Improved motion correction using interleaved b=0 volumes and b-vector correction in DTI

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Introduction: Diffusion imaging acquisitions are sensitive to head motion, making the collection of a large number of directions problematic, especially in motion-prone populations such as children. Standard preprocessing often includes eddy current correction (FMRIB Diffusion Toolbox), which corrects for both gradient distortions and simple head motion. However, in the case of large head motions, eddy current correction may be insufficient at minimizing error in the diffusion tensor estimates. In this study, we propose splitting long acquisitions (40+ directions; > 8 minutes), into separate, shorter acquisitions (ie. 2 x 20 dir; 4 minutes each) and including interleaved b=0 reference volumes to facilitate improved motion and b-vector correction. The interleaved reference images allow for a closer registration target and a better estimate of head position which should improve tensor fitting.

Methods: Six 40 direction diffusion datasets were collected on a healthy 26 year old male participant using a 3T MRI system (Tim Trio, Siemens) and a 12-channel head coil. The protocol included a high-resolution anatomical T1 MPRAGE (1 mm iso; TR/TE/TI/FA = 2300/2.96/900/9) and a 40 direction DTI acquired as two separate acquisitions with b=0, reference, volumes at the beginning, middle and end of each acquisition (2mm iso; TR/TE/FA = 8800/87/90). The subject remained still for two of the datasets, and periodically moved their head for the other four acquisitions.

A novel procedure for preprocessing the motion-corrupted data was evaluated. This method involved eddy-correcting each volume to its closest reference volume, which was in turn aligned to a single reference volume for both acquisitions. In addition, the b-vector of each direction was corrected to account for these transformations. Standard FSL tools were used to calculate DTI vectors, register the data to the MNI152 template and mask the data using the JHU white matter tract atlas (25% certainty threshold). All six datasets were analyzed using this *align-to-b0* pipeline and a standard eddy correct pipeline, where the DTI data was treated as a single acquisition. The *align-to-b0* and eddy correct pipelines were compared using voxel-wise scatter plots of FA and MD of the motion-corrupted data against the 'gold-standard' motion-free eddy-corrected dataset. The slope of the major-axis and percent shared variance between these datasets were calculated using PCA. The effect of motion correction on accurate estimation of V1 was determined by calculating the angular difference between motion-corrupted datasets against the gold standard. Given the small initial sample size (2 reference vs. 4 motion), paired, non-parametric tests were used to determine if significant differences existed between the *align-to-b0* and eddy correct pipelines.

Results: The *align-to-b0* pipeline exhibited lower median V1 orientation error than the standard eddy correct pipeline on each of the four motion-corrupted datasets. Figure 1 illustrates this finding using one of the motion-corrupted datasets as an example. As shown, the *align-to-b0* has pipeline has a lower median orientation error, and fewer voxels with an orientation error greater than ~30 degrees. In addition, a repeat acquisition is shown to illustrate the reproducibility of the V1 estimation.

Figure 2 shows voxel-wise scatter plots of FA data comparing the eddy correction and *align-to-b0* pipelines applied to a motion-corrupted dataset and the gold standard. At this point, there is not sufficient data to perform accurate statistical testing, but the preliminary results show that FA maps closer to the gold standard for each of the four motion-corrupted datasets (demonstrated by a slope closer to 1). No difference was found running these same analyses on MD data.

Conclusions: Preliminary evidence shows an advantage to using *align-to-b0* with interleaved b=0 volumes over standard eddy correction on data with heavy motion-corruption. Future work involves performing these analyses on more subjects, with and without motion, as well as evaluating its effectiveness in analyzing data collected from clinical populations and children. Ideally, we hope to understand which degree of motion corruption warrants the proposed *align-to-b0* pipeline. Furthermore, splitting long DTI acquisitions into shorter, separate acquisitions allows for this improved method of motion correction, as well as being more patient-friendly and flexible in terms of only repeating necessary blocks of data acquisition.

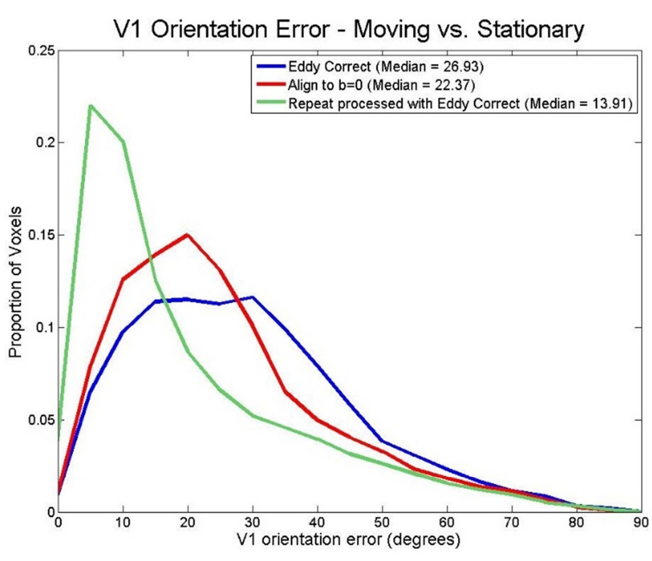

Figure 1: Histogram of V1 orientation errors for one of the motion-corrupted datasets processed with each pipeline.

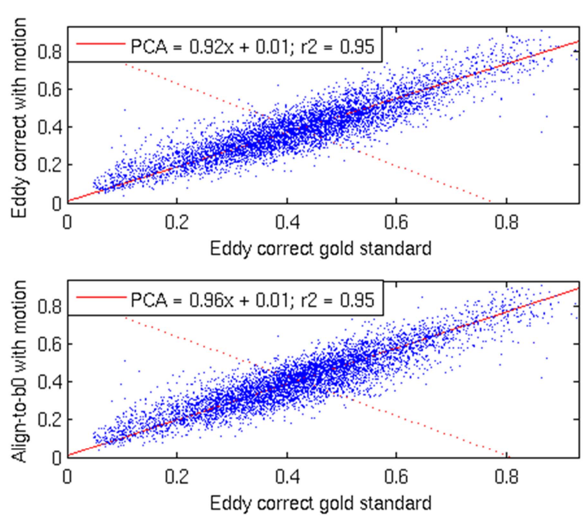

Figure 2: Voxel-wise scatter plot comparing eddy correction (top) and *align-to-b0* (bottom) to the gold standard.