Slice-by-slice motion correction in spinal cord fMRI

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Challenges in spinal cord fMRI

- Spinal cord is a thin structure
  - Small voxels → Low SNR
  - Partial volume effect → Weaken focal activations[1]
- Physiological fluctuations
  - Cardiac and respiratory motions, CSF and vascular pulsation
    → High autocorrelations critical with statistical methods (GLM)[2]
    → Motion of structures[3]
- Susceptibility artifacts
    → Image distortions, signal dropout
    → Susceptibility-related motion[4]

[1] Cohen-Adad, *Neuroimage* (2009) ; [2] Brooks, *Neuroimage* (2008) ; [3] Figley, *Magn Reson Med* (2007)
[4] Van de Moortele, *Magn Reson Med* (2002)

Axial slice-independent motion

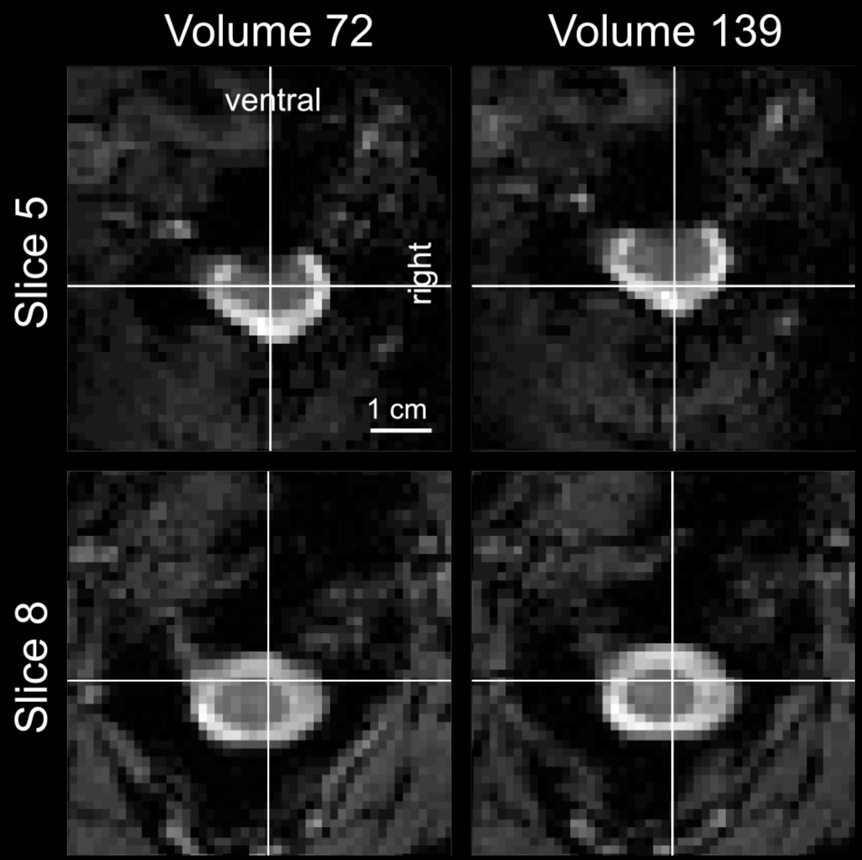
Causes

- Spinal cord articulated geometry
- Physiological fluctuations (CSF pulsation)
- Susceptibility-related motions due to respiration

Consequences

- Slice-independent motions in A-P or R-L directions

→ Critical for detecting focal activations



Motion correction

Classical method

- 3d rigid-body realignment of volumes
- Six degrees of freedom (Tx,Ty,Tz,Rx,Ry,Rz)

→ Lack of precision if slice-independent motion[1]

Proposed method

- 2d rigid-body realignment of slices
- Three degrees of freedom (Tx,Ty,Rz)
- Realistic assumptions
  - No rostro-caudal subject motion (Tz=0)
  - No rotation around X and Y axis (Rx=Ry=0)

[1] Cohen-Adad, *IEEE-EMBS* (2007)

Algorithm

- Estimation of three parameters (Tx,Ty,Rz) per slice
- Cost function = Correlation
- Target image = Mean image
- Minimization algorithm = fmeansearch[1]
  - Maximum number of iterations = 500
  - Termination tolerance = 0.0001
  - Initial conditions = Parameters from previous slice

