inputting the relaxivity maps from GREASE-II voxel by voxel into the lookup tables and finding the percentages per tissue type. This method builds three separate maps: %CSF, %gray matter and % white matter, which were than combined into one complete tissue map that shows the partial voluming in the brain.

Results:

This method of tissue separation delineates the different tissue types. It is shown in Figure 1a that the CSF can be well separated from the rest of the brain exhibiting partial voluming effects with approximately one voxel deep into the gray matter. This separation is due to the large difference in relaxivities between CSF and the other two tissues. In the gray matter map, very few voxels are actually 100% gray matter due to the thickness of this tissue and voxel dimensions. The rest of the gray matter voxels are either partial volumed with CSF or white matter. Finally, the white matter is also well separated with expected partial voluming of it with gray matter.

Figure 1b is the combination of the three tissues into a single separation map, where the specific tissue components can be seen in three colors red, green and blue, for CSF, gray matter and white matter. This map shows a separation of the different tissue types along with the partial voluming. The partial voluming is displayed by the combined shades of red and green as well as green and blue. It should be noted that there were very few combinations of red and blue as it is very unlikely that a voxel contains both CSF and white matter in the illustrated slice of the brain.

These segmentation maps have great potential in the fMRI and fcMRI fields. These maps enable more aggressive image masking to reduce both false positives in gray matter. The aggressive masking of grey matter will help to mitigate the multiple statistical comparisons of active voxels. With this ability, more accurate fMRI and fcMRI studies can be conducted with 1-to-1 registration of the functional data to the underlying anatomy without the need for non-linear image registration. Finally, aggressive masking can increase the speed at which the data is processed by reducing the necessary number of computations 20 fold. Further, weighted averaging of voxels in regions of interest based upon gray matter content is expected to yield improved fMRI and fcMRI signals.

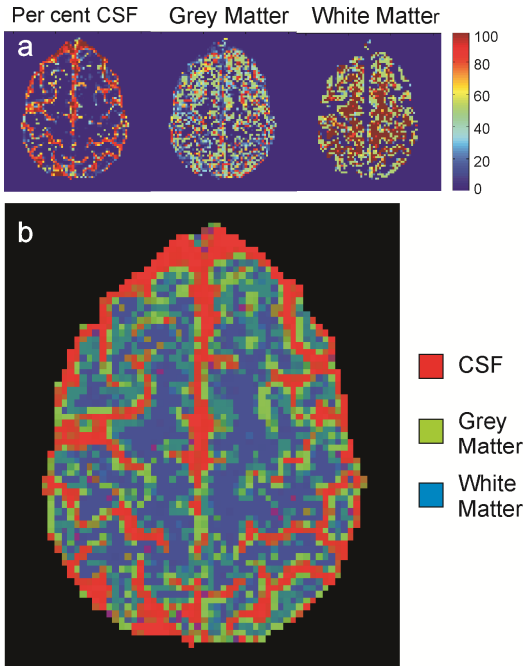

Figure 1: a. Display of the percentage of each brain tissue in each particular voxels. b. Mapping of the brain tissues combined into a single image, which shows the partial voluming of the gray matter.

References:

1. Makris et. al. *Journal of Cognitive Neuroscience* 2003. 15:4:584-599
2. Shefchik et. al. *Proc. ISMRM*. 2011. 19:4510