Correction of intra-volume movement and motion-by-susceptibility distortion in fMRI

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Introduction: Subject head motion produces disruption to the BOLD signal that can lead to both reduced power and spurious results in downstream processing, particularly in high motion cohorts such as children and babies. Two, rarely corrected, motion related artefacts are (1) intra-volume movement which is a consequence of rapid movement during acquisition of a volume, and (2) changes in the susceptibility-induced field due to the subject's movements. Here we present initial results that demonstrate the benefit of correcting specifically for these artefacts in a high-motion cohort of neonates

Methods: Motion and distortion correction (MCDC) was performed using the FSL EDDY tool[1-3]. EDDY was designed for diffusion data and its use on functional data is not supported by FSL at this time. When applied to fMRI, EDDY does not model eddy currents and uses a predictive model that assumes the contrast is identical across volumes. EDDY performs a slice-to-volume (S2V) reconstruction to correct for intra-volume movement. This is achieved by using a continuous model of movement over time with degrees of freedom less than or equal to the number of slices/multiband group. These parameters are used to reconstruct a volumetric representation of the object. EDDY corrects for the motion-by-susceptibility distortion (MBS) by modelling the susceptibility-induced field as a continuous function of subject orientation to allow for the estimation of a unique susceptibility field for each volume. The full MCDC proceeds by first estimating between-volume movement, followed by estimation intra-volume (S2V) movement. Finally MBS is estimated, interspersed with updating of the S2V movement estimates. Once all the parameters have been estimated a single resampling of the data is performed. MCDC is evaluated on 40 neonatal fMRI datasets (MB9, TE/TR=38/392ms, 2300 volumes) from the Developing Human Connectome Project[4]. For comparison, a rigid-body (between-volume) motion correction was also applied to the fMRI data using FSL MCFLIRT[5]. Temporal signal-to-noise ratio (tSNR) was calculated per-voxel as the temporal mean divided by the temporal standard deviation.

Results: Rigid-body (RIGID) motion correction significantly improves tSNR compared to the RAW data (Figure 1A) mostly at the cortex and edges of the brain, S2V correction significantly ($p<0.001$) improves tSNR compared to RIGID across the whole brain, and S2V+MBS further improves tSNR in anterior and posterior areas where susceptibility distortions are expected. The correction of S2V artefacts can be visually observed in an exemplar volume from a single subject in Figure 1B.

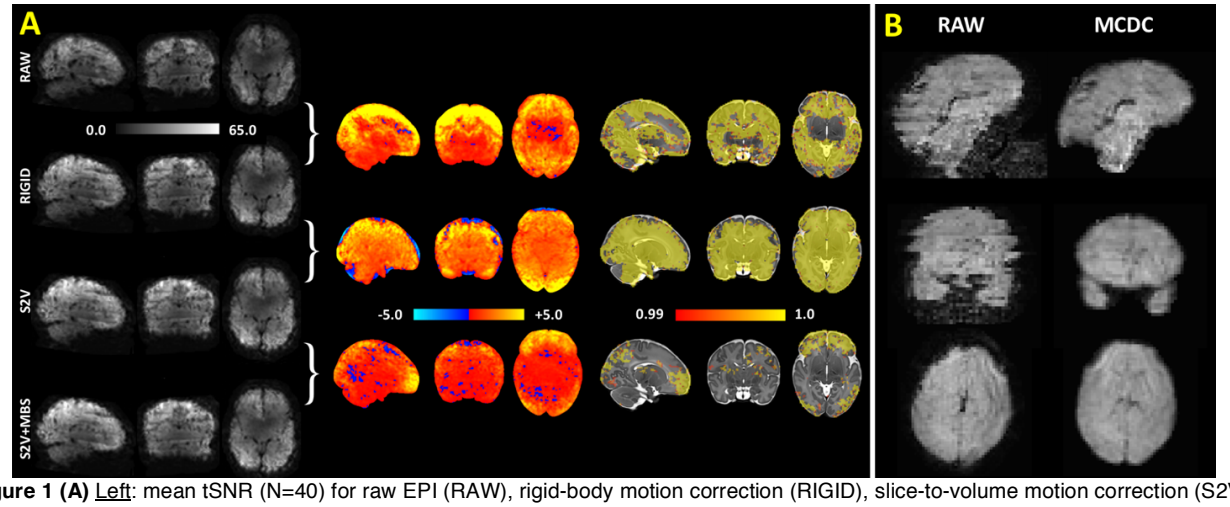

Figure 1 (A) Left: mean tSNR (N=40) for raw EPI (RAW), rigid-body motion correction (RIGID), slice-to-volume motion correction (S2V), and S2V + motion-by-susceptibility distortion correction (S2V+MBS). Centre and right: difference maps and p-values ($p<0.001$) for RIGID tSNR minus RAW tSNR (upper), S2V tSNR minus RIGID tSNR (middle) and S2V+MBS tSNR minus S2V tSNR (lower). **(B)** Exemplar single-volume of an EPI from a single-subject with intra-volume movement before (original) and after motion and susceptibility distortion correction (MCDC).

Conclusion: Whilst these results demonstrate that gains in tSNR can be obtained with S2V and MBS, it is important to reiterate that EDDY was designed for diffusion data and its use on functional data is not yet supported by FSL. Nonetheless, the results herein, and other results in preparation (not shown) are starting to build a strong case for the use of EDDY on fMRI data.

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