FATCAT: an (efficient) Functional And Tractographic Connectivity Analysis Toolbox

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INTRODUCTION

We present a suite of software tools for facilitating the combination of FMRI and diffusion-based investigation, the Functional And Tractographic Connectivity Analysis Toolbox (FATCAT).

The point of these tools is to assist in quantitatively studying both functional networks and their associated WM pathways with the regions of interest (ROIs) forming each network delineated, to the greatest degree possible, by each individual's own data. A diagram showing possible stages for combining FMRI and DW-tractographic analyses is shown in Fig. 1.

This toolbox was designed to integrate as easily as possible with existing standard software such as AFNI, FSL and TrackVis [1-3]. FATCAT is now freely available in AFNI along with demo data.

METHODS

FMRI. Maps of standard functional connectivity (FC) parameters such as ALFF, fALFF, RSFA and ReHo can be calculated simply using 3dRSFC and 3dReHo. 3dMatch compares sets of wholebrain maps and matches similar ones based on voxelwise comparison; this can be useful in group studies, for example to match subject ICA components.

3dROIMaker parcellates wholebrain FC maps into networks of GM ROIs by value thresholding and spatial clustering size. WM and CSF maps can be input to reduce partial voluming effects. A correlation matrix of mean time series between all pairs of the GM ROIs can be calculated using 3dNetCorr.

In order to turn the GM clusters into "targets" for tractography 3dROIMaker can inflate their volumes. The expansion of an ROI is halted wherever it reaches WM-labeled voxels in the reference image, reducing errors from overexpanding. An example of converting Z-score maps into networks of target ROIs is shown in Fig. 2.

DWI. Deterministic tractography is a useful first step for visualizing data. 3dTrackID estimates tracts between ROIs using the FACTID(fiber assessment by continuous tracking including diagonals) algorithm [4], and it calculates basic statistics of the region though which numerical tracts pass. Tracts can be mapped to other coordinates using map_TrackID, for example, for multisubject comparisons in standard space.

In order to perform probabilistic tractography, the uncertainty of DTI parameters due to noisy measures must be estimated. 3dDWUncert uses jackknife resampling to analyze subsets of a data set (no extra acquisitions necessary) in order to build a theoretical pseudo-population. Fig. 4 shows a schematic of the process, as well as slices of bias and σ for FA and the two degrees of freedom of the first eigenvector, **e1**.

3dProbTrackID performs probabilistic tractography using the parameter uncertainty estimates and a large number of Monte Carlo iterations of wholebrain (deterministic) tractography using FACTID. Locations of tracts which intersect any pairs of ROIs are recorded. The set of all voxels connecting a pair of target ROIs forms a WM ROI; statistics are calculated automatically.

