Using edge voxel information to improve motion regression for rs-fMRI connectivity studies

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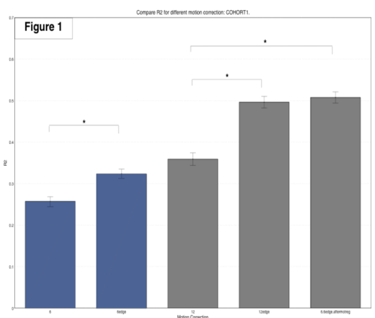
Target audience and purpose: This work is of interest to the scientific community that makes use of functional MRI (fMRI) for clinical or method-oriented research. It aims at providing novel preprocessing tools to improve motion correction and obtain better results. Namely, motion-related information contained in the brain edge voxels is extracted using a principal component analysis (PCA) and included as regressors of no interest in a linear regression algorithm to reduce the influence of motion on functional connectivity measures.

Background: Recent fMRI studies have outlined the critical impact of in-scanner head motion as well as the importance of using motion correction schemes to generate believable results[1,2,3,4]. For example, studies by Van Dijk et al., and Power et al. [1] called attention to the particularly deleterious effects of subject motion in resting fMRI (rs-fMRI), leading to a series of studies focused on improving the veracity rs-fMRI connectivity measures and determining the precise cause of these motion-related results[5,6,7]. The authors have generously made their data publicly available via the FCON1000 initiative, thus giving the opportunity for many other groups to test their own hypotheses and tools on a common dataset. Our goal was to test a novel motion reduction strategy using this dataset.
Standard motion corrections include either 6 parameters of motion or these 6 parameters of motion and their derivatives in a nuisance regression. A prior study by Birn et al.[8] showed that task-related motion effects in task-activation fMRI could also be successfully modeled using signal intensity time courses from the edge of the brain, a region where motion effects are particularly prominent. These edge voxel time series can more accurately reflect the amplitude of signal changes induced by complex 3d head motion. We hypothesized that there is redundancy of information in the standard set of 6 or 12 motion regressors and that a set consisting of the same number of regressors made of principal components (PCs, independent of each other by definition) of the edge voxel time series would explain more variance (i.e. higher R^2) and improve data quality (i.e. lower DVARS[1] and temporal SNR).

Methods: We used the subjects from cohort1 (n = 22, age = 8.5 +/- 1 yrs) of the data from Power et al. Each subject's rs-fMRI data were pre-processed including the following steps: slice-timing correction, realignment, mode 1000 normalization, alignment to a template, spatial and temporal smoothing, and nuisance regression. Nuisance correction included WM, CSF, and global signal regression as well as motion regression. This motion regression consisted of either 1) the 6 realignment parameters (hereafter "6"), 2) the 6 realignment parameters and their first derivatives (hereafter "12"), or 3) the SPCs from the brain's edge voxels. To compare our method to the "6" method, we used the first 6 PCs of the edge voxel time series o(hereafter 6edge); for comparison with the "12" method, we used the first 12 PCs (hereafter 12edge), in order to keep the same number of nuisance regressors (degrees of freedom) for the methods being compared. Finally, we tested a combination of the standard method and our method: 6 PCs derived after motion regression plus the 6 motion realignment parameters, giving a total of 12 regressors (hereafter 6.6edgeaftermotreg). We did not include a combination of the 6 realignment parameters and 6 PCs derived before motion regression, as those PCs would likely include redundant information with the 6 parameters of motion. Global signal correction has been shown to influence motion correction results[7] so we repeated the study without the use of global signal.

Results and discussion: As shown in Figure 1, our hypothesis is confirmed; the PCs derived from edge voxels explained significantly more variance than the standard methods. Figure 2 shows that any motion correction significantly improves image quality (lower DVARS); it also confirms our expectations about an increase in image quality when our edge-voxel regression methods are used as compared to the standard approach. However, no significant improvement was found in the whole-brain average tSNR (graph not shown here), likely due to the relatively small amount of variance explained by motion across the whole brain. Similar results were found when global signal was not used.

Conclusion: In conclusion, using independent regressors derived from signal intensity time courses at the edge of the brain significantly improves motion correction, explaining more variance and improving image quality.



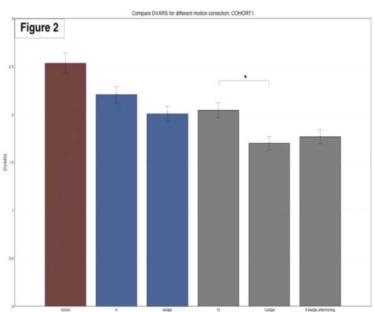


Figure1: Variance explained by each regression (R^2). Axis labels: x-axis – motion regression (6, 6edge, 12, 12edge, 6.6edge.aftermotreg); y-axis: Variance explained (R^2). * = significant difference. Blue = 6 regressors. Gray = 12 regressors.

Figure2: DVARS results for each regression. Axis labels: x-axis – motion regression (no motion regression, 6, 6edge, 12, 12edge, 6.6edge.aftermotreg); y-axis: DVARS. * = significant difference. Red = no motion regression. Blue = 6 regressors. Gray = 12 regressors.

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