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Mask_explorer: A tool for exploring brain masks in fMRI group analysis

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ABSTRACT

Background and objective: Functional magnetic resonance imaging (fMRI) studies of the human brain are appearing in increasing numbers, providing interesting information about this complex system. Unique information about healthy and diseased brains is inferred using many types of experiments and analyses. In order to obtain reliable information, it is necessary to conduct consistent experiments with large samples of subjects and to involve statistical methods to confirm or reject any tested hypotheses. Group analysis is performed for all voxels within a group mask, i.e. a common space where all of the involved subjects contribute information. To our knowledge, a user-friendly interface with the ability to visualize subject-specific details in a common analysis space did not yet exist. The purpose of our work is to develop and present such interface.
Methods: Several pitfalls have to be avoided while preparing fMRI data for group analysis. One such pitfall is spurious non-detection, caused by inferring conclusions in the volume of a group mask that has been corrupted due to a preprocessing failure. We describe a MATLAB toolbox, called the mask_explorer, designed for prevention of this pitfall.
Results: The mask_explorer uses a graphical user interface, enables a user-friendly exploration of subject masks and is freely available. It is able to compute subject masks from raw data and create lists of subjects with potentially problematic data. It runs under MATLAB with the widely used SPM toolbox. Moreover, we present several practical examples where the mask_explorer is usefully applied.
Conclusions: The mask_explorer is designed to quickly control the quality of the group fMRI analysis volume and to identify specific failures related to preprocessing steps and acquisition. It helps researchers detect subjects with potentially problematic data and consequently enables inspection of the data.

1. Introduction

Functional magnetic resonance imaging (fMRI) is widely used in neuroscience research. The increasing number of papers related to fMRI proves that this technique remains a subject of interest. Many types of fMRI experiments and analyses can be used to infer knowledge about the brain in health or disease. Single-subject statistics is a method of obtaining subject-specific information; this is the first step for other type of

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analyses. However, testing hypotheses related to a population of subjects (second-level or group-level statistics) is typically the goal of most neuroscience studies. In this case, an experiment is repeated across individuals, and researchers evaluate the effect of the experiment on the target population [1]. Group analysis is performed within the volume of the group mask. This is a common space with all considered subjects contributing information. During the preparation of fMRI data for group fMRI analysis, researchers face many challenges. In terms of a group mask, there are two kinds of pitfalls. The first is related to a deficiency in the field of view (FOV) of some subjects, leading to spurious non-detection in some brain areas. The second problem is related to misinterpretations caused by the large spatial displacement of individual subjects, e.g. a shift in the position of a specific subject's brain from the Montreal Neurological Institute [2–4] (MNI) space by a number of centimeters due to a failure during the image preprocessing (e.g. coregistration or spatial normalization). In this paper, we introduce the tool mask_explorer which aims to increase researcher awareness of the aforementioned issues.

Currently, there are several software tools available for fMRI data analysis, such as AFNI [5,6], BrainVoyager [7], FreeSurfer [8], FSL [9], and SPM [10]. These toolboxes are very useful in preprocessing, single-subject fMRI analysis, and group fMRI analysis. They offer many advanced statistical analytical methods, but they lack methods for dataset exploration based on the superposition of subject data masks in relation to our region of interest, the region intended to infer group fMRI results.

The SPM package is able to create masks (e.g. stored as a product of GLM analysis). The image of a sum of masks (SM) can be obtained using the ImCalc button and explored using the Display button in the basic SPM fMRI graphical user interface. When a loss of data or mask misplacement (e.g. evident failure of coregistration) is visually observed, it is difficult to recognize which mask is responsible for it. The Check Reg can be used then. Here the user can load several masks and examine them together with axial, sagittal, and coronal views for each mask. The Check Reg is limited to 15 (24) simultaneously loaded masks in SPM8 (SPM12). Even if it were not limited, this type of visualization is not easy to follow in large-group fMRI data sets (e.g. more than 30).

The AFNI package contains several programs suitable for creating masks (e.g. 3dAutomask) and using them for calculations (e.g. 3dmask_tool, 3dmaskdump, 3dcalc), but none of the programs enables the detection of masks that are unsuitable for defined positions of interest. The sum of masks can be calculated using 3dcalc. When a reduced or misplaced mask is visually observed, the exploration of a group of masks in AFNI relies on visual inspection via AFNI GUI, where only individual inspection subject by subject is possible. The user can simultaneously open all individual masks, and the checking of the masks is quite similar to use of "Check Reg" in SPM. Again, it is not easy to follow in large-group fMRI data sets.

The FSL library contains the FSLView tool. It can be used to create image masks. The fslmaths program from the Fslutils tool can be used to create the SM image. The created image can be explored in FSL View, but the ability to detect and report unsuitable masks with respect to specified positions of interest is not implemented. The most straightforward technique for exploring a group of masks is to use slicesdir script or FSLView tool and perform a visual check. This is good for small datasets with visually evident problems in individual masks. But again, in large datasets or with less evident problems (e.g. smaller signal dropouts) the failure can remain undiscovered.

Neither of the commonly used tools for fMRI analysis possess the ability to (1) detect and report unsuitable masks with respect to specified positions or regions of interest; (2) automatically detect outlying masks; (3) directly identify particular masks during the visual inspection of an SM image; or (4) offer easy-to-follow visualization for exploration of large group of masks. Therefore, the tool mask_explorer was developed. A comparison of the features related to exploring fMRI masks is presented in Table 1.

We introduced this tool in [11] where we very briefly described preliminary version of the mask_explorer. Here we provide detailed view on major update of functionality, introduce updated tool and practical examples of the mask_explorer's helpful usage. Updates involve batch mode for mask estimation, upgrades in list of unsuitable and suitable subjects, fixed bugs and reorganization of the code and performance, menu with functions on top of GUI window, importing and exporting coordinates, interactive listbox with coordinates and the code is now publicly available.

The paper is organized as follows. First, we explain the design of mask_explorer and the usage of this tool, including details on data processing. The estimation of binary masks, coordinates of interest, and lists of unsuitable masks are subtopics. Then we describe the data set used for a practical demonstration of mask_explorer. In the results section, we show two practical cases where mask_explorer is very effective. The conclusion is devoted to recommending a position for

Table 1 – Available features for mask exploration in three common fMRI tools and mask_explorer.

	SPM	FSL	AFNI	Mask_explorer
Creating masks	Yes	Yes	Yes	Yes
Computing sum of subject masks image	Yes (function ImCalc)	Yes (function fslmaths)	Yes (function 3dcalc)	Yes (function Load1)
Clear simultaneous visual inspection of large datasets (>30 masks)	Limited, not easy to follow (Check Reg)	Not easy to follow (slicesdir)	Not easy to follow (AFNI GUI)	Yes
Exploration of group of masks in relation to ROIs (e.g. percentage of coverage)	No	No	No	Yes
Automatic detection of outlying masks	No	No	No	Yes
Direct identification of particular masks during visual inspection of SM image	No	No	No	Yes