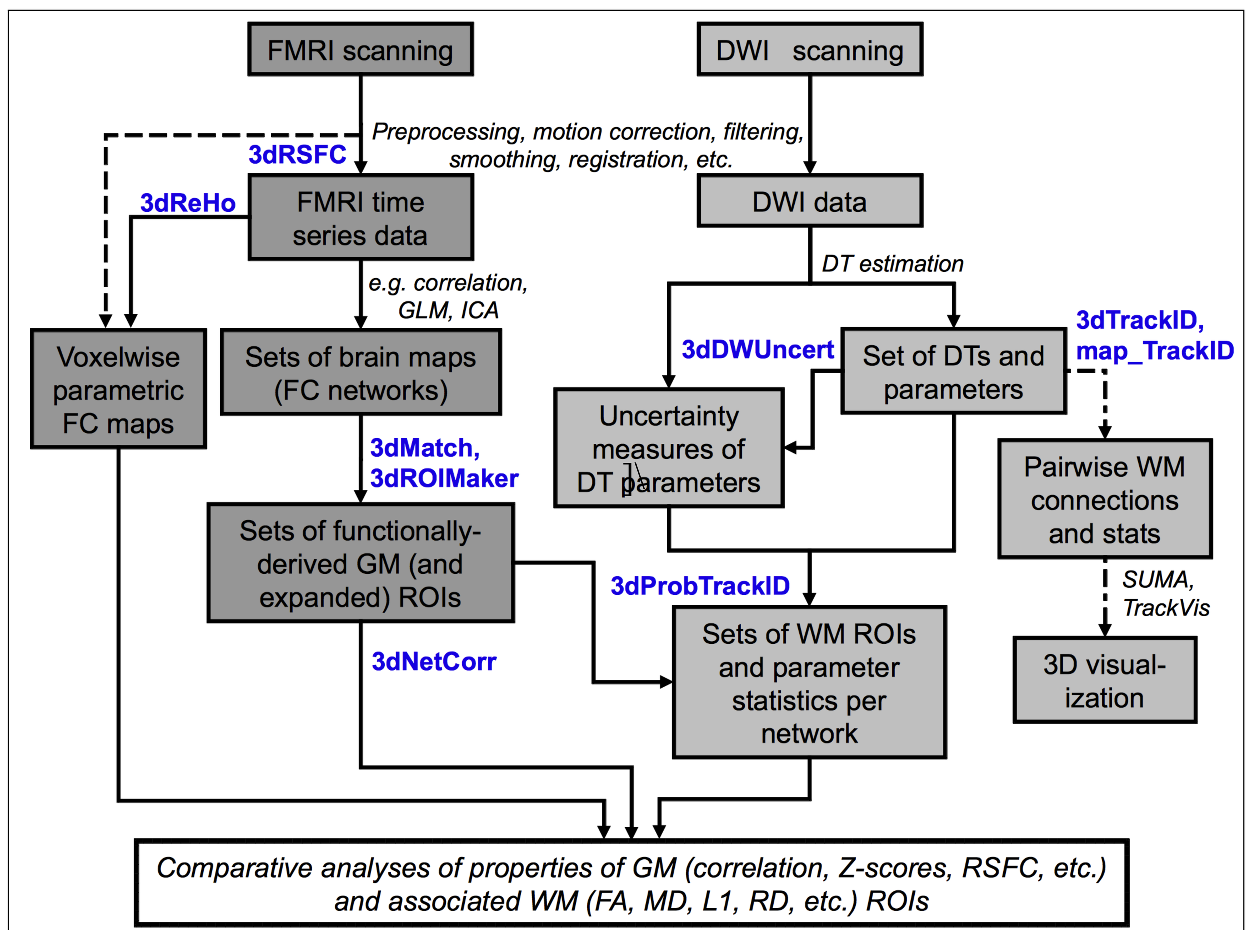

Figure 1. Schematic of FMRI (dark gray) and DTI-tractography (light gray) analyses, highlighting possible uses of FATCAT programs (blue), with additional steps in existing software (italics).

