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Generating and reporting peak and cluster tables for voxel-wise inference in FSL

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Abstract

Mass univariate analyses, in which a statistical test is performed at each voxel in the brain, is the most widespread approach to analyzing task-evoked functional Magnetic Resonance Imaging (fMRI) data. Such analyses identify the brain areas that are significantly activated in response to a given stimulus. In the literature, the significant areas are usually summarised by providing a table, listing, for each significant region, the 3D positions of the local maxima along with corresponding statistical values. This tabular output is provided by all the major neuroimaging software packages including SPM, FSL and AFNI. Yet, in the HTML report generated by FSL, peak and cluster tables are only provided for one type of inference (cluster-wise inference) but not when a voxel-wise threshold is specified. In this project, we proposed an update for FSL to generate and report peak and cluster tables for voxel-wise inferences.

Keywords

fMRI, Mass univariate analyses, Results reporting

Introduction

Mass univariate analyses, in which a statistical test is performed at each voxel in the brain, is the most widespread approach to analyzing task-evoked functional Magnetic Resonance Imaging (fMRI) data. Such analyses identify the brain areas that are significantly activated in response to a given stimulus. In the literature, the significant areas are usually summarised by providing a table listing, for each significant region (also known as "cluster"), the 3D positions of the local maxima (also known as "peaks") along with corresponding statistical values. This tabular output is provided by all the major neuroimaging software packages including Statistical Parametric Mapping (SPM Penny et al. 2011), the FMRIB Software Library (FSL Jenkinson et al. 2012) and Analysis of Functional NeuroImages (AFNI Cox 1996).

Yet, in the HTML report generated by FSL, peak and cluster tables are only provided for one type of inference (cluster-wise inference) but not when a voxel-wise threshold is specified. The goal of this project was to extend the functionalities of FSL to generate and report peak and cluster tables for voxel-wise inference.

As part of its outputs, FSL FEAT generates an HTML result page for each contrast of interest (e.g. "cluster_zstat1.html") which includes two tables. The first table provides a list of the significant clusters with their size in voxels; the cluster p-value, $-\log_{10}(\text{p-value})$, equivalent z-statistic and x, y, z coordinates of the voxel with the maximum statistic value as well as the estimated contrast value and the x, y, z coordinates of the voxel with the maximum contrast estimate. The second table provides a list of equivalent z-statistics and x, y, z coordinates for each peak in each cluster. Both tables are stored as text files (e.g. cluster table in "cluster_zstat1.txt" and peak table in "lmax_zstat1.txt"). Coordinates (x, y, z) are provided both in voxel space (e.g. "cluster_zstat1.html") and standardised world space (e.g. "cluster_zstat1_std.html") for first-level analyses and in standardised world space only for higher-level analyses (e.g. "cluster_zstat1_std.html").

Approach

First, we updated and refactored the FSL core "ztop" utility to generate p-values for corrected and uncorrected voxel-wise statistics. "ztop" is a command line tool which returns the p-value corresponding to an input z-statistic value. We extended "ztop" with a "-g" option which can be used to input the volume of the search space in resels in which case the command returns an FWE-corrected p-value (estimated using random field theory) rather than an uncorrected p-value (default). The computation of corrected and uncorrected p-values from z-statistic was extracted as a function so that it could easily be re-used (the "ztop" command line tool uses the "ztop_function").

Second, we updated the FSL core "cluster" class which creates the cluster and peak tables and saves them as text files (e.g. "lmax_zstat1.txt" and "cluster_zstat1.txt"). We added two new options for corrected ("--voxthresh") and uncorrected ("--voxunthresh") voxel-wise

thresholds and added calls to the “ztop_functoin” function where necessary to deal with these new options.

Finally, we updated “featlib.tcl” to add the relevant calls to the “cluster” command when voxel-wise thresholds are used. “featlib.tcl” is the main script to run the fMRI analysis from pre-processing to the generation of the HTML results page using FEAT in FSL.

We performed a series of tests to check that fMRI analyses performed with FEAT could run without error on a set of studies that were designed to cover major fMRI use cases (Pauli et al. 2016).

Results

The proposed update for FSL is publically available at <https://github.com/cmaumet/fsl> (cf. [pull request 3](#) and [5](#)). The datasets that were used for testing are available at <https://github.com/incf-nidash/nidmresults-examples/> (cf. [pull request 97](#)).

