Physics-Informed Deep Learning for Motion-Corrected Reconstruction of Quantitative Brain MRI

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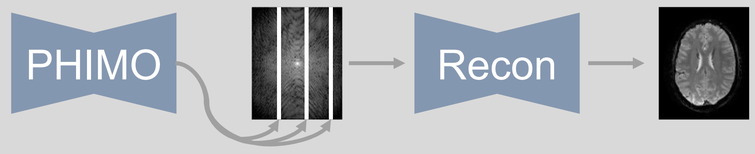
Motion in quantitative MRI

- Motion-induced **B_0 inhomogeneity changes** particularly impact **T2* quantification** from GRE MRI[1]
- Current HR/QR-MoCo[2] relies on repeated acquisitions
  → substantially **increased acquisition time**
- Most **learning-based brain MoCo[3]** developed for high-resolution scans or without ensuring data consistency

Acquisition time reduced by over 40%

PHIMO avoids repeated acquisitions by utilizing information from the T2* quantification to **detect and exclude motion-corrupted k-space lines** from a data-consistent DL reconstruction:



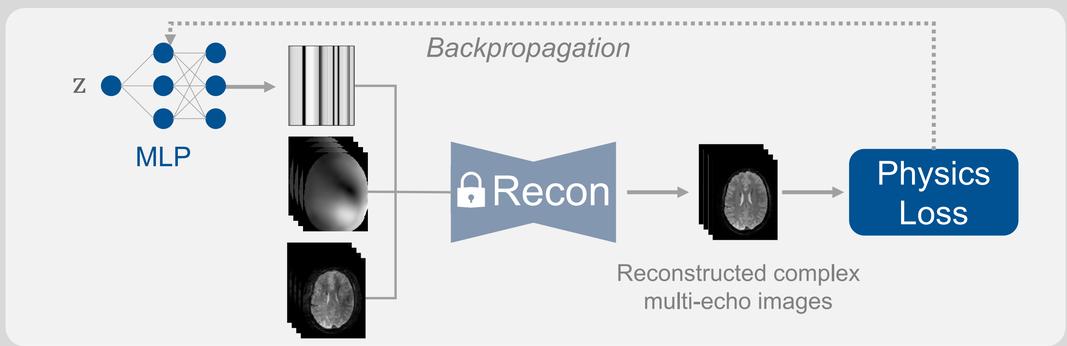
→ **Significantly improves image quality** in presence of motion

Physics loss enables self-supervised and subject-specific motion correction

Assumption of individual motion events allows to split MoCo into:

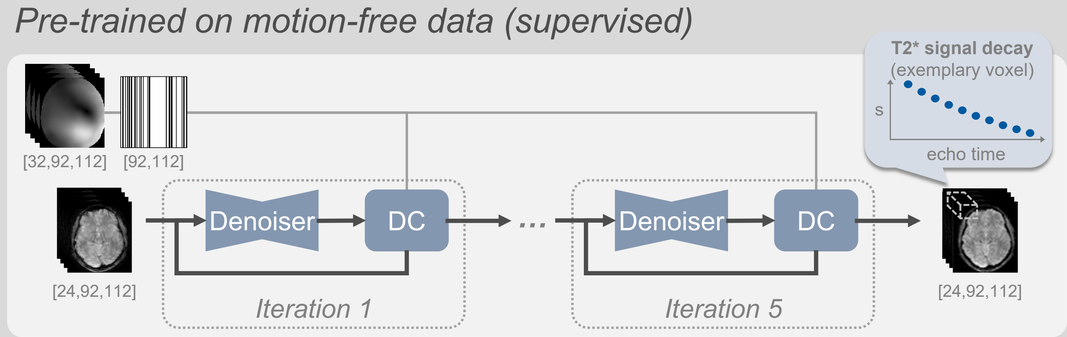
1. Detection and exclusion of motion-corrupted k-space lines

