Evaluating Artifact Introduced by Intra-Subject Motion Correction in Functional MRI

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Target audience

Experienced MR scientists who are interested in new progress of motion correction;
Clinicians who need to interpret diagnostic results and avoid spurious activation region.

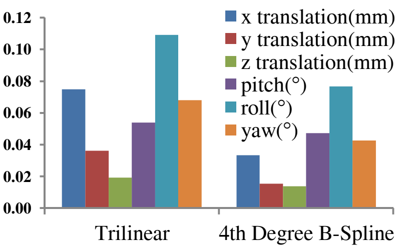
Purpose

Even extremely subtle head motion could affect outcomes of functional connectivity network maps[1, 2].Such motion-induced signal changes may reflect both motor-related neuronal activity and motion artifact[3]. In addition to magnetic susceptibility, a potential source of motion artifact could be image-processing operations. As one of most typical image process, spatial resampling is demanded by head-motion correction of functional images. It deals with interpolation among neighboring voxels, and could be problematic when local signal is not homogeneous. The goal of this study was to evaluate the spatial resampling process during motion correction, and to verify that this artifact occurs at areas can be easily affected by the partial volume effect. In order to exclude the effect of motor-related neural activity, simulation experiments were designed and three types of data were created corresponding to common types of head motion.

Methods

The simulation was based on a real dataset that includes 30 subject's resting-state functional scans. These functional time series were first realigned to the first frame to correct head motion, output motion parameters of six directions and mean image for each subject. After that, spatial normalization and smoothing were also applied. (*Simulation 1*): In the first experiment, we translated and rotated the mean image of a randomly selected subject with certain distances and degrees, which has 200 frames randomly distributed in a range of -3~ 3 mm or degree. It formed a new motion-corrupted dataset, and they were then motion corrected. The newly output parameters were compared with initial input parameters, and their differences in each direction gave the error introduced by resampling. To emphasize the influence, two typical interpolation methods, i.e. trilinear and 4th B-Spline, were compared. Further simulations only used B-Spline because of its better performance. (*Simulation 2*): The second test was to measure the relative amplitude of interpolation-introduced error. The mean image of each subject was now moved based on one's own real motion parameters. The amplitude of low frequency fluctuation was computed from both simulated signal and real BOLD signal, and their ratio was standardized by subtracting out whole brain mean ratio and then divided by whole brain variance[4]. A group one-sampled t-test was then conducted to determine the most suspicious regions. (*Simulation 3*): Correlation between motion parameters and interpolation-introduced error was also investigated. We simulated three typical cases: *minor motion* less than 0.6, obtained by restricting real motion parameters in the range of -0.6~0.6 mm or degree; *abrupt motion*, obtained by randomly permuting frames of the minor motion data to be more noisy; and *big-spike motion*, obtained by multiplying 5% of motion values of minor motion data by 3. These data were all corrected and processed as regular procedure. At the same time, Voxel-specific framewise displacement (FDvox) was measured per voxel as motion signal[5]. And correlation between the motion signal and BOLD signal was computed and transformed to z-values. One sample t-test was run to find the most correlated regions in-group. Furthermore, motion-models used in literatures, including Rigid-body 6-parameter model, Derivative 12-parameter model, Friston 24-parameter model, and Voxel-specific 12-parameter model were calculated to further reduce head motion effects on each simulated motion cases[5,6].

Fig. 1 Absolute maximum simulation errors in six directions with different interpolation methods



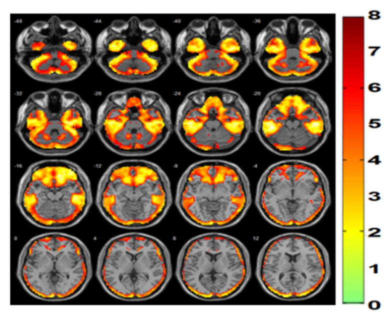


Fig.2 One sample t-test on all individuals' standardized ratio maps between ALFF maps of simulation data and those of human data.

Results

Simulation 1 reveals that trilinear interpolation produced slightly larger errors than 4th B-Spline, although this difference doesn't reach a significant threshold (Fig. 1). The amplitude study of simulation 2 shows that the relative error was greater in regions including frontal gyrus, subcallosal gyrus, temporal gyrus, fusiform gyrus and cerebellum posterior lobe (Fig. 2). These regions are also found most correlated with motion-signals (Fig. 3). In anatomy, the above-mentioned areas are near tissue boundary or close to CSF. In additional, an increasing trend can be observed from minor motion (Fig. 3A), abrupt motion (Fig. 3B) to big-spike motion (Fig. 3C). This indicates that when head motion gets worse, the interpolation process may even bring in more unexpected errors. Results after motion model correction mentioned that Friston 24 model and Voxel-specific 12 model showed better performance in reducing motion artifact, but the figures were not shown in this abstract due to limited space.

Discussion and Conclusion

In this study, we investigated the error signal introduced during head-motion corrected by simulation studies. The obtained results are solely based on image operation and have no impact from neural activities. Most possibly, the observed error signal is related with partial volume effect and local signal inhomogeneity. Compared with human brain activity, fluctuation amplitude of motion artifact in the regions including frontal cortex, cerebellum posterior lobe and temporal cortex had non-negligible effect. So results (such as significant motion-BOLD correlation, functional connectivity network maps) obtained in these areas regions need to be interpreted with special caution. At the same time, we cannot simply correction head motion when dealing with human data with big-spike motion, such as with Parkinson's patient data. Fortunately, Friston 24 model and Voxel-specific 12 model can partly reduce artifact introduced by motion correction. Minor motion, abrupt motion and big-spike motion are very common in daily life, so these related simulated results are instructive for our regular preprocessing operations and results interpretation.

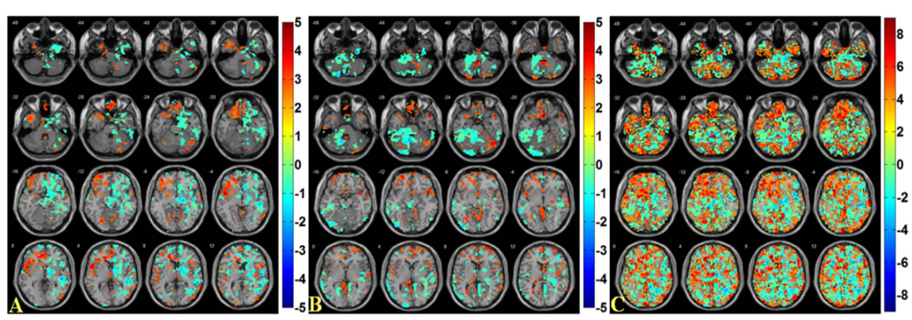


Fig. 3 One sample t-test on all individuals' Fisher's Z-score maps for the FDvox-BOLD relationship of three types of simulation data.

References

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