HYBRID MOTION CORRECTION: WITHIN-ECHO-TRAIN MOTION CORRECTION FOR 3D T2W-TSE INNER EAR MRI

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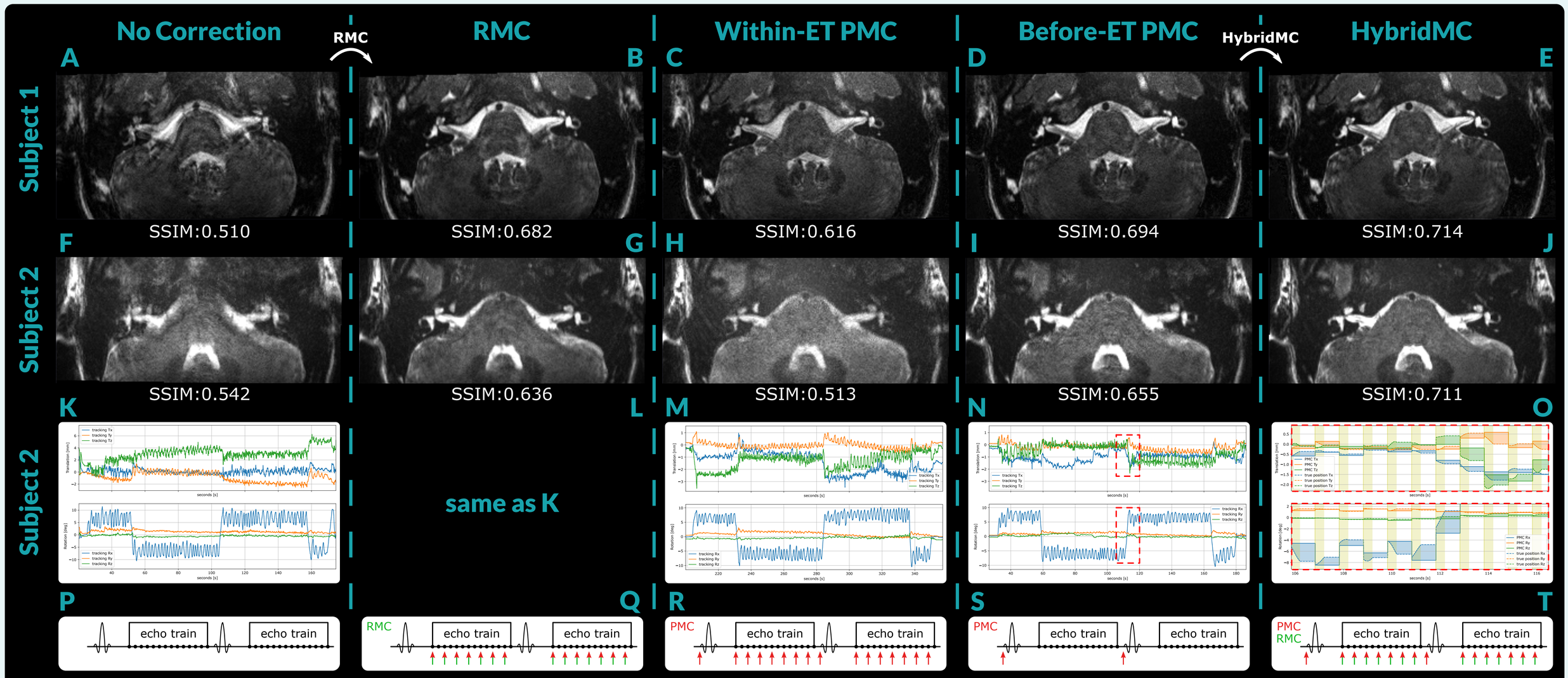

Figure 2: *Comparison of uncorrected motion and four motion correction methods of the same motion paradigm repeated three times during a 3D T2w-TSE 0.6mm isotropic inner ear scan (SPACE ZOOMIT, 3T Prisma, 64ch head coil, Siemens Healthineers, Erlangen, Germany). (**A-J**): Uncorrected motion scan and four motion correction methods reconstructed using the same RMC-capable pipeline. Image quality is assessed using the Structural Similarity Index Measure (SSIM) with a reference image without correction or deliberate motion reconstructed using the same pipeline; (**K-N**): Motion tracking during acquisition of images **F-J**; (**O**) A zoomed view shows residual tracking (fill) applied using RMC on raw data already corrected with before-ET PMC, to increase update frequency and correct for delay during PMC. Yellow areas indicate read-out times of the sequence; (**P-T**): Illustrations showing distribution of motion updates applied with PMC and RMC for each motion correction method.*

INTRODUCTION

High temporal frequency within-echo-train (within-ET) Prospective Motion Correction (PMC) outperforms before-echo-train (before-ET) PMC for 3D MPRAGE [1]. However, within-ET updates were ineffective in 3D T2w-TSE limiting update frequency to before-ET [1]. Hybrid motion correction (HybridMC) – combining before-ET PMC and within-ET Retrospective Motion Correction (RMC) – can alleviate these shortcomings and correct for motion during echo-trains in 3D T2w-TSE.

