Correcting Motion Induced Connectivity Changes in Resting-State fMRI

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Introduction: Motion correction is a typical step employed in the processing of Resting State fMRI (RS-fMRI) data to alleviate the effects of head motion on functional brain signal. It usually involves alignment of functional time frames using image registration and regression of the motion related parameters from the MRI signal [1-3]. However, it has been shown that customary approaches do not totally remove the artifactual signal and that remnant motion affects functional connectivity measures and results in altered connectivity patterns [1-3]. Data scrubbing, which involves identifying and removing volumes with excessive motion from the functional MRI timeseries, has been proposed to alleviate these effects and has been shown to diminish the changes in connectivity induced by head motion [4]. Data scrubbing however raises several questions and problems, including the proper order of processing steps [5, 6] and validation of filtering and statistics due to variable sampling rate induced by excluding volumes. Independent Component Analysis (ICA) has been used for identification and correction of several artifacts, including head motion [7]. In this study we investigated the feasibility of ICA-based motion correction to effectively decrease spurious motion related RS-fMRI connectivity. Data scrubbing, ICA motion correction, and customary, basic motion correction were evaluated by examining and comparing their effect on the default mode network connectivity.

Methods: Nineteen healthy subjects were scanned using a 3T Trio Siemens MRI scanner. RS-fMRI images were acquired using a GRE-EPI sequence (TR/TE = 2000/29 ms, flip angle = 90°, 36 slices, ~3.2x3.2x3.2mm^3, 200 volumes). Processing was performed with locally developed software and FSL and included frame alignment, brain extraction, B0 field inhomogeneity correction, spatial smoothing with 5mm FWHM kernel, temporal filtering (0.01 – 0.1 Hz), and inclusion of the six motion parameters, white matter, and CSF signals as regressors. To identify subjects with excessive head motion, framewise displacement (FD) and temporal derivative of RMS variance (DVARS) were calculated for each volume [4]. Subjects were assigned to a high-motion group if any volume of their dataset had FD greater than 0.5 and DVARS greater than median plus one standard deviation. The remaining subjects were assigned to a reference, low-motion group. The motion in the high motion group was corrected in three ways: 1) using the above-mentioned steps and no extra motion correction (*Basic Correction*); 2) using the additional data scrubbing step; i.e., eliminating volumes with excessive motion along with one volume before and two volumes after each volume with motion (*Scrubbing*); 3) using ICA motion correction; i.e., identifying and extracting motion-related components with ICA (*ICA*). To investigate the effect of different motion correction methods, the default mode network was identified by calculating voxel-wise connectivity to Posterior Cingulate Cortex (PCC). For each motion correction method, group average connectivity maps were generated for the high-motion and reference groups. Difference maps between the PCC connectivity of the two groups were used to assess each method's efficacy in suppressing excessive head motion.

Results: Six subjects were assigned to the high motion group and 13 to the reference, low-motion group. Difference maps between default mode network connectivity in high and reference groups generated for each of the three motion correction methods are shown in Figure 1. Several areas, including the precentral gyrus, lateral occipital cortex, middle frontal gyrus, and occipital pole, show increased motion induced connectivity to PCC when only the *Basic Correction* is employed. Similar patterns of atypical connectivity are obtained for the *Scrubbing* method. For *ICA* motion correction, only small, restricted areas show connectivity differences to the reference data set.

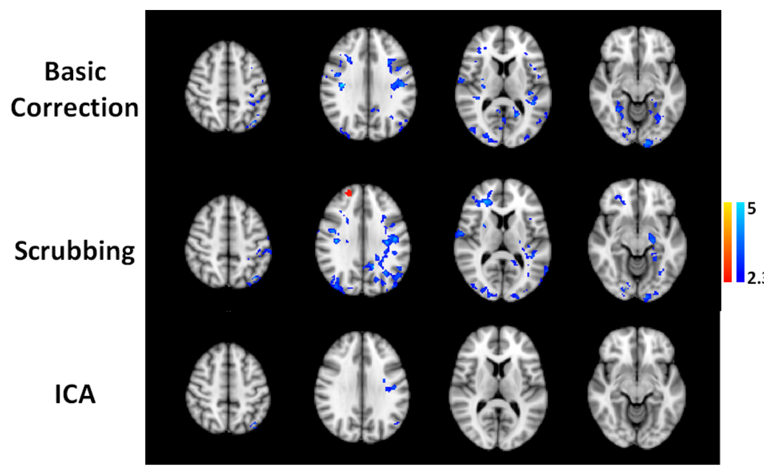

Figure 1. Difference maps between the PCC connectivity of the high-motion and reference groups. Red shows areas where connectivity in the high motion group is lower and blue areas where connectivity is higher than in the reference group.

Discussion: Adequate motion correction of the RS-fMRI data is of paramount importance given this method's applicability to study brain dysfunction in a wide variety of disorders. Using basic motion correction, PCC shows increased connectivity to several brain regions in the high-motion compared to the reference group, indicating that regular motion correction steps cannot eliminate the effect of excessive head movement and consistent with previous studies that have used similar regressors to the ones employed here[2]. The *Scrubbing* method does not seem to improve upon the altered connectivity patterns observed for *Basic Motion Correction* in our data set. Finally, the *ICA* method appears to give the best results in suppressing motion-induced connectivity increases. These results suggest ICA as an effective approach in reducing motion deleterious effects on functional connectivity. ICA motion correction however must be performed with caution, as identifying motion related components could be complex and subjective. Further studies will examine its efficacy for extended brain networks and in larger populations and will compare its results to other newly introduced approaches [2].

References: [1] Van Dijk KRA, et al. 2012. Neuroimage 59, 431; [2] Satterthwaite TD, et al. 2013. Neuroimage 64, 240; [3] Satterthwaite TD, et al. 2012. Neuroimage 60, 623 ; [4] Power JD, et al. 2012. Neuroimage 59, 2142; [5] Carp J. 2012. Neuroimage; [6] Power JD, et al. 2012. Neuroimage; [7] Liao R, et al. 2006. Magn Reson Med. 55(6), 1396.