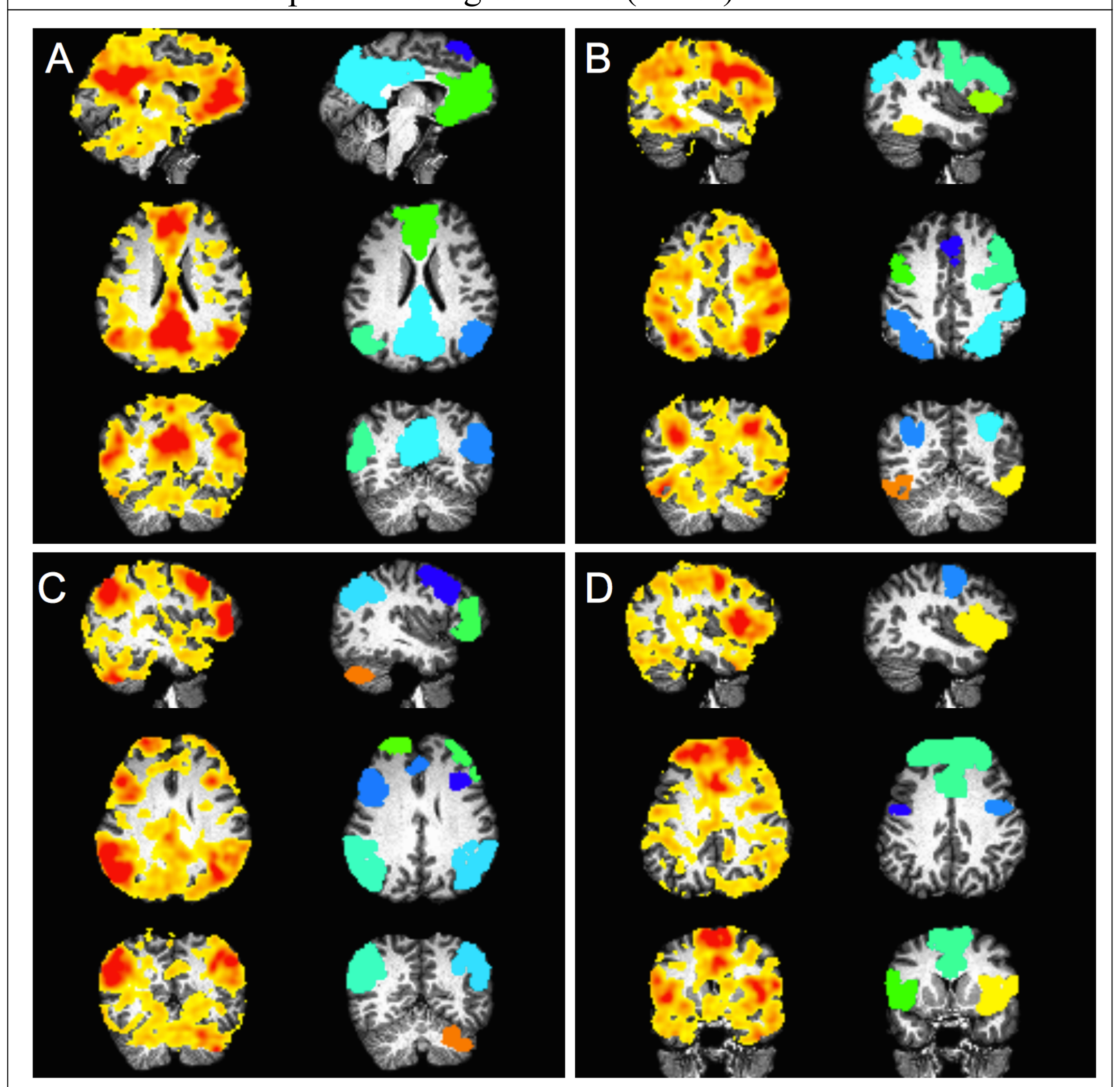

Figure 2. (Left per panel) Z-score maps (Z>0) from ICA of resting state FMRI, and (right) matching, inflated ROIs created using 3dROIMaker (clusters >130 voxels and inflation stopped at WM skeleton).

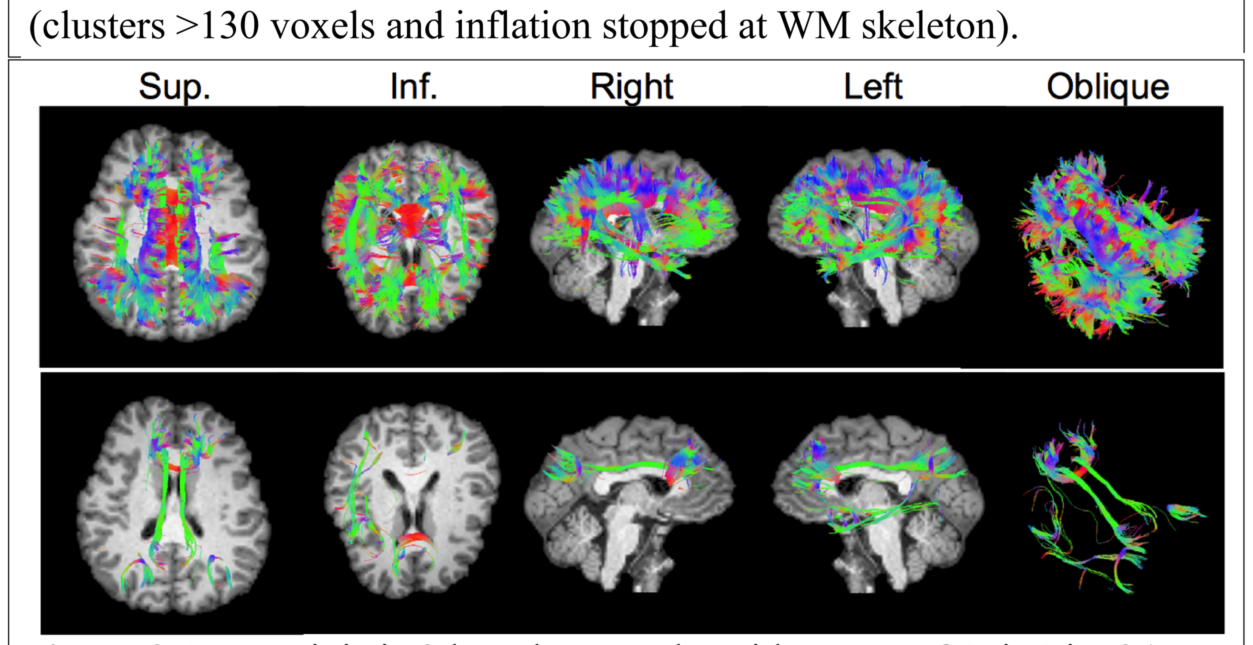

Figure 3. Deterministic 3dTrackID results with target ROIs in Fig. 2A. Shown are (top) tracks through any target ROI (OR logic), and (bottom) tracks passing through pairs of ROIs (pairwise AND logic).