[1] Lagarias, *SIAM J on Optimization* (1998)

Validation in real data

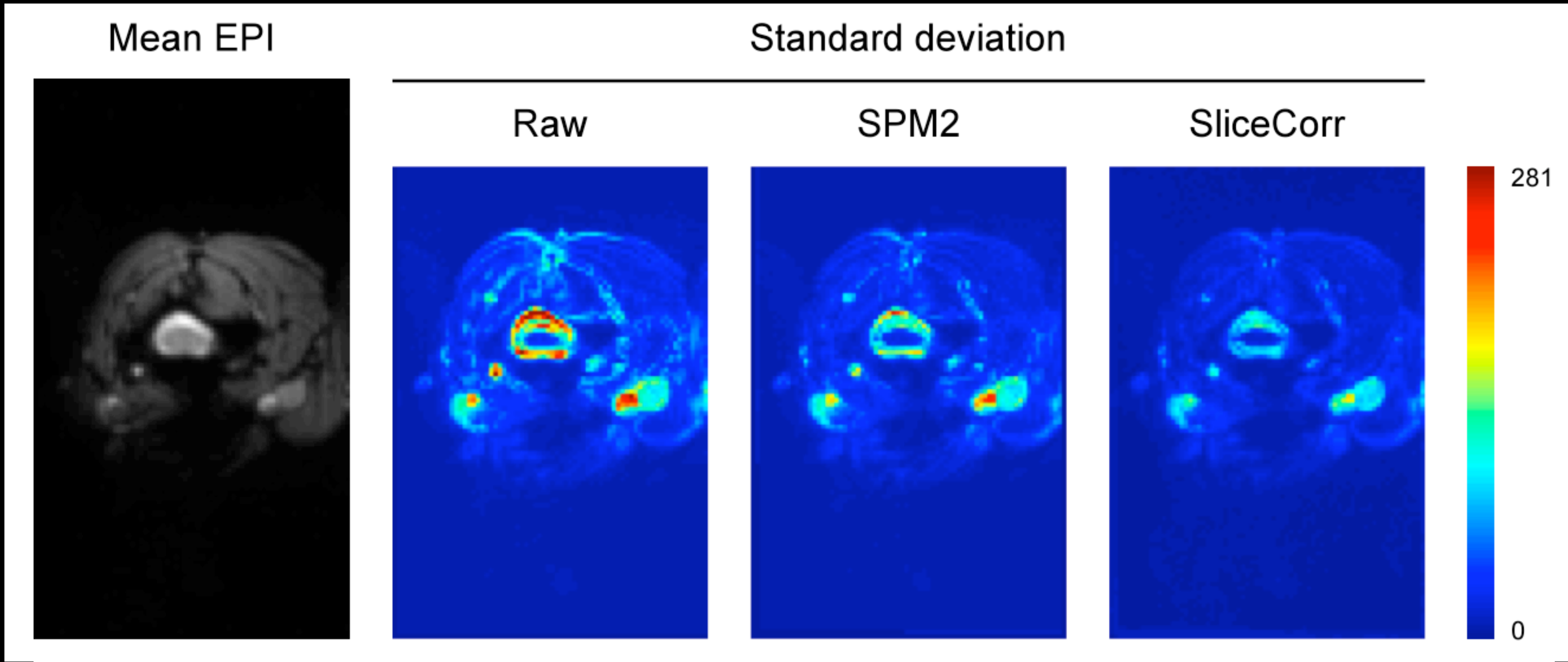
- Healthy volunteers (N=6)
- 3T MRI system (head & neck coils)
- Axial EPI (TR/TE = 3000/35 ms)
- 1.5×1.5 mm^2 in-plane resolution
- 4 mm slice thickness (80% gap)
- iPAT = 2 (R-L phase-encoding)
- Eight minutes acquisition at rest

Evaluation of the method

- Comparison with 3D method (SPM2)[1]
- Visual inspection of time series
- Standard deviation maps
- Root mean square error (RMSE) computed between each realigned volume and one target volume (mean volume)

