

A survey of patient motion in disorders of consciousness and optimisation of its retrospective correction

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Target audience

Users of retrospective motion correction in clinical populations.

Purpose

Functional magnetic resonance imaging (fMRI) is a powerful imaging modality in human brain research. Image quality, however, can be seriously impaired by patient motion. In this study, we explored the extent of motion in a clinical population and compared the performance of retrospective correction with rigid-body alignment as implemented in widely used software packages (of 100 randomly selected fMRI studies published in 2013, 55% used SPM [1], 15% used FSL [2] and 14% used AFNI [3]). We compared these packages in addition to the oldest tool available to us, AIR [4]. We evaluated the effect of user-changeable parameters in SPM8 for optimal results.

Methods

Patients with various degrees of disorders of consciousness ($n = 63$) were scanned using a Siemens Trio system at 3T with an fMRI visual checkerboard paradigm for 160 frames (EPI: TR/TE 2000/30ms, matrix 64×64 , FOV $192 \times 192 \text{mm}^2$, 32 slices of 3mm thickness with 0.75mm gap) producing a total of 121 series for analysis. Time series were corrected for motion with each package and the resulting transformations were used to calculate a motion score. Following [5], this score was defined by taking the RMS translation of temporal frames with rotational components included as the equivalent translation of points on a 64mm sphere. Each package was evaluated by comparing the motion score obtained by re-running the tool on the corrected data. For a consistent comparison between patients, a publicly available sample fMRI dataset (SPM auditory data, [6]) was artificially modified with the motion detected in each patient with each tool. The performance of each tool was measured by comparing the number of supra-threshold voxels in the largest significant cluster after standard fMRI analysis with SPM8 ($p_{\text{FWE}} < 0.05$ in the dataset without motion). We assessed the effect of user-changeable parameters on motion correction performance in SPM (separation, smoothing FWHM, quality factor and interpolation method) on the motion trajectory from each time series.

Results

Motion scores for all patients are shown in Figure 1. The mean score was 1.5mm during the time course, though 84% of patients showed motion less than 2mm. There was good agreement between the scores as measured by each package (see Figure 2). The time taken to finish all 121 time series is shown in Figure 3 and the residual motion score on the second pass is shown in Figure 4. For comparison, the interpolation error was measured by displacing the sample dataset with no motion by half a voxel in each dimension and this resulted in a cluster size of 93.4% of its original size. Figure 5 compares the mean cluster size obtained following motion correction by each package. SPM most closely matches the data without induced motion, followed by AFNI, AIR then FSL. Relative cluster sizes are represented in Figure 6 for different values of user-changeable parameters in SPM. The quality factor and interpolation method have no effect on the cluster size, while higher separation and smoothing reduce it.

Discussion

The majority of patients showed motion comparable to the voxel size of acquisition, with some severe outliers. There were considerable differences in the performance of packages used, with SPM giving the best performance closely followed by AFNI. FSL and AIR were considerably worse, and took more time to run. We did not find any combination of realignment parameters that increased the size of the fMRI activation cluster in SPM8. We therefore recommend choosing parameters that require the shortest time without affecting statistical power: realignment takes 4.2min with 8mm separation, 5mm FWHM (default), bicubic interpolation and a quality factor of 0.001. This is about 3 times faster than with the default values, and the cluster size remains unchanged (98.5%).

Conclusions

Our findings suggest that SPM offers the best compromise of time and performance for retrospective motion correction of fMRI time series.

References

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- [6] <http://www.fil.ion.ucl.ac.uk/spm/data/auditory/> (page visited on 2014-04-10).

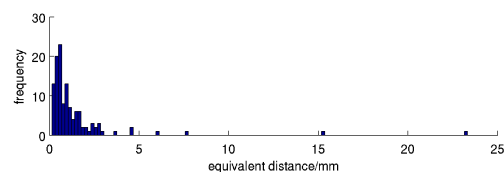


Figure 1 Estimates of motion in 121 fMRI time series obtained using SPM.

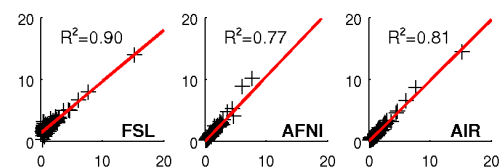


Figure 2 Comparison of motion parameters from different packages, with SPM plotted on the x-axis in each case. Units are equivalent distance (mm).

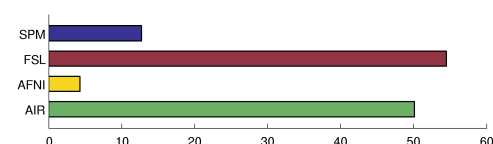


Figure 3 Time taken (minutes) to correct the motion of 121 datasets by each tool. SPM and AFNI were limited to 12 CPUs, whereas FSL and AIR made use of the full 32 CPUs of the machine.

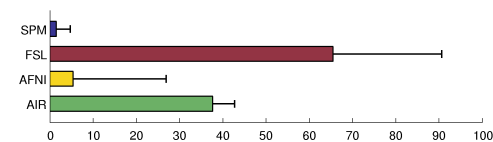


Figure 4 Residual motion (%) detected in a second pass of each tool on the corrected images. Error bars show standard deviations.

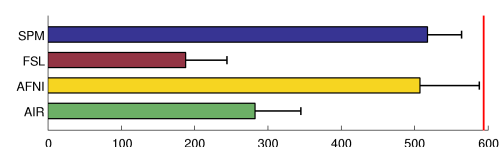


Figure 5 Cluster sizes obtained for each software package used for motion correction. A cluster size of 594 is obtained without motion (corresponding to $p_{\text{FWE}} < 0.05$). Error bars show standard deviations.

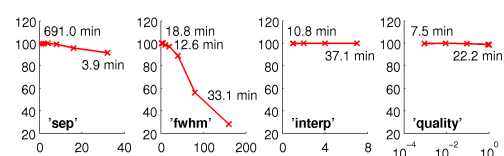


Figure 6 Cluster sizes (relative to result with default parameters, %) for different separation, smoothing FWHM, interpolation method and quality factor in SPM8 realignment. The time taken is shown for the first and last parameter values. It varies monotonically, except for smoothing, where it decreases rises again after the third data point (12.6min).