Prospective Motion Correction of Segmented Diffusion Weighted EPI

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Purpose: Recently, multiplexed sensitivity encoding (MUSE) [1] was introduced to combine segments of under-sampled diffusion weighted data to achieve high resolution DTI. While the algorithm provides good results in cooperative volunteers, macroscopic motion during the data acquisition was not accounted for. In this work MUSE is combined with the continuous prospective motion correction (PMC) of a segmented diffusion weighted acquisition.

Methods: All experiments were conducted on a 3T scanner (Siemens Healthcare). For motion tracking, an in-bore camera system was used (Metria Innovation). A diffusion weighted segmented EPI sequence using a double spin echo approach and was modified to enable prospective position updates between excitations and during the diffusion weighting period [2]. The MUSE algorithm uses a two-step approach to reconstruct segmented EPI scans. First, each segment is reconstructed using SENSE. The calculated phase map of each segment is combined with the coil sensitivities to perform a second-level SENSE reconstruction of the full data set.
Experiment 1: Effects of intentional head motion. A reference scan without motion was performed first, followed by two scans with comparable motion (absolute rotation of about 4 deg). One of the 'motion' scans was corrected prospectively, using the tracking data from a marker fixed to the forehead of the volunteer. A 12 channel head-coil was used. Sequence parameters were: TR: 2000ms, TE: 93ms, b: 0, 500, and 1000 s/mm^2, 6 directions, matrix 128×128, FoV 220×220mm^2, 2 EPI segments, and 9 slices of 3mm.
Experiment 2: High resolution DWI. The second volunteer was instructed to lay as still as possible during two measurements. One of the measurements was prospectively corrected to account for involuntary head motion. For this experiment, a 32 channel head-coil was used and the marker was fixed to a custom made mouthpiece to provide optimal stability and to enable a line of sight from the camera to the marker. Sequence parameters were: TR: 3700ms, TE: 114 ms, b: 0, 1000 and 1500 s/mm^2, 20 directions, matrix 256×256, FoV 220×220mm^2, 4 EPI segments, and 9 slices of 3mm, acquisition time: 10min.

Results: Figure 1 shows data from the first experiment, with and without motion. Each row displays one exemplary slice and one out of 6 weighting directions for both b-values. In fig 1a and b, the results of the scan with no intentional motion are displayed for comparison. The images in fig 1a were reconstructed using a conventional Cartesian reconstruction while the images in fig 1b-d were reconstructed using MUSE. Figure 1c demonstrates substantial degradation of image quality when motion was not corrected; the same was true for all slices acquired. However, PMC dramatically improved image quality (fig 1d); in fact, motion corrected images were comparable to those acquired without motion. In this experiment, the subject performed quasi-periodic head rotations of up to 4 deg (tracking data of the motion corrected scan, fig 1e). The improvement in quality due to motion correction is also visible in the mean diffusivity maps (fig 1, right column), reconstructed for a diffusion weighting of b = 500 s/mm^2.
Figure 2 shows results of the second experiment (no intentional motion, a: no correction, b: PMC). The three rows show diffusivity images (MD) for the two diffusion weightings (1000 and 1500 s/mm^2, left and center) and the fractional anisotropy (FA) maps (right column), respectively. Both scans show comparable image quality, probably due to the relatively small amplitude of the motion as well as the reliability of the reconstruction algorithm. However, without PMC (top row), small changes in head position during the long acquisition (about 10min) lead to some blurring in the MD images and decreased quality of the FA maps (top row). These artifacts were substantially reduced when PMC was enabled (bottom row).

Conclusion: Prospective motion correction during segmented DWI substantially improved image quality in the case of subject motion. In fact, our approach resulted in better image quality even without intentional subject motion. Of note, our experiments do not only demonstrate that it is possible to correct for such small motions, but also that prospective motion correction does not increase the artifact level. In conclusion, the combination of PMC and MUSE allows for high resolution DWI even in the presence of substantial head motion.

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References: [1] Chen, et al. A robust multi-shot scan strategy for high-resolution diffusion weighted MRI enabled by multiplexed sensitivity-encoding (MUSE). Neuroimage 2013;72(0):41-47. [2] Herbst, et al. Prospective motion correction with continuous gradient updates in DWI. MRM 2012;67(2):326-338.

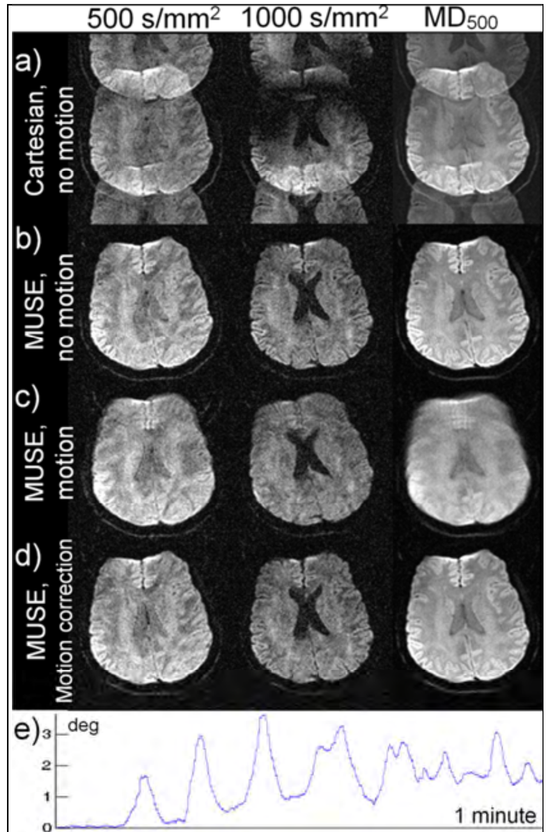

Fig.1: (a) images without motion, using conventional reconstruction followed by images reconstructed with MUSE. (b) No motion, (c) motion, no correction (d) motion plus correction. For each measurement one image from each weighting and the MD image are shown. Additionally, the tracking data from the third measurement are presented (e).

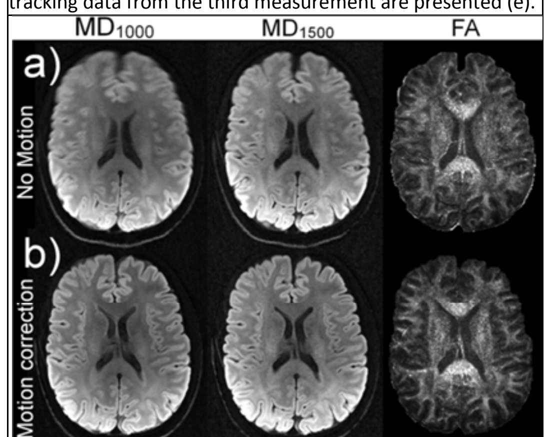

Fig.2: The results of the experiment without intentional motion are shown. Mean diffusivity images and the FA maps are displayed. (a) No correction was used; (b) prospective motion correction was enabled.