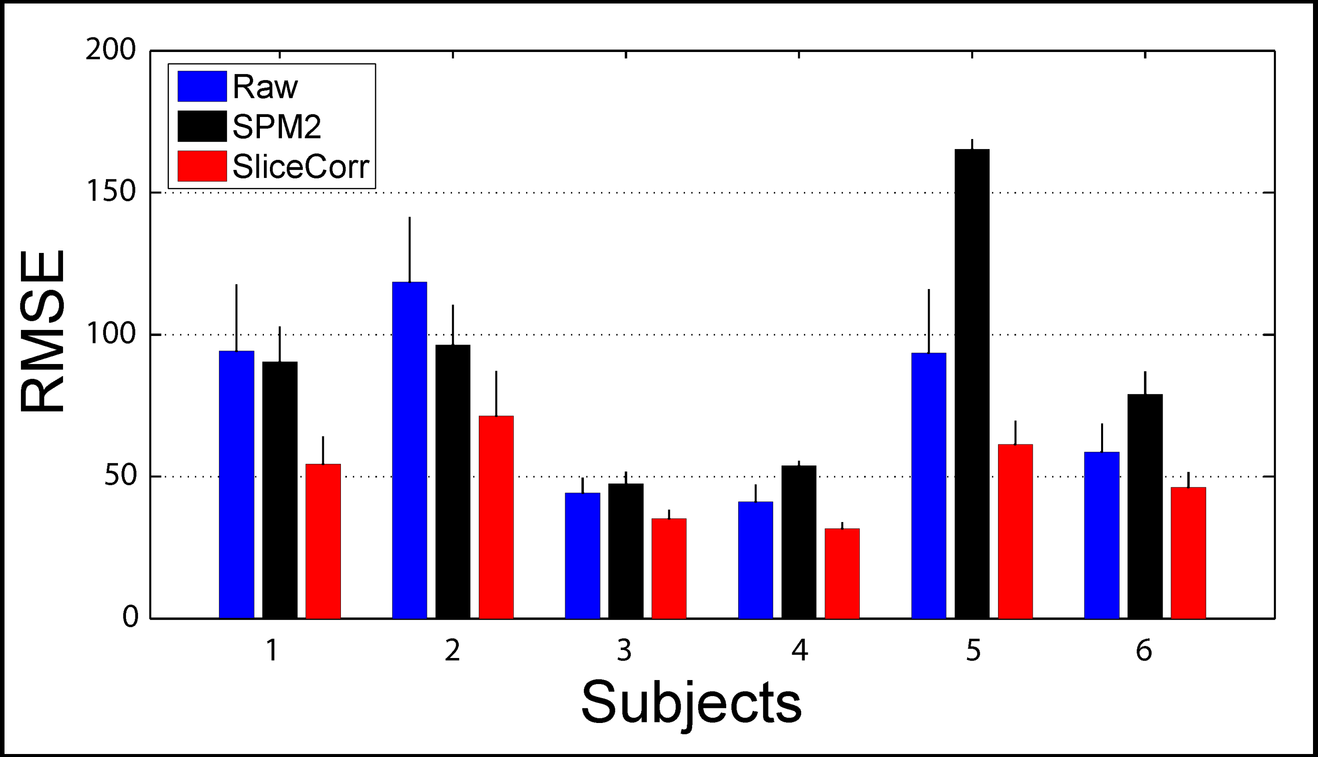
[1] Friston, *Human Brain Mapping* (1995)

Standard deviation map



Typical standard deviation map for one subject and one slice located at C4. This figure shows the improvement of motion correction in axial plane for the 2D method.

RMSE



Root mean square error (RMSE) computed between each volume and an average volume. RMSE was computed within a mask covering the spinal cord. Error bars shows inter-slice variability

Conclusion

Synthesis

- Efficient motion correction in spinal cord fMRI is crucial
- 2D slice-by-slice motion correction yields best accuracy

Limitation

- Although more robust, 2D registration assumes no through-slice motion (Z=0)
- The proposed method has been validated for axial acquisition only

Perspectives

- Validation in non-axial acquisitions (re-slicing required)

Acknowledgements

Claudine GAUTHIER
Carollyn HURST
André Cyr

Jonathan BROOKS
Mark JENKINSON

Grants: