Spectral clustering of low-frequency fluctuations in fMRI data reveal a distinct separation between the superior temporal sulcus and the superior temporal gyrus

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Introduction

Low Frequency Fluctuations (LFFs) are known to represent a large portion of the variance of the BOLD signal, especially in non-primary areas of cortex. Furthermore, such fluctuations generally have significant spatial coherence. Task-dependent condition-locked fMRI data has confirmed an important role of the superior temporal cortex in many language and hearing related processes. Within this area, many studies have claimed to identify activation distinct to superior temporal gyrus (STG) and superior temporal sulcus (STS), for different stimuli ([1],[2]). Using a data-driven clustering technique applied to LFFs, we investigated the spatial coherence structure of the upper temporal lobe and sought to substantiate the suggested functional distinction of gyrus and sulcus.

Data and Methods

Functional MRI/EPI data were acquired of 17 normal volunteers on a 3T MRI scanner (Siemens Trio) using TR=9 sec, TE=30ms, 3x3 mm^2 in-plane resolution, 3 mm slice thickness, 1mm gap between slices. The subjects performed a passive listening task and heard German sentences, both correct as well as syntactically violated, in intelligible and unintelligible (spectrally inverted) format. Importantly, though, our analysis of LFFs focuses on the variance *not* explained by the experimental design (see below). All data sets were initially registered to an AC/CP coordinate system where the data were resampled to an isotropic voxel grid with a resolution of 3x3x3 mm^3. A general linear model was fitted to the data such that Y = X b + e where Y denotes a measured time course in one voxel, X denotes the design matrix and e the residuals. The residuals e were bandpass-filtered so that only low-frequency components between 0.05 Hz and 0.01 Hz remained. We manually delineated an anatomical region of interest covering the entire STS/STG region containing 722 voxels. We then set up a similarity matrix of size 722 x 722 where each entry r_ij denotes the correlation of the time courses in voxel i and j. We transformed the correlation values r using Fisher's transform log((1+r)/(1-r)) and averaged the transformed correlation matrices across all test subjects. We then applied spectral clustering [3] to the averaged correlation matrix. The number of clusters is a free parameter. In order to avoid an arbitrary choice of this parameter, we used cross-validations to determine the number of clusters which yielded optimal consistency across subjects and hence the optimal number of clusters. Specifically, we employed a leave-one-out method where each subject's data is left out from the averaging (jack-knifing). For each subject, we checked the consistency between the clustering results of the single subject and the average across the remaining subjects using Cramer's V. Cramer's V has values in the interval [0,1] where high values indicate good consistency. A value of '1' indicates a perfect match.

Results

The inter-subject consistency check was performed for k=2,3,4,5 number of clusters. It yielded best results for k=4 clusters with an average consistency of Cramer's V = 0.56. The result is shown below. It could also be shown that Cramer's V was significantly higher for the 4-and 5-cluster solutions than for the 2– and 3-cluster solutions.

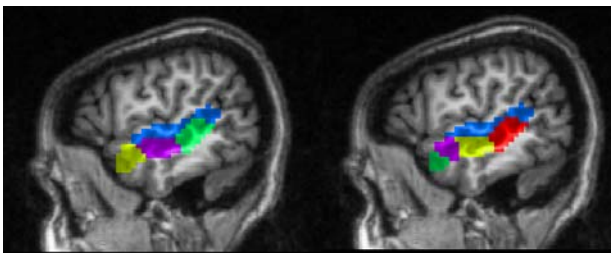

Figure 1: Result of spectral clustering using 4 clusters (left) and 5 clusters (right). The STG appears as a single cluster shown in blue. STS is divided into 3 or 4 clusters.

Discussion

Spectral clustering of low-frequency fluctuations in fMRI data showed a distinct separation between STG and STS. Using inter-subject consistency as a criterion we found that 4 or 5 clusters best describe the subdivision. The difference between the 4-cluster and the 5-cluster result is a finer subdivision of the lower bank of the temporal pole. Common to both solutions is a clear-cut cluster separation that follows the anatomical separation between STS and STG, as well as a clustering of at least three distinct STS clusters from posterior to anterior (Fig. 1). This goes beyond what the variety of different hearing and language studies could offer so far. Also, the clustering that was gained here "blindly" through spectral clustering can now serve as regions of interest for experimental design questions. Spectral clustering of low-frequency fluctuations appears as a powerful tool to detect underlying commonalities in hemodynamic behaviour across a set of voxels. As it deliberately exploits the data left unexplained by the experimental design, this method allows for important additional and complementary conclusions to be drawn from fMRI data sets.

References

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