→ *Optimise for the best mask on motion-corrupted data*

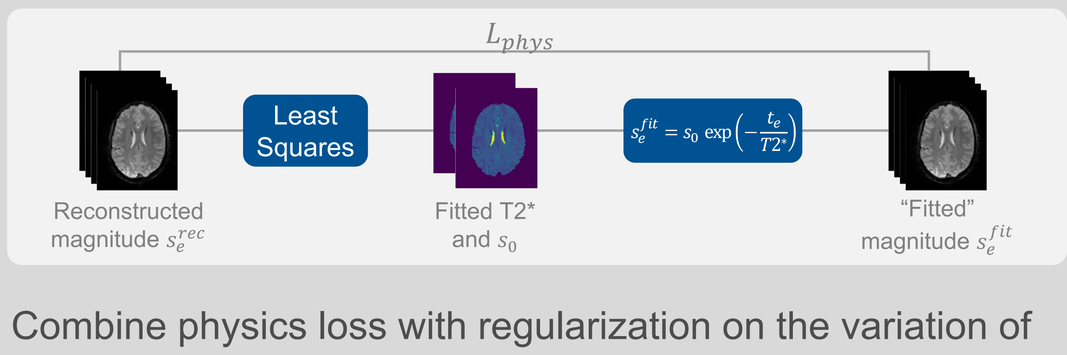


2. Reconstruction of undersampled data with unrolled network

→ *Pre-trained on motion-free data (supervised)*



Utilizing empirical correlation coefficient as physics loss

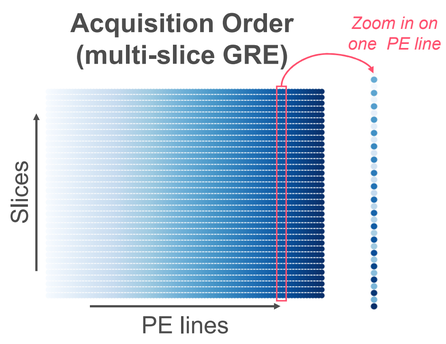


→ Combine physics loss with regularization on the variation of predicted masks for adjacent slices:

$$L = L_{phys} + \lambda L_{reg} = L_{phys} + \lambda \sum_{z=1}^{Z} | \mathbf{\Omega}_z - \mathbf{\Omega}_{z+2} |$$

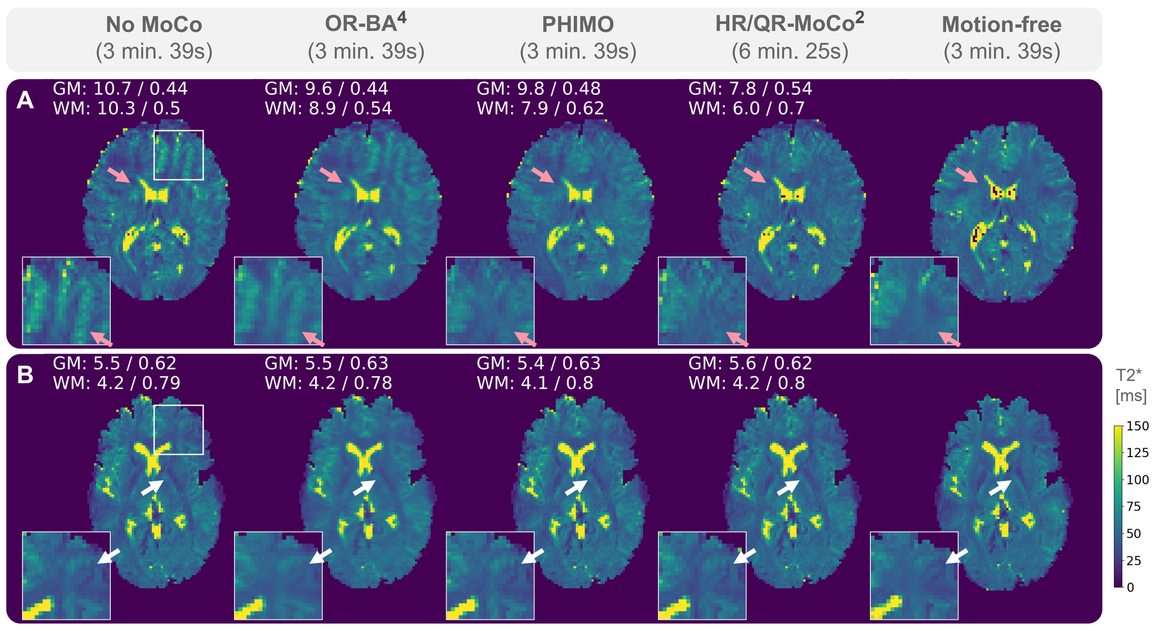
Data details

- Multi-coil raw k-space data from 15 volunteers (6/2/7 subjects for train/val/test set)
- Repeated scans with and without voluntary head motion

