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

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TARGET AUDIENCE: Those interested in motion correction strategies and improvement of fMRI temporal stability.

PURPOSE: Motion is the most critical artifact in functional MRI (fMRI). High speed optical tracking combined with prospective motion correction (PMC) was shown to effectively reduce motion artifacts in 3D anatomical brain imaging[1] and 2D echo-planar imaging (EPI)[2]. We extended its application to 3D EPI, which was shown to outperform 2D EPI for high resolution imaging[3]. The method uses a high frame rate optical camera to track the six degrees-of-freedom movement of a Moire phase marker that is attached to the subject[1]. This information is continuously fed to the scanner host computer to dynamically update the imaging gradients necessary for rigid body realignment of the data to be acquired. We implemented and tested the PMC method for 3D EPI, focusing on improvements in temporal signal-to-noise ratio (tSNR).

METHODS: 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. The PMC camera (Kineticor, HI) determined the head position at 80 Hz and the imaging gradients were modified to track the head position for each k_z partition using the XPACE libraries[1]. Sequence parameters were: 3 mm isotropic resolution, 64x72x48 image matrix, TR = 55 ms, TE = 25 ms, 2367 Hz/pixel bandwidth, 15º flip angle, 105 image volumes acquired every 2.64 seconds.

Two volunteers were imaged in a Siemens 3T TIM Trio scanner using the 3D EPI sequence and a 32-channel head coil. Each volunteer used a custom-made bite bar such that the Moire marker was rigidly attached to the upper teeth. All imaging was done during rest (i.e. no functional task). Two experimental conditions were varied: 1) the volunteer lying as still as possible versus the volunteer performing intentional head movements; and 2) imaging with the PMC enabled versus disabled. The volunteers were blinded as to whether the PMC was enabled during imaging. All data sets were post-processed using SPM-8 to realign the image volumes[4]. Two metrics of image quality were considered to assess the performance of the PMC method: 1) the tSNR of the time series of image volumes, calculated as the mean image magnitude over all time frames divided by the standard deviation of the linearly detrended image magnitude over time; 2) a root mean square error (RMSE) for each time frame, calculated over all voxels in the brain based on the difference between each individual image and the mean image magnitude over all time frames.

RESULTS: Figures 1A-D show one sagittal slice through the tSNR maps of volunteer #1 for each of the four experimental conditions. Corresponding histograms of the tSNR data throughout the entire brain are shown in Figures 1E-H. Figure 2 shows a scatter plot of the RMSE values for each image volume as a function of how much total motion occurred during the acquisition of that volume, with data from both volunteers combined into the same plot. The total motion value is calculated by integrating each XPACE motion measurement over the time of acquisition and combining the six values in sum of squares fashion. Linear fits to the data give slopes of 0.85 for the PMC Off data and 0.54 for the PMC On data.

CONCLUSIONS: The PMC system improves the data quality of 3D EPI sequences when moderate patient motion is present. Future work will quantify what level of motion the PMC method can effectively correct, investigate the impact on image quality of motion occurring at different times along the k_z phase encoding dimension, and consider further post-processing correction steps for data that is known to be motion-corrupted beyond the limits that the PMC can handle.

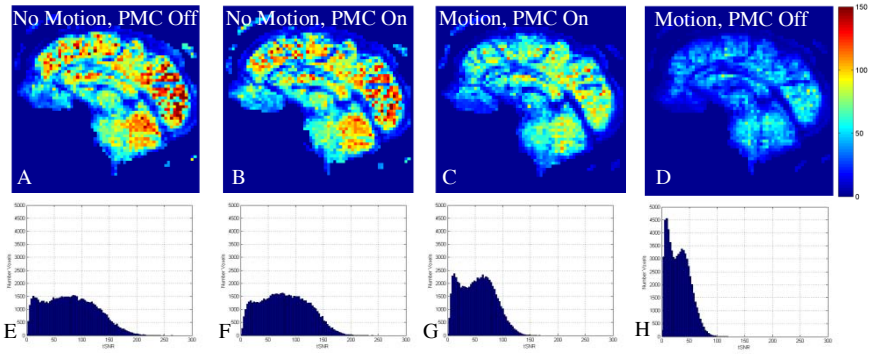

Figure 1: tSNR data from volunteer #1. The top row shows one sagittal slice through the tSNR map for the four permutations of the experimental conditions. The bottom row shows corresponding histogram plots of all tSNR values throughout the entire brain.

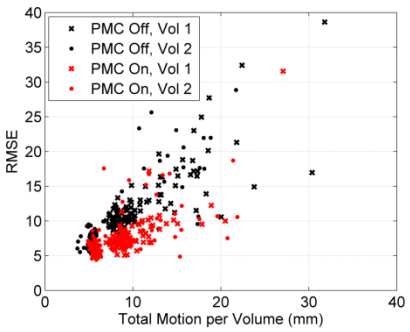

Figure 2: RMSE of individual image volumes as a function of total motion during acquisition of that volume. Combined data from volunteers 1 and 2 is shown.

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