Prospective Motion Correction for Improved Image Volume Alignment

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Introduction: Subject motion during acquisition of a temporal series results in volume-to-volume misalignment which can corrupt data analysis. Prospective Motion Correction (PMC) continually measures changes in geometry due to subject motion throughout a scan. PMC makes real-time adjustments to the ongoing scan so subsequent images are correctly aligned upon acquisition thereby improving volume alignment.

PMC Design: PMC runs as a background application on the host with connections to the scanner and reconstructor. Upon reconstruction of each image volume, PMC registers the image data to the first dynamic volume using a rigid-body algorithm. PMC interprets the geometric transformation data, calculates the adjusted acquisition parameters, and updates the scanner on the fly. This version of motion correction differs from a previous implementation, known as PACE [1] in that it is not limited by TR or other timing restrictions. In PACE, geometry updates must reach the scanner before the next acquisition is begun. With PMC, adjustments are made on the fly without interrupting scan progress or limiting allowable TR.

Methods: PMC was implemented on a Philips Achieva 3.0T clinical scanner (Philips Medical Systems, Best, The Netherlands). Representative studies were performed on a human volunteer with an EPI sequence using the following parameters: FOV = 220 x 220 mm^2, matrix = 64 x 64, 16 slices, slice thickness / gap = 3 / 0 mm, TE / TR = 35 / 3000 ms, number of dynamics = 80, total scan time = 4 min. The subject was asked to make random motions approximately every 20 sec. To demonstrate PMC's performance in short TR situations, the scan was repeated with minimum TR (1 sec). As an example of the effect of PMC on fMRI data analysis, two image series (one with PMC, one without) were acquired with TR = 3 sec with alternating periods (period = 10 dynamics) of hand grasping and rest. Retrospective registration was performed on the image data from both series to correct residual volume misalignment. Cross-correlation activation maps were computed using Philips iViewBold software. The experiments were repeated four times on the same subject, alternating which scan (PMC or non-PMC) was performed first each day.

Results: PMC corrected subject motion in both the long and short TR situations. Figure 1 is an example of a through-plane motion (head nod) which was corrected immediately in time for the next dynamic in the long TR situation. Figure 2 is an example of an in-plane transformation (head tilt) which was corrected three dynamics later in the short TR situation. Although it is impossible to explicitly quantify improvement in fMRI data analysis in this situation, the PMC-enabled fMRI activation maps showed a consistent improvement compared to the non-PMC data in all four experiments (Figure 3). The PMC-aided maps showed more intense activation in the motor cortex. The activation regions in the PMC maps were also more closely congruous with the anatomy compared to the non-PMC data, which were generally more diffuse.

Discussion: Without PMC, involuntary subject motion accumulated throughout the scan as measured by the residual registration data (Figure 4). Volume realignment via retrospective registration is able to correct in-plane transformations using interpolation, but unable to entirely compensate for through-plane transformations due to partial volume effects. By adjusting to both in- and through-plane motions, PMC captures image data that would otherwise be unrecoverable by retrospective alignment [2,3]. PMC continuously corrected the involuntary motion thereby maintaining volume alignment evidenced by the close proximity to the zero line in Figure 4.

Conclusions: PMC maintains volume alignment throughout a dynamic series without restrictions on TR or sequence timing. By correcting for in- as well as through-plane motions, PMC comprehensively preserves image data resulting in superior fMRI activation maps.

References: 1. Thesen S, Heid O, Mueller E, Schad L.R. Magn Reson Med 2000; 44:457-65. 2. Friston KJ, et al. Magn Reson Med 1996; 35:346-55. 3. Naganawa S, et al. Eur Radiol 2004; 14:1484-88.