METHODS

The study used:

- a PMC-enabled 3D T2w-TSE sequence [1] with "blipped" RF-excitation enabling tight FOV around the inner ear.
- a markerless optical motion tracking system (Tracoline TCL 3.2, TracInnovations) supplying 30 head pose estimates per second.
- an RMC-capable reconstruction pipeline utilizing the Fourier Shift Theorem and a non-uniform Fourier transform. [2]

Four correction methods were compared: before-ET PMC, within-ET PMC, within-ET RMC, and HybridMC. Motion correction frequency was 30Hz (once every 5.5 lines on average) except for before-ET PMC with a motion correction frequency of 1Hz.

HybridMC: the residual between the motion corrected by before-ET PMC and tracked motion during the ET, filtered with a non-causal lowpass filter, is applied using RMC on the raw data already corrected with PMC. In addition to increasing motion correction frequency, HybridMC also compensates latency-induced errors by applying the residual between PMC updates and motion tracking precisely synchronized to the scanner. [3] (See **Figure 1: Right**)

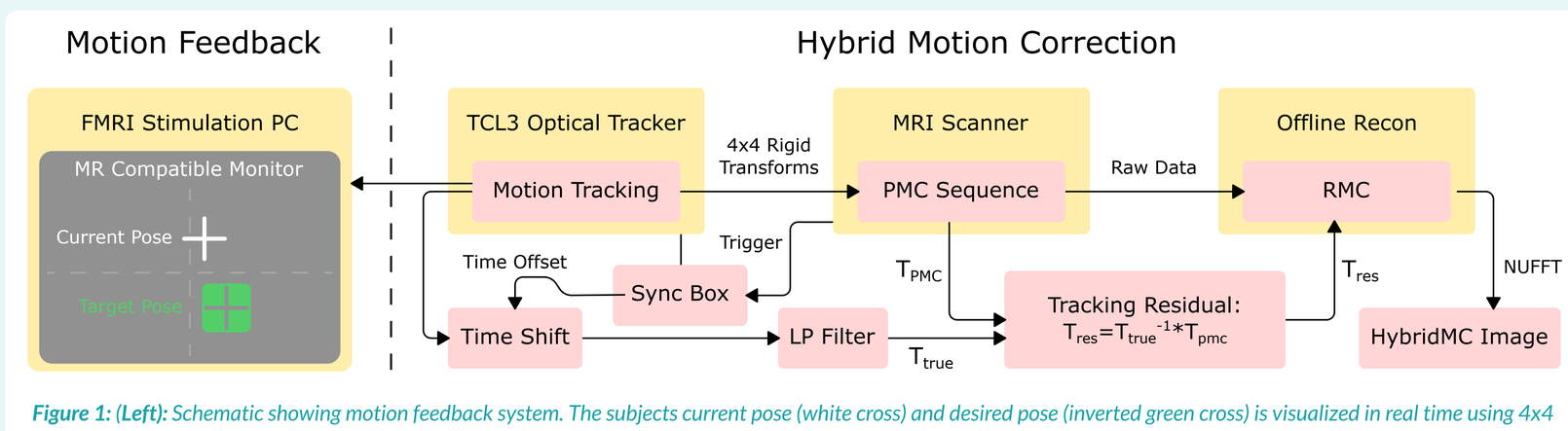

***Figure 1:** (**Left**): Schematic showing motion feedback system. The subjects current pose (white cross) and desired pose (inverted green cross) is visualized in real time using 4x4 rigid transforms broadcasted from the optical motion tracker, and a predefined motion trajectory, respectively. The subject is instructed to keep the white cross lined up with the inverted green cross for the duration of the scan. Only 3 axis of rotation are visualized. (**Right**): Schematic showing HybridMC used to increase motion correction frequency, and to compensate delay during before-ET PMC. After scanning, the true position of the patient (T_{true}) is approximated by tightly synchronizing the motion tracking to MR acquisition using triggers from the scanner, and by low-pass filtering (cutoff=5Hz). The residual tracking (T_{res}) between T_{true} and the tracking used during PMC (T_{pmc}) is corrected using RMC on already PMC-corrected raw data.*

Two healthy volunteers performed a motion paradigm with/without PMC, guided by a motion feedback system displayed on an MR-compatible screen (NordicNeuroLab, Bergen, Norway) (see **Figure 1: Left**). Motion consisted of four slow head nods (8 & 12 deg. rotation for subj. 1 & 2 respectively) with addition of heavy breathing motion in a pseudorandom pattern (1.5 & 2 deg. rotation for subj. 1 & 2 respectively, with 20-60 breaths per minute).

RESULTS

- Bulk motion is sufficiently corrected using before-ET PMC while within-ET motion remains uncompensated.
- Enabling within-ET PMC leads to a loss of contrast and SNR.
- Combining before-ET PMC and RMC using HybridMC sufficienty compensate within-ET motion, achieving superior image quality and SSIM (see **Figure 2**).

DISCUSSION

- The study indicates that within-ET updates are worse than before-ET PMC for 3D T2w-TSE, causing loss of signal and SNR, limiting PMC to correct inter-ET motion only.
- A combination of PMC and RMC can be used to overcome these limitation enabling intra-ET correction in 3D T2w-TSE.
- Future research should explore the efficacy of HybridMC across different types of motion, and other TSE sequence variants.

REFERENCES

[1] Frost R, et al. 2019 [doi: 10.1002/mrm.27705].
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[3] Laustsen M, et al. 2024, Proc 33rd ISMRM, p. 2660
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