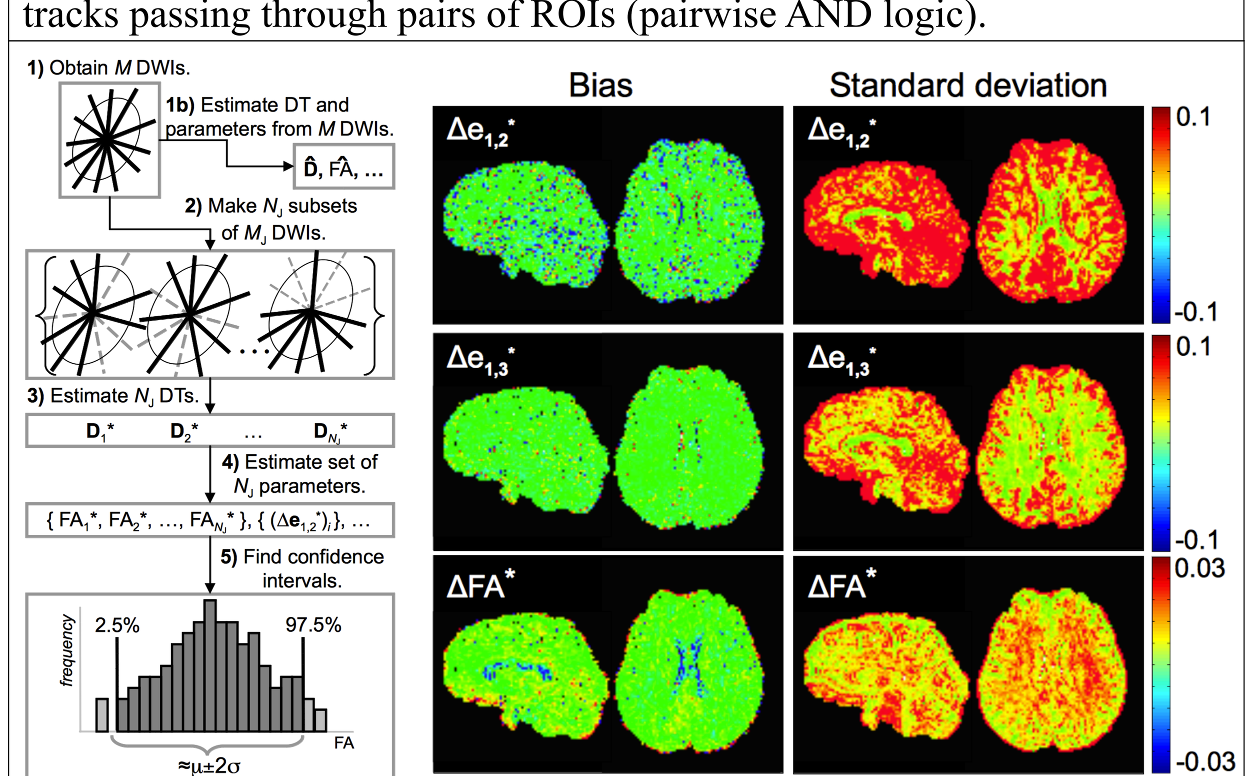

Figure 4. Schematic of jackknife resampling (left), and examples of uncertainty values across brain slices estimated using 3dDWUncert. Differences in GM and WM are evident, as well as the qualitative difference in $\mathbf{e}_1$ uncertainty along the different degrees of freedom.

Fig. 5 shows a comparison of FATCAT methods (blue) and existing FSL software (purple) for the four networks shown in Fig. 2 (orange ROIs). Results are broadly similar, and some differences are highlighted with arrows: red for regions having very different characteristics (e.g., a filled in volume vs filamentary structures), and yellow for tracks appearing in only one set of results. Qualitatively, 3dProbTrackID tracks tended to follow more circumscribed paths and generally found connections between more ROIs.

