Prospective motion correction of 3D EPI data for functional MRI using optical tracking.

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INTRODUCTION: Motion is the most important factor affecting the MR signal temporal stability during functional MRI (fMRI) studies. This is especially true for fMRI using multi-shot 3D echo planar imaging (EPI) sequences as even short time scale motion can corrupt an entire image volume. The goal of this work is to implement a prospective motion correction (PMC) technique for 3D EPI and evaluate image quality as a function of both the magnitude of the motion and where the motion occurs with respect to the 3D partition encoding (i.e., slow phase encoding direction).

METHODS: The PMC method used an 80 Hz frame rate optical camera (Kineticor, HI) to track the six-degrees-of-freedom movement of a Moire phase marker that was rigidly attached the subject's head[1]. XPACE libraries[2] implemented in the Siemens IDEA sequence programming environment used the motion information to modify the imaging gradients before each RF pulse. Thus, the head position was rigidly realigned with its original location before acquisition of each k_x-k_y plane of data.

The 3D EPI sequence acquired each k_x-k_y plane of data in one echo train and applied linearly ascending phase encoding along the k_z dimension[3], where k_z is the slow phase encoding direction. Sequence parameters were set for a typical fMRI study and included: 3 mm isotropic resolution, 64x72x48 image matrix, TR = 57 ms, TE = 25 ms, 105 image volumes, each acquired every 2.74 seconds.

Two volunteers were imaged in a Siemens 3T TIM Trio scanner under a 2x2 factorial design with permutated conditions of lying still versus performing intentional head movements and PMC enabled versus disabled. All data sets were post-processed using SPM-8 to realign the image volumes[4]. The extent of motion was quantified in three ways: 1) the total motion speed was calculated as the root sum of squares combination of the time derivatives of all six motion parameters, 2) the integrated motion per volume was calculated by integrating the motion speed over the time required to acquire all data for one image volume, and 3) the integrated motion metric was further refined by weighting the motion according to the amount of k-space energy in the partition that was being acquired when the motion occurred (called *partition weighted integrated motion*). This measure was expected to predict the relative amplitude of the motion artifacts better. The image quality of individual volumes was assessed using a root mean square error (RMSE), which was calculated over all voxels in the brain based on the difference between each individual image volume and the mean image volume magnitude over all time frames where the integrated motion metric was below a retrospectively determined threshold value.

RESULTS: Figure 1A shows the motion quantification metrics from a portion of the imaging done on Volunteer #2 (PMC off), and 1B the corresponding RMSE values. The grid lines indicate the volume acquisition time and the dot markers are placed at the time that the central partition was acquired. Arrows 1 and 2 point to two time frames that show how the timing of the motion relative to the partition acquisition can affect the image quality: arrow 1 data showed motion near the central k_z partition lines and large RMSE, while arrow 2 data showed motion during the outer k_z partitions and lower RMSE. Figures 2A and 2B show scatter plots of the RMSE values for each image volume as a function of the partition-weighted integrated motion per volume for the PMC off and PMC on cases, with data from both volunteers combined into the same plot and linear fits to the data.

CONCLUSIONS: The presented PMC technique can significantly improve data quality for 3D EPI scans when moderate subject motion is present. Knowledge of the subject motion parameters relative to the timing of the 3D data acquisition can be used to predict the impact that the motion will have on the image quality and may be used in the future for determining a data rejection threshold.

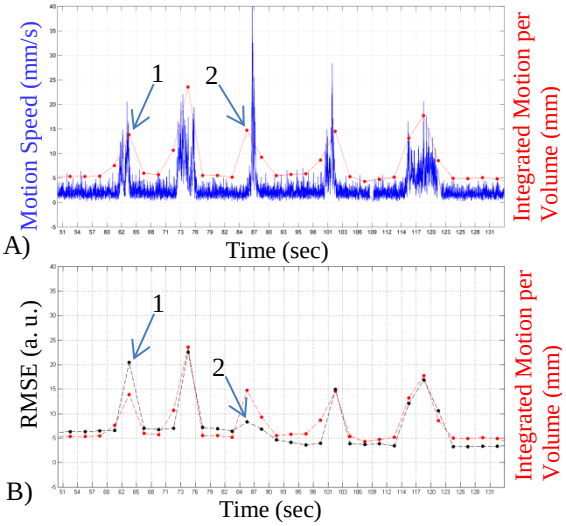

Figure 1: Motion data and RMSE values from several image volumes of volunteer #2 with PMC off.

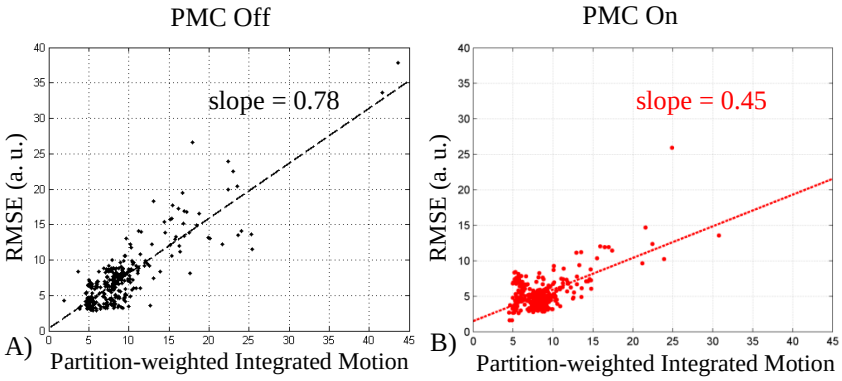

Figure 2: RMSE of individual image volumes as a function of the partition-weighted integrated motion. The partition weighting takes account of the fact that 3D k-space has more energy at the center than at the peripheral partitions and therefore motion occurring at different times of the volume image acquisition will have different effects on the image quality. Combined data from volunteers 1 and 2 are shown.

REFERENCES: 1. Maclaren et al. PLOS One, 7(11) e48088, 2012. 2. Herbst et al. MRM. DOI 10.1002/mrm.24645. 3. Lutti et al. MRM 69(6); 1657-64, 2013. 4. SPM8 framework, Wellcome Trust Centre for Neuroimaging, London (http://www.fil.ion.ucl.ac.uk/spm/).
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