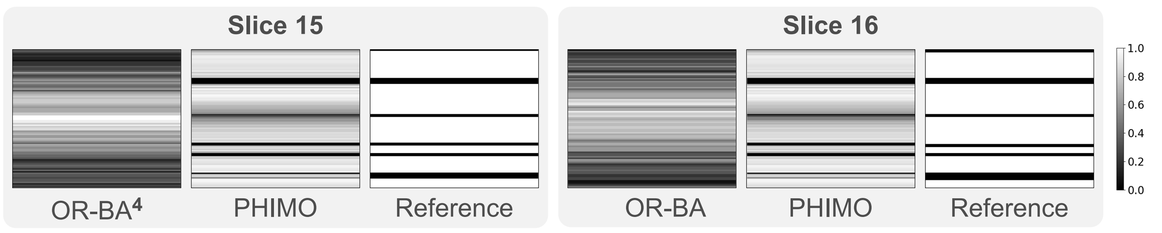


PHIMO detects and excludes motion

PHIMO suppresses severe motion artefacts and preserves image quality for minor motion case

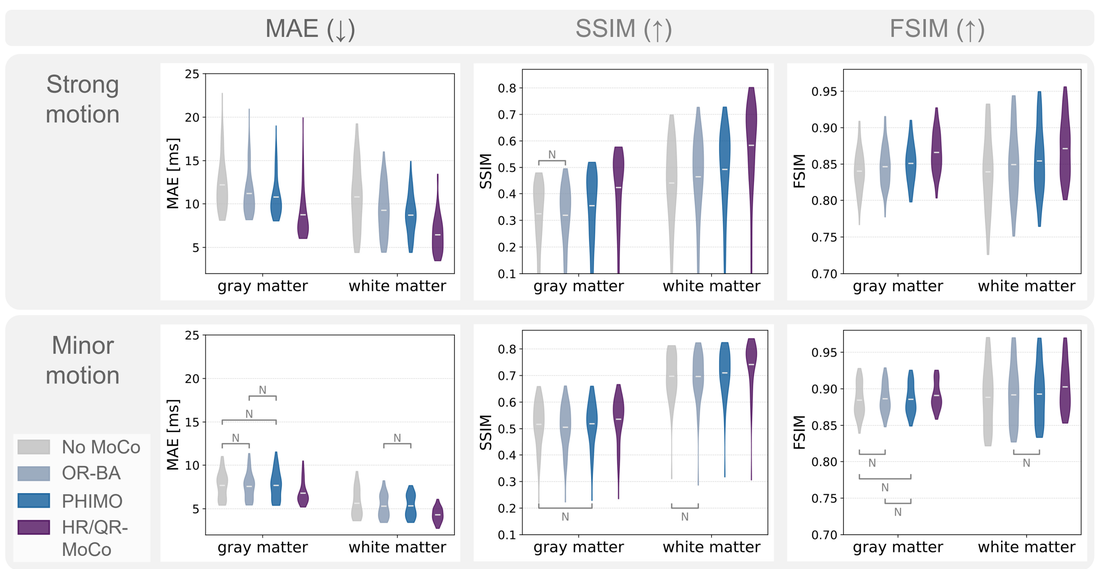


PHIMO detects individual motion events:



Improved image quality

PHIMO quantitatively approaches the performance of HR/QR-MoCo and outperforms OR-BA:



4 test subjects with severe and 3 test subjects with minor motion; brackets indicate comparisons with no statistical significance

References

1 Magerkurth et al., "Quantitative T2* -mapping based on multi-slice multiple gradient echo flash imaging: Retrospective correction for subject motion effects: Movement correction in T2* mapping." MRM (2011).
2 Nöth et al., "An improved method for retrospective motion correction in quantitative T2* mapping." NeuroImage (2014).
3 Spieker and Eichhorn et al., "Deep Learning for Retrospective Motion Correction in MRI: A Comprehensive Review." IEEE TMI (2024).
4 Oh et al., "Unpaired MR Motion Artifact Deep Learning Using Outlier-Rejecting Bootstrap Aggregation." IEEE TMI (2021).