Regional Distribution of Outliers of Diffusion MRI in the Human Brain

L. Walker[1], J. Yang[2], X. Wu[2], K. Simonyan[3], R. Verma[2], and C. Pierpaoli[1]

[1]NICHD, NIH, Bethesda, MD, United States, [2]Dept of Radiology, University of Pennsylvania, Philadelphia, PA, United States, [3]NINDS, NIH, Bethesda, MD, United States

Introduction: Perturbation of the NMR signal by motion including bulk subject motion and pulsatile motion as a result of the cardiac cycle is known to affect diffusion weighted images (DWI), and consequently diffusion tensor (DTI) derived quantities such as anisotropy, trace(D) and eigenvectors [1-3]. Some of these artifacts can be avoided by the use of cardiac gating at the time of acquisition. However, cardiac gating remains uncommon in the DTI community. In a survey of 450 journal articles from 2005 and 2006, only 29 reported the use of cardiac gating. In the case that cardiac gating has been neglected, robust tensor fitting can be used to account for outliers [4-5]. There is, however, controversy over the importance in correcting for these effects [6], whether by gating or by a robust tensor estimation. To our knowledge, no systematic study of these effects across a population has been performed to date. This is a necessary step toward resolving this controversy. We present a preliminary analysis of the effects of outliers across a population of healthy volunteers using both non-linear least squares and the RESTORE [5] robust tensor fitting algorithm.

Methods: *Subjects* – 20 healthy volunteers (age 52.7 ± 9.49 years, 8 male, 12 female) were scanned on a 3.0T GE Excite scanner using an eight-channel coil (GE Medical Systems, Milwaukee, WI). Whole brain single-shot echo-planar (EPI) DWI datasets were acquired with the following parameters: TE/TR = 73.4/13000ms, 0.9375x0.9375mm^2 in-plane resolution, with 54 slices at 2.4mm thickness, b-value of 1000s/mm^2 in 33 non-collinear directions, plus 3 images at a b-value of 0s/mm^2, with two replicates, SENSE acceleration factor = 2. No cardiac gating was performed. *Post-processing* – Images were corrected for motion and eddy current distortions [7] and EPI distortion [8]. Tensor fitting was performed twice on each subject, once using a non-linear least squares algorithm, and once using the RESTORE robust method to identify and reject outliers. Tensor derived quantities were then calculated, including FA and trace(D). We also calculated an outlier rejection map from the RESTORE fitting for each individual, with brighter areas indicating a higher number of outliers rejected. For the purposes of population analysis, 1 of the 20 subjects was selected as a template, and all subjects were spatially normalized to that subject, using a method that performs a fully deformable registration of the tensor datasets to the target dataset [9] including reorientation of the tensors post normalization. We chose this method to reduce the variance normally associated with standard spatial normalization techniques that use affine transformations. The deformation of each individual subject was then applied to their FA, trace(D), and outlier maps. The mean, spatially normalized, outlier map was calculated from the 20 subjects to create an outlier rejection probability (ORP) map for the population.

Results: The figures below show the mean FA map computed from the spatially normalized FA maps of the 20 subjects, and their corresponding ORP maps. In the ORP map the brightest value (white) corresponds to a 15% rejection of data points as outliers. Anatomical details can be clearly identified in the mean FA maps reflecting the very good quality of the spatial normalization procedure. The ORP map shows a clear regional distribution of outliers in the population, with a higher percentage of outliers in the medial portions of the cerebellum**,** middle cerebellar peduncles, discrete regions in the temporal lobes (**Fig. 1)** ventricles, midline portion of the genu and splenium of the corpus callosum (**Fig. 2)** as well as at air-tissue interfaces and csf-tissue interfaces (**Fig. 3)**.

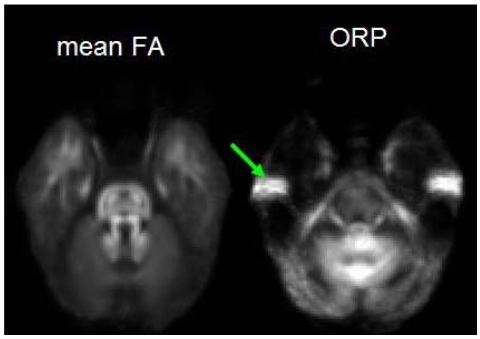

Figure 1: Mean FA and outlier map at level of the cerebellum. The green arrow indicates discreet area of susceptibility artifact in the temporal lobes.

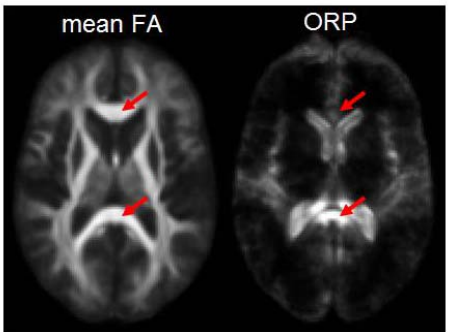

Figure 2: Mean FA and outlier maps at the level of the corpus callosum. The red arrows indicate the midline of the corpus callosum.

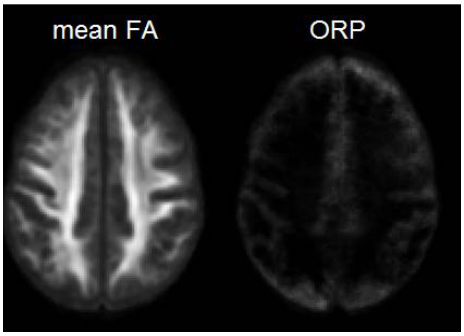

Figure 3: Mean FA and outlier map the top of the brain, showing outliers at the csf-tissue interfaces

Discussion: The outliers are caused by several factors; A. intravoxel distortion due to shear of tissue during cardiac pulsation in the cerebellum and corpus callosum, B. areas where magnetic susceptibility artifacts are present, as shown in Figure 1, C. flow in the ventricles, D. poor SNR at air-tissue interfaces, and E. local fluctuations in signals due to time varying partial voluming in the csf-tissue interfaces. What is most striking is the fact that the regions of high percentage outlier rejection are very well defined on the ORP, indicating consistent areas affected by these distortions in the brain within the population. The regions identified here were previously reported in single subject cases [1,2], but have never been shown to be consistent within a population. This consistency implies a regionally varying statistical power which should be considered when performing both ROI-based and VBM style analysis.

Conclusion: Outliers caused by motion, including pulsatile motion due to the cardiac cycle, are regionally consistent in the brain within a population of 20 healthy volunteers. This result implies a need for correction either by cardiac gating or by use of a robust tensor fitting algorithm, and is an important consideration for DTI analysis.

References:

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