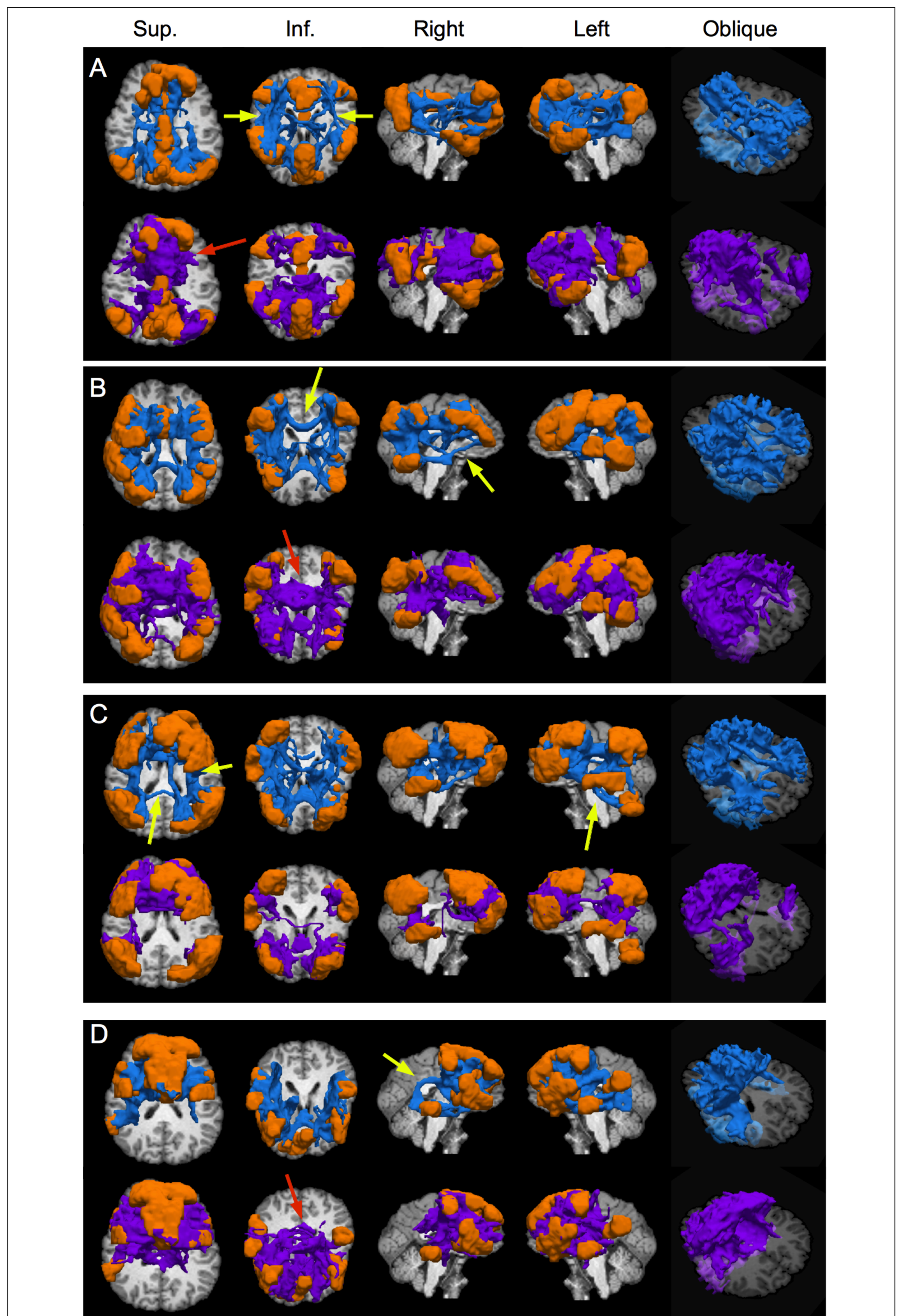

Figure 5. Probabilistic tractography results for 3dDWUncert and 3dProbTrackID (blue) and FSL's bedpostX and probtrackX (purple). Similar tracking options were used (FA>0.2, angular deflection <60deg, one propagation direction per voxel, 5000 iterations).

CONCLUSIONS

A striking feature of the FATCAT programs is their relative execution speed. While many programs (including those tested here using FSL) can run for more than a day for uncertainty estimation and tracking for a single network, 3dDWUncert and 3dProbTrackID completed execution in approximately 7min and 25min, respectively, on the same hardware (Mac OS, 2.3 GHz proc. and 4GB RAM) and for four rather than one network. One of the reasons for this sizable decrease in runtime is the algorithmic efficiency of jackknife resampling and FACTID propagation. Moreover, simultaneously testing for connectivity among several networks adds very little computational time. Multi-direction Q-ball modeling and tractography will soon be added, and users are encouraged to use AFNI's message board for support and feedback.

REFERENCES

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