INTRODUCTION - Head motion artifacts are a substantial source of error in Blood Oxygen Level Dependant (BOLD) fMRI that limits its use in neuroscience research and clinical settings. Real-time scan-plane correction by optical tracking has been shown to correct two well known artifacts: 1) slice misalignment and 2) non-linear spin-history effects [1], however residual artifacts due to dynamic magnetic field non-uniformity may remain in the data. EPI sequences, commonly used for fMRI, suffer from pronounced geometric distortion in the phase-encode (PE) direction due to sensitivity to magnetic field non-uniformity. Geometric distortion can result in erroneous localization of brain activity. A recently developed correction technique, PLACE [2], can correct for absolute geometric distortion using only the complex image data from two EPI images, with slightly shifted k-space trajectories, separated by a linear phase ramp from $-\pi$ to $\pi$ across the FOV. Briefly, after imaging, the linear phase ramp is distorted along with the object in the PE direction. Deviations from linearity can be used to restore signal back to its original location within the FOV. Here we demonstrate a novel correction approach that integrates geometric distortion correction by PLACE into a real-time scan-plane update system by optical tracking, applied to an fMRI finger tapping experiment with overt head motion to induce dynamic field non-uniformity.

METHODS - Real-time scan-plane update was achieved using an optical tracking system consisting of two MR-compatible infrared (IR) cameras (MRC Systems, Germany) [3]. To enable PLACE geometric distortion correction, each alternate volume was acquired with an additional linear phase ramp from $-\pi$ to $\pi$, by shifting k-space in the PE direction by one ‘blip’. Functional MRI finger tapping experiments were performed by four healthy young adult subjects (right-handed males, average age 27 years, range 24-32 years). The first task involved self paced bilateral finger tapping, with known activation patterns in the primary sensory motor cortex (SMC). The second and third tasks included deliberate intermittent in-plane (yaw) axial or though-plane (roll) nodding rotations during the finger tapping task. To reduce intra and inter subject motion variability the subjects were trained using visionmotor feedback prior to the experimental session. Each experiment was repeated without and with real-time correction. Real-time corrected data were further corrected for geometric distortion retrospectively in Matlab (V4.2c, The MathWorks, Inc., Natick, MA) by generating correction maps from opposed EPI images collected with the head in the same relative orientation as determined by the reported motion data. All subsequent post-processing was performed using AFNI [4], with an FDR corrected p-value of $q = 0.01$.

RESULTS - The results from a representative fMRI experiment are shown in Fig. 1. In the case with no deliberate motion the activation map shows typical activity in the left and right SMC. In the case of in-plane rotation or nodding with no correction, the activation maps show an increase in the number of false-positive activations outside the SMC, around the edges of the brain in in-plane rotation and within the frontal lobe for nodding. There is also marked reduction in the number of voxels identified in the SMC. With real-time correction, the activation maps show a reduction in the number of false-positive activations outside of the SMC and an increase in the number of activations detected in the SMC compared to the cases with no correction. When the data from real-time scan plane correction are further corrected for geometric distortion using PLACE, the activation images includes even fewer instances of false-positives and a further increase in the number of voxels identified in the SMC. The activation patterns more closely resemble the static case compared to the case with real-time correction only and have shifted slightly anterior due to the distortion correction. A summary of the mean voxel counts for each experimental condition over the four subjects is presented in Figure 2. The observed trends for the case presented above were consistent between subjects.

DISCUSSION - Initial fMRI experiments suggest that despite the success of real-time scan-plane update, artifacts due to dynamic geometric distortion can still confound fMRI analysis. Including volume by volume, geometric distortion correction by PLACE can suppress such artifacts in-vivo and provide more robust activation maps. Future work will focus on the efficacy of the integrated correction approach in the case of random continuous motion, and in patient populations.