

# rsfMRI of the human spinal cord: technical challenges, solutions and reproducibility

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**Target Audience** Neuroscientists interested in rsfMRI of the spinal cord

**Purpose** This study reports the first demonstration of reproducible rsfMRI of the human spinal cord. The challenges and solutions associated with spinal cord rsfMRI were described. As a demonstration, we focused on rsfMRI analysis of the cervical spinal cord from C1-C4.

**Methods** Four self-declared normal volunteers were studied. For each subject, 4 repeated BOLD rsfMRI scans were performed at 3T, covering the bottom of C1 to C4. Gradient-echo EPI parameters were: axial FOV=128x128mm, matrix=128x128, TR=2s, TE=26ms, Thk=3mm, 23 slices, 300 time points (10 mins). Anatomical T2 turbo spin echo images were also obtained with TR=6.9s, TE=70ms, flip angle 150°, NT=2, and 1x1x3 mm. Coregistration was done semi-manually. rsfMRI was analyzed on the masked spinal cord using independent component analysis (ICA).

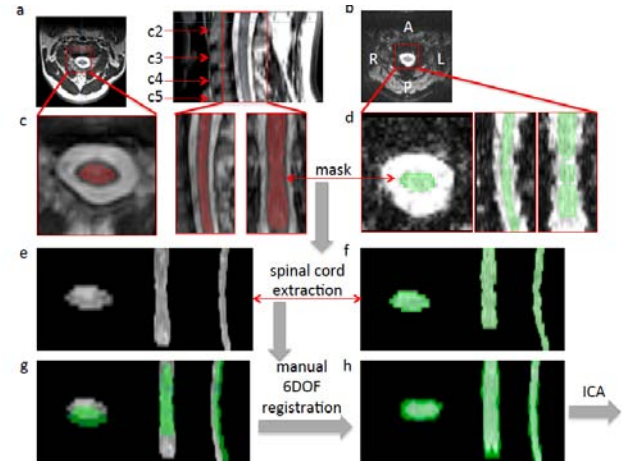
**Results** rsfMRI of the spinal cord was more susceptible to motion artifacts compared to the brain. Subjects often adjusted neck positions for comfort. The use of a neck brace markedly reduced motion artifacts and facilitated co-registration across multiple rsfMRI trials within as well as across subjects. Signal fluctuation from physiological noise in the spinal cord was apparent in the time-loop movies, likely due to its small structure, cardiac and respiratory motion, and cerebrospinal fluid pulsation.<sup>1,2</sup> The small spinal cord structures also required relatively higher spatial resolution. Magnetic field inhomogeneity around the intervertebral disks created distortions but was not a significant issue in the spinal cord. The shape of the spinal cord varied substantially across individuals. Co-registration was done semi-manually within and across subjects as there are no automated algorithms in contrast to the brain.

**Figure 1** displays a schematic of the rsfMRI analysis, where the spinal cord was extracted and time series EPI were co-registered to the anatomical images. To demonstrate reproducibility, we examined the rsfMRI maps of four repeated trials from the same subjects in the same scan sessions. **Figure 2** shows three of the rsfMRI ICA components across 4 repeated trials. The rsfMRI patterns were reproducible.

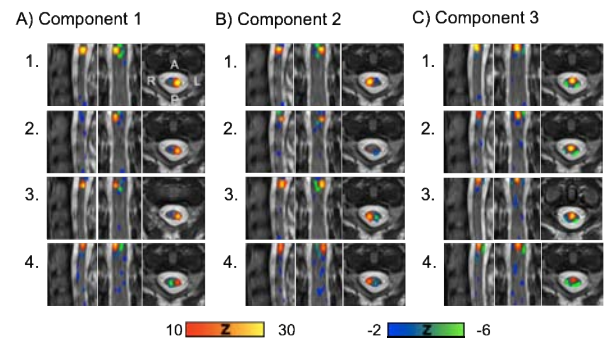
The group-averaged rsfMRI maps from 4 subjects are shown in **Figure 3**. The majority of the rsfMRI patterns were localized to gray matter albeit with some partial-volume effects. Some rsfMRI patterns were bilateral (component #5,8,11,14) while others were unilateral (component #2,3,7,9,10). Some components also showed top-down functional connectivity, most evident from the sagittal and coronal views (component #3-7,10-13). Some components also showed anti-correlation (blue-purple pixels).

**Discussion & Conclusions** This study demonstrates a novel rsfMRI application in the human spinal cord. The challenges and solutions are detailed. Reproducibility within and across subjects was demonstrated. A major finding is that there are multiple prominent rsfMRI patterns in the spinal cord, showing extensive unilateral, bilateral, and top-down functional connectivity. Future studies will improve spatial resolution, image the entire spinal cord, map spinal cord connectivity with the brain, as well as explore clinical applications, such as post-traumatic injuries and neurodegenerative conditions.

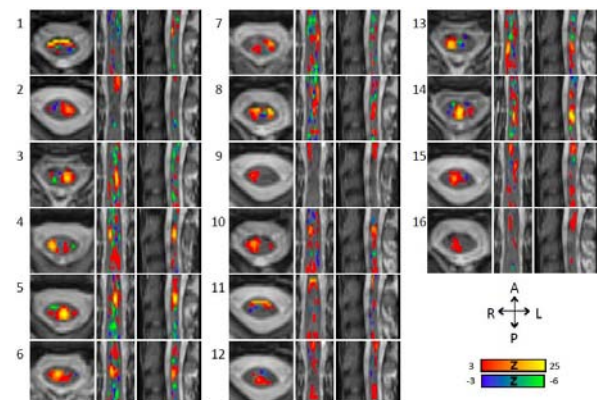
**REFERENCES** (1) Brooks et al. Neuroimage 2008;39:680. (2) Kong et al. Neuroimage 2012;60:1538.



**Figure 1.** Schematic of the ROI extraction of the spinal cord and co-registration.



**Figure 2.** Reproducibility. rsfMRI map of three of the rsfMRI ICA components across 4 repeated trials for one subject. Sagittal, coronal, and axial images are shown from left to right for each trial.



**Figure 3.** rsfMRI of the spinal cord showing different ICA components