Fig. 1 displays examples of command-line calls to the updated “cluster” function for cluster-wise and voxel-wise thresholds.

```

Voxel-wise corrected

$FSLDIR/bin/cluster -i thresh_estat1 -c stats/cpe1 -t 3.0962 -d 0.780797 --volume=38344 -r 6.66989
--otresh=thresh_estat1_2 -o cluster_mask_estat1 --connectivity=26 --olmax=lnax_estat1.txt --scalarname=z
--voxthresh

Cluster Index Voxels Z-MAX Z-MAX X (vox) Z-MAX Y (vox) Z-MAX Z (vox)
Z-CDS X (vox) Z-CDS Y (vox) Z-CDS Z (vox) COPE-MAX COPE-MAX X (vox) COPE-MAX Y (vox) COPE-MAX Z (vox)
COPE-MAX V (vox) COPE-MAX Z (vox) COPE-MEAN
28 27 7.47 19 48 18 18.8 48.3 17.9 428 18 42 19 243
19 13 7.49 16 25 28 15.9 25 19.9 222 16 25 28 159
18 11 7.26 49 34 28 48.8 34.5 19.4 194 58 34 28 153
17 18 6.76 21 18 11 21.7 19.2 19.6 323 23 9 18 226
15 18 6.12 44 13 23.4 43.8 13.6 235 23 44 13 180
15 8 6.83 36 37 23 35.9 36.8 22.5 222 35 37 23 167
14 6 5.86 25 9 14 24.2 9.49 13.7 323 24 9 14 236
[...]

Voxel-wise uncorrected

$FSLDIR/bin/cluster -i thresh_estat1 -c stats/cpe1 -t 3.0962 -d 0.780797 --volume=38344 -r 6.66989
--otresh=thresh_estat1_2 -o cluster_mask_estat1 --connectivity=26 --olmax=lnax_estat1.txt --scalarname=z
--voxthresh

Cluster Index Voxels Z-MAX Z-MAX X (vox) Z-MAX Y (vox) Z-MAX Z (vox)
Z-CDS X (vox) Z-CDS Y (vox) Z-CDS Z (vox) COPE-MAX COPE-MAX X (vox) COPE-MAX Y (vox) COPE-MAX Z (vox)
COPE-MAX V (vox) COPE-MAX Z (vox) COPE-MEAN
147 795 7.47 19 48 18 24.7 41.7 18.4 632 28 56 17 168
146 243 7.49 16 25 28 18.4 23.6 18.8 428 17 19 23 135
145 161 4.56 42 43 14 39.3 44.2 15.1 479 33 36 11 199
144 152 7.26 49 34 28 47.7 35 19.7 218 52 38 16 117
143 66 4.76 21 18 11 22.3 18.9 13.3 323 23 9 18 171
142 65 5.04 46 23 28 45.3 28.7 28 242 41 18 21 131
141 42 4.95 48 46 17 48.1 45.7 17.9 357 47 47 17 184
[...]

Cluster-wise corrected (same as before)

$FSLDIR/bin/cluster -i thresh_estat1 -c stats/cpe1 -t 2.3 -d 0.780797 --volume=38344 -r 6.66989
--otresh=thresh_estat1_2 -o cluster_mask_estat1 --connectivity=26 --olmax=lnax_estat1.txt --scalarname=z -p 0.85

Cluster Index Voxels P -log10(P) Z-MAX Z-MAX X (vox) Z-MAX Y (vox) Z-MAX Z (vox)
Z-CDS X (vox) Z-CDS Y (vox) Z-CDS Z (vox) COPE-MAX COPE-MAX X (vox) COPE-MAX Y (vox) COPE-MAX Z (vox)
COPE-MAX V (vox) COPE-MEAN
7 3338 0 68.9 7.47 19 48 18 32.5 39.9 18.1 632 28 56 17 139
6 521 6.02e-28 19.2 7.49 16 25 28 16 22.4 17.5 428 17 19 23 118
5 167 1.7e-08 7.77 4.71 39 8 12 43.9 14.9 9.45 533 43 16 7 146
4 99 1.58e-05 4.8 4.76 23 19 13 23.1 18.5 12.5 323 23 9 18 143
3 43 0.017 1.77 4.83 36 7 6 35.5 8.35 3.75 288 31 8 4 128
2 41 0.0227 1.64 4.61 27 18 17 27.9 14.6 17.6 263 28 13 18 131
1 48 0.9263 1.58 4.77 47 23 15 48 38.8 14 288 48 19 14 182

```

Figure 1.

Examples of calls of the updated “cluster” command for voxel-wise and cluster-wise thresholds.

Fig. 2 presents an example of table generated by the updated FSL for a study using an FWE-corrected voxel-wise threshold.

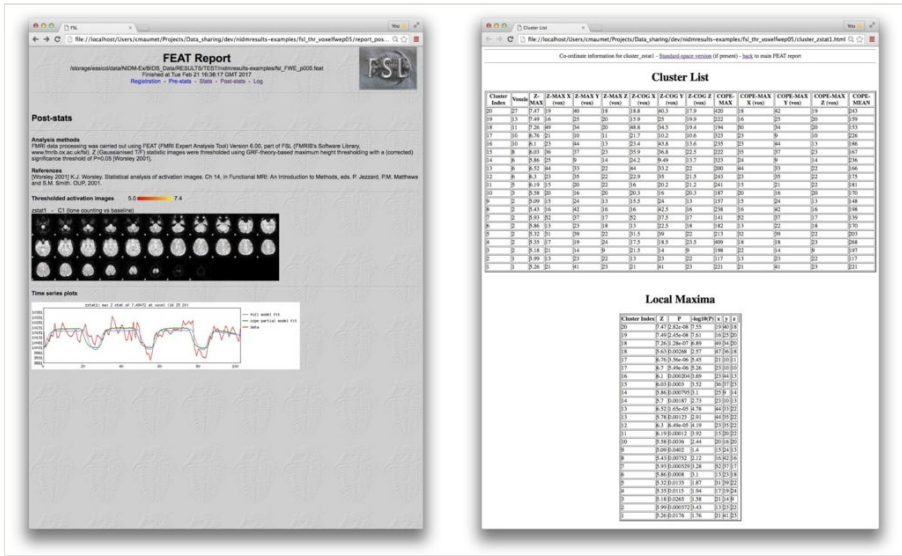


Figure 2. Cluster and peak tables for $p < 0.05$ FWE-corrected voxel-wise results (dataset "fsl_thr_voxelfwep05")

Conclusion

We have provided an update to generate tables of peaks and clusters for voxel-wise inference in FSL. This extension will be useful in the development of standardised exports for results of task-based fMRI studies (e.g. Maumet et al. 2016).

Author's contributions

TEN updated the "ztop" function and provided guidance in the update of the "cluster" class. CM performed the rest of the implementation and wrote the report.

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