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PREPROCESSING STEPS IN fMRI: SMOOTHING

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ABSTRACT. Functional magnetic resonance imaging is a technique with a primary and dominant effect in the investigation of the cognitive functions of the brain since it has a complex structure. In this study, data obtained from single subject was examined. First statistical parametric mapping results were obtained after applying the standard preprocessing steps with including smoothness. Spatial smoothing was performed using a 3 mm Gaussian kernel which is twice of the voxel size. Second, statistical parametric mapping results were obtained with applying standard preprocessing steps without smoothing. The effects of these two applications on the mapping results were compared for selected slices and locations in terms of statistical and pattern.

1. INTRODUCTION

During neuronal activity there is an increase in blood flow to the brain, resulting in increased oxygen consumption and an expansion of blood vessels [1],[2]. The fMRI method developed to measure this change [3] is used as an important technique to understand brain functions and connectivity in the brain. Prior to performing statistical analysis and statistical parametric mapping in functional magnetic resonance imaging (fMRI) some preprocessing steps applied to the data. The main purpose of this process; remove unrelated variable from the data and prepare the data for statistical analysis. In this study, the effects of smoothing on mapping results was investigated.

Statistical parametric mapping results were obtained by applying the standard preprocessing steps with including smoothness. Spatial smoothing was performed using a 3 mm gaussian kernel. Secondly, statistical parametric mapping results were obtained with applying standard preprocessing steps without smoothing to investigate the effects of smoothing process.

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The change in signal obtained in fMRI is directly dependent on the blood oxygenation. Because the level of blood oxygenation changes rapidly following the activity of neurons in the brain region. Thus, the positions of the active brain regions are determined by means of the fMRI [4]. What changes in the brain of a neural stimulus has recently been followed predominantly by fMRI techniques. Processing and mapping of the signal obtained after stimulation is a necessity that requires statistical analysis. In the fMRI, activation is determined in the relevant region of the brain using various statistical test methods for signal exchange at any firing neurons in response to a stimulus. Since this change is very small, statistical methods are used to determine the activation. Before performing statistical mapping, some preprocessing steps should be applied to remove unrelated variable from the data. These steps include; realignment (eliminates effects of motion), coregistration (to show activation results on high-resolution structural images), segmentation, normalization (that spatial transformations into standard anatomical space) and smoothing.

2. Imaging Method and Analysis

Data were collected using a Siemens Magnetom 7 T (CMRR, USA) system. The block design consists of 10 data sets with a 12 seconds rest as 12 seconds task (figure 1) and the slice thickness is 1.5 mm. The motor task in the experiment consisted of pressing the button with the left or right hand and a left-facing arrow for left-handed movement and a right-facing arrow for right-handed movement. In this experiment data were collected from a single subject with has no neurological dissorder. EPI pulse sequence was used for the scans (TR: 2700 ms, TE: 15, slice thickness of 1.5 mm).

This study is concentrated on how smooth and not smooth process affects the results of activation mapping for left hand movement.

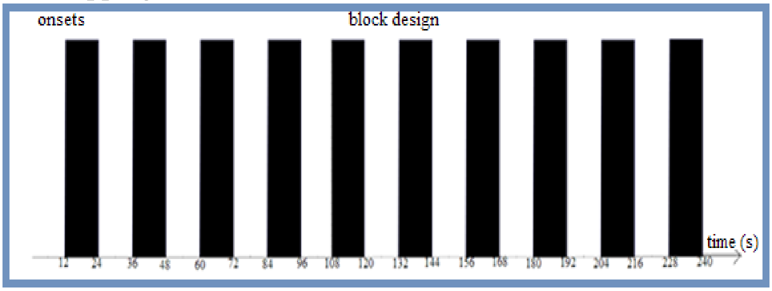


Figure 1. Block design with a 12 seconds rest (white block) as 12 seconds task (black block-left hand movement)

The experimental design as shown figure 1, defines the nature of the hypothesis testing to be applied. In this study a block design was used and 90 functional images were taken with this design, then the data was preprocessed and analyzed before the statistical analysis preprocessing steps applied to the data.
Figure 2 shows realignment results. This process is intended to minimize the effects of movement.

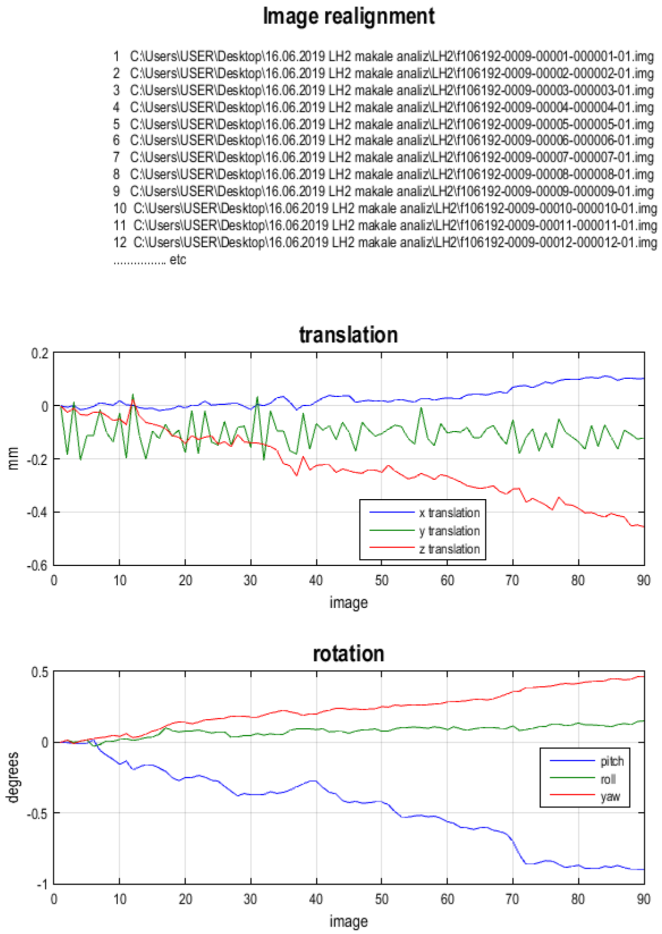


FIGURE 2. Realignment results for left hand movement data. Rotation and translation amounts are shown for 90 images

One of the most important preprocessing steps in fMRI is realignment. Since head motion is an huge problem while analyzing the data this helps to reduce the effect of movements for finding brain activations. After realignment, data normalized and smoothed for analyzing.

The General Linear Model (GLM) was used for statistical analyzing. GLM is the most often used model for functional magnetic resonance imaging [5]. Statistical parametric mapping is performed by placing the activation information on the structural MR images. In order to perform statistical parametric mapping, linear models are used which vary according to one or more explanatory variables. Test methods such as t-test, f-test, analysis of variance (ANOVA), correlation calculation are frequently used for parameter estimation in the General Linear Model.

The dependent variable $\boldsymbol{Y_i}$ in the GLM model has been predicted via the explanatory variables $\boldsymbol{X_i}$ and given by

$$\boldsymbol{Y_i} = \beta_{\mathbf{0}} + \boldsymbol{X_i}\beta + \varepsilon_i, \quad i = 1, 2, ..., n. \tag{2.1}$$

Here $\boldsymbol{Y_i}$ is the dependent variable such that $E(Y_i) = \beta_{\mathbf{0}} + \boldsymbol{X_i}\beta_{\mathbf{1}}$ and $Var(\boldsymbol{Y_i}) = Var(\varepsilon_i) = \sigma^2$ and $\beta_{\mathbf{0}}$ and $\beta_{\mathbf{1}}$are the model parameters to be estimated. Estimated time series values $\hat{Y}$, including the linear combination of explanatory variables are calculated as $\boldsymbol{\hat{Y}}=\boldsymbol{X\hat{\beta}}$**,** the residual values

$$\boldsymbol{\hat{\varepsilon}} = \boldsymbol{Y} - \boldsymbol{X\hat{\beta}} \tag{2.2}$$

Because error values contain both positive and negative values, the GLM procedure does not estimate beta values that minimize the sum of the error values, but finds these beta values by minimizing the sum of the square error values. Thus the sum of error differences for all time points given in eq. (2.3)

$$\sum_{i=1}^{n}(\mathrm{Yi} - \hat{\mathrm{Y}}\mathrm{i})^2 = \sum_{i=1}^{n} \varepsilon_i^2 \tag{2.3}$$

Least squares estimator of $\boldsymbol{\beta}$ parameter vector ($\boldsymbol{\hat{\beta}}$) given by eq.(2.4)

$$\boldsymbol{\hat{\beta}} = \left(\boldsymbol{X^T X}\right)^{-1}\boldsymbol{X^T Y} \tag{2.4}$$

The main assumption at the model has been done on the error terms ε_i. In order to estimate the parameters $\beta_{\mathbf{0}}$ and $\beta_{\mathbf{1}}$ it's assumed that ε_i's are independent and identicaly distributed random variable with mean zero and constant variance σ^2. Moreover, for any statistical inference it's also assumed that the error terms are normally distiributed random variables for this an AR(1) model was performed during parameter estimation [6], [7], [8]. GLM parameters were estimated classical (Restricted Maximum Likelihood, ReML) parameter estimation.

The data analyzed with *Statistical Parametric Mapping8* (SPM8) programme [9] which is freely available for brain researchers. Single subject data analysis and parameters estimations were performed with the t test and for $p < 0.05$ active brain regions were marked.

3. Results and Conclusion

After perform preprocessing steps, data would be ready for the statistical analysis. In our work, images acquired with 1.5 x 1.5 x 1.5 mm resolution, the level of smoothing can be estimated as FWHM=3 mm.

In this section activation maps results were performed with and without smoothing. After 3 mm Gaussian kernel was used in smoothing stage, model specification and parameters estimations were done respectively. T test evaluates the effect of a parameter also to distinguish the contrasts of rest and task conditions used in the experiment. In order to identify the active voxels, the significance value of the test was determined as 0.05. In fMRI T contrast is one dimensional and can be expressed as

$$C^T = [1\ 0\ \dots\ ] \tag{3.1}$$

The contrasts can be specified to examine for conditions in the model. The sum of the contrasts of the conditions must be equal to 1. Main effects for active condition given as "1", (active > rest) and "-1" for rest condition (rest > active). High resolution anatomical images are used to show activation results after estimation (Figure 3).

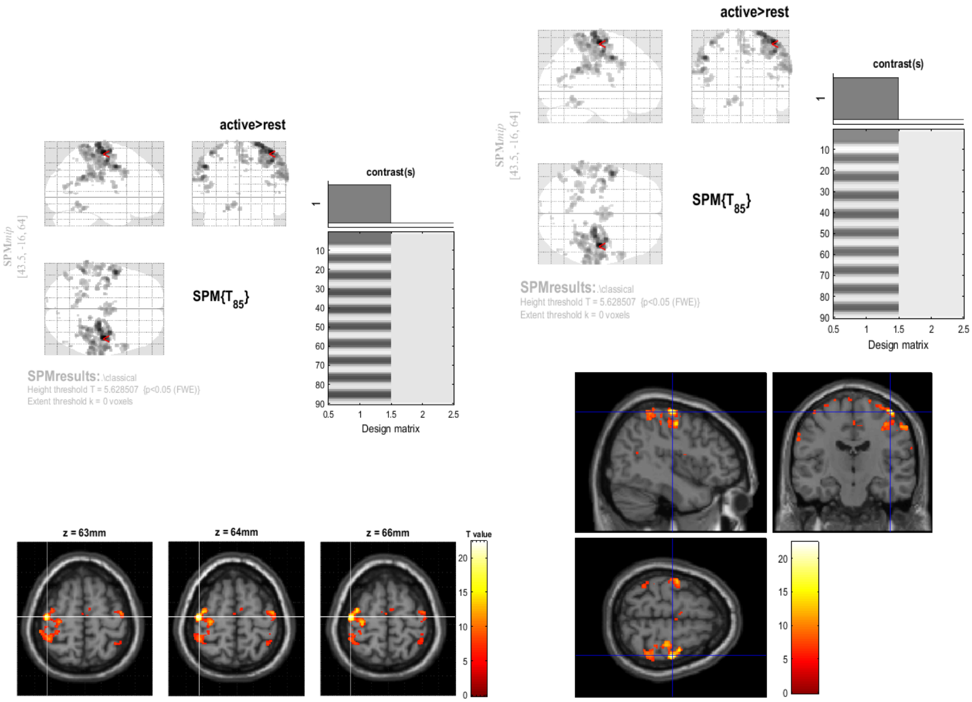


FIGURE 3. Statistical parametric mapping results using 3 mm smoothing and a significance threshold of $p < 0.05$

Left Hand Movement Activation Results with 3 mm Smoothing

The effects of the smoothing process can be applied differently on single or group fMRI data [8]. The goal is to improve the normality of the data with spatial smoothness. In general the smoothing process increases the signal to noise ratio [10], [11].

Statistical parametric maps shown in figure 3 was obtained in such a way that the activations would be on the right side of the motor cortex for the left hand movement.

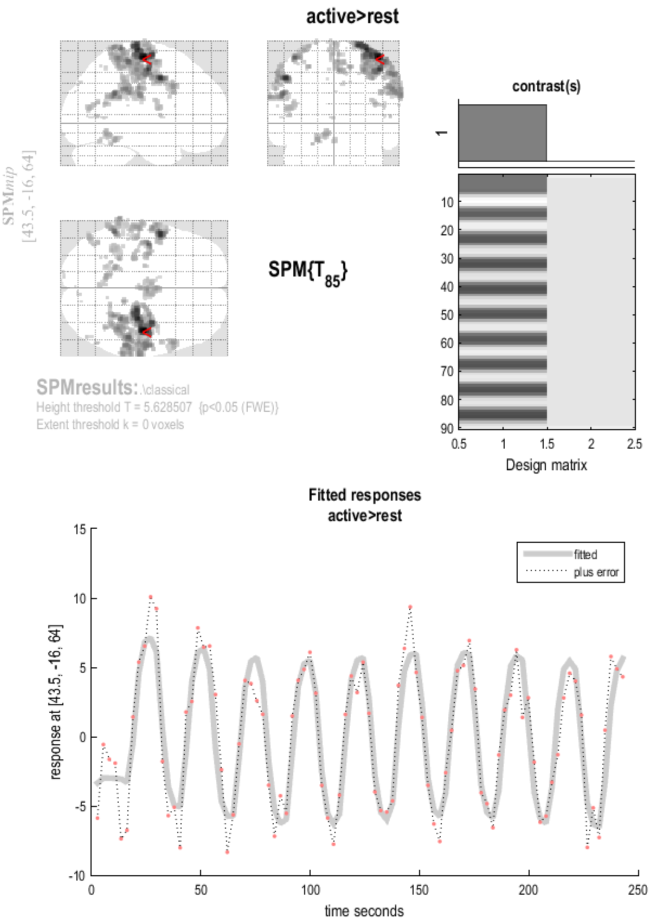
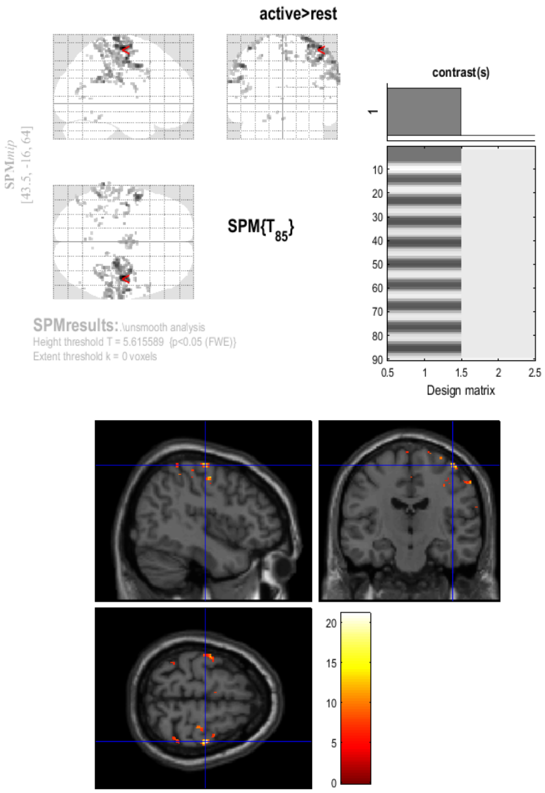


FIGURE 4. Time series for a selected active voxel

In the time series obtained for a selected active voxels, it is seen that the model and the results are compatible with each other. In the presence of the stimulus, a peak is observed in the signal, while in the case of rest, the signal shows a depression. In the graph, the time series is plotted with the addition of errors predicted with GLM (Figure 4).

Activation Results Without smoothing

All preprocessing steps were used without smoothing for same data. Statistical parametric mapps shows active brain regions were marked in figure 5 without smoothing.



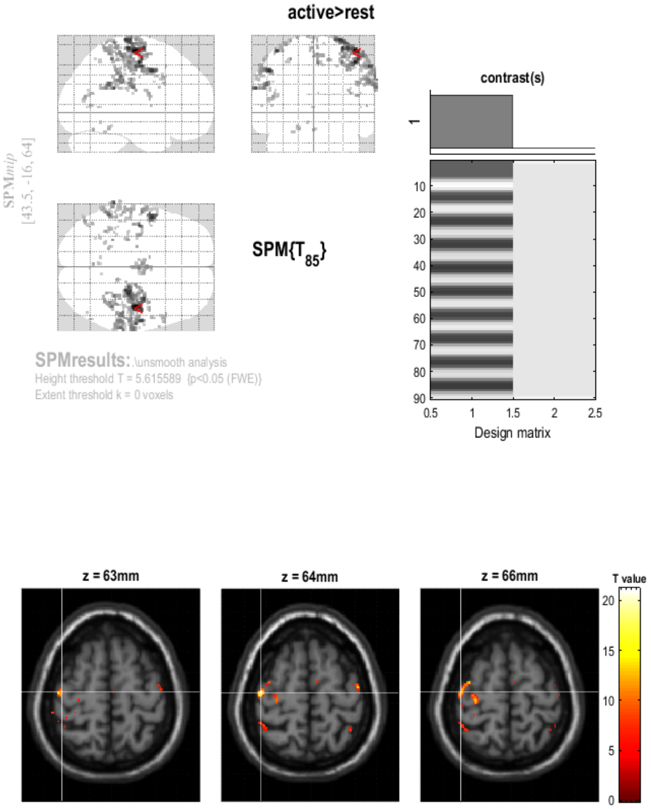


Figure 5: Statistical parametric mapping results using a significance threshold of p< 0.05 without smoothing

Results show that active voxel count decreasing without smoothing. The activation map results obtained with our data that is not applied smoothing in the pre-processing steps results less active voxels. For left hand movement task activation was achieved on the motor corteks right side similarly with results figure 3.

If the preprocessing steps are done correctly, this increases the functional resolution of fMRI experiments. Spatial smoothing is for applying a small blurring kernel across the images and for averaging densities from neighboring voxels together. Using a 3 mm smooth application allows us to obtain more active brain regions.

This process can be applied both the single-subject and the group analysis. fMRI data has a lot of noise in it, but studies have shown that most of the spatial noise is mostly Gaussian and is independent from voxel to voxel, and almost centered around zero.

Smothing makes the data more normal as statisticaly and also increases the signal to noise ratio (SNR). Thus smoothing process gives more reliability for single subject data analysis. Smoothing should be used in Neuroimaging to determine the active voxels correctly. In addition, these results can be used an alternative for studies on identifying specialized brain regions [12].

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