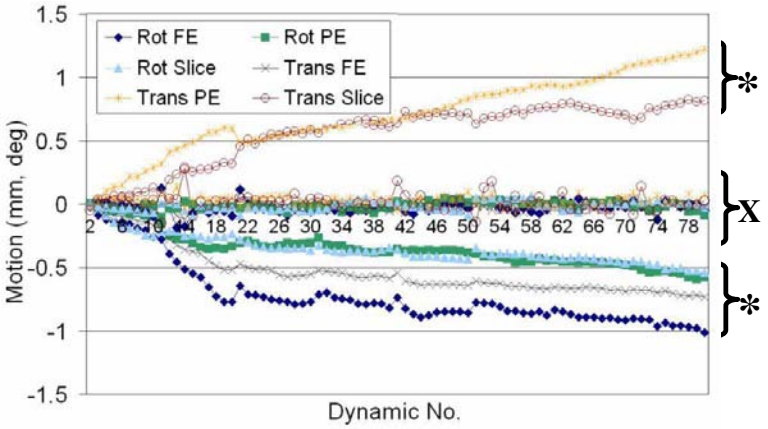

Figure 4: Residual transformation data for non-PMC (*) and PMC (**X**) fMRI studies. Rotations and translations for frequency-encode (FE), phase-encode (PE) and slice axes were measured from retrospective registration

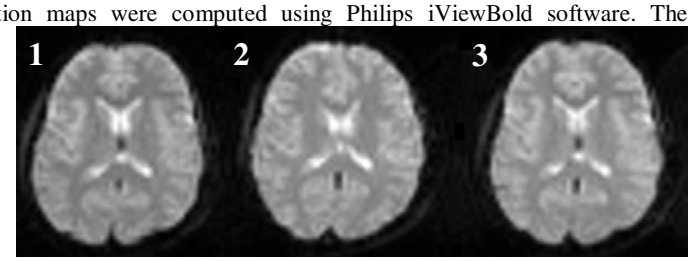

Figure 1: Representative images acquired with TR = 3 sec. Following dynamic 1, the subject nodded (~9°), causing dynamic 2 to be misaligned. PMC detected the motion and made adjustments so the acquisition of dynamic 3 was correctly aligned.

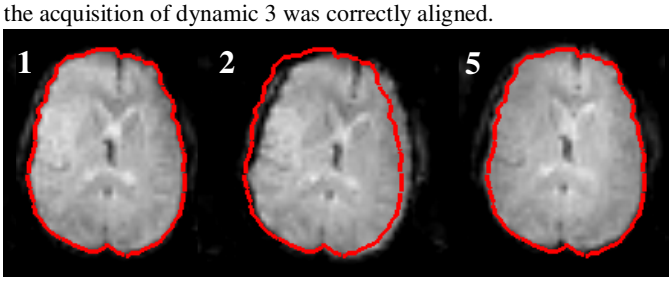

Figure 2: Representative images acquired with TR = 1 s. Following dynamic 1, the subject tilted (~5°). While the next scans were underway, PMC detected the motion and sent the adjustments to the scanner on the fly in time for dynamic 5 to be correctly aligned.

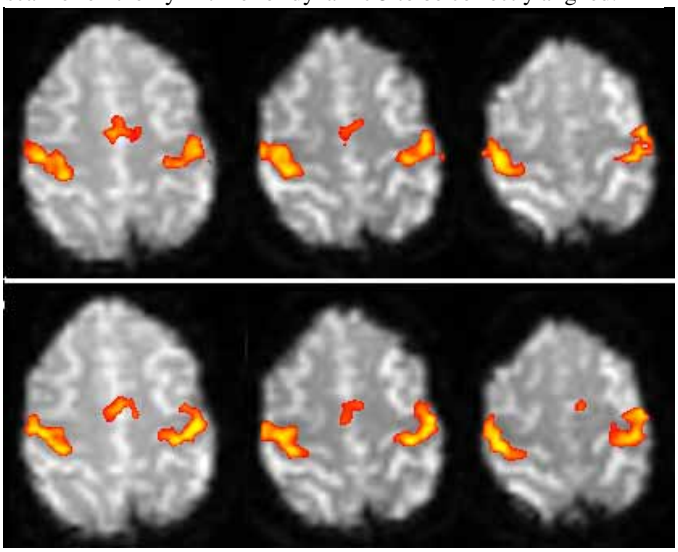

Figure 3: Representative fMRI activation maps. Top row: Non-PMC study. Bottom row: PMC-aided study.