Nonparametric statistical inference for functional brain information mapping

Dissertation, 2014

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An ever-increasing number of functional magnetic resonance imaging (fMRI) studies are now using information-based multi-voxel pattern analysis (MVPA) techniques to decode mental states. In doing so, they achieve a significantly greater sensitivity compared to when they use univariate analysis frameworks. Two most prominent MVPA methods for information mapping are searchlight decoding and classifier weight mapping. The new MVPA brain mapping methods, however, have also posed new challenges for analysis and statistical inference on the group level. In this thesis, I discuss why the usual procedure of performing t-tests on MVPA derived information maps across subjects in order to produce a group statistic is inappropriate. I propose a fully nonparametric solution to this problem, which achieves higher sensitivity than the most commonly used t-based procedure. The proposed method is based on resampling methods and preserves the spatial dependencies in the MVPA-derived information maps. This enables to incorporate a cluster size control for the multiple testing problem. Using a volumetric searchlight decoding procedure and classifier weight maps, I demonstrate the validity and sensitivity of the new approach using both simulated and real fMRI data sets. In comparison to the standard t-test procedure implemented in SPM8, the new results showed a higher sensitivity and spatial specificity.

The second goal of this thesis is the comparison of the two widely used information mapping approaches – the searchlight technique and classifier weight mapping. Both methods take into account the spatially distributed patterns of activation in order to predict stimulus conditions, however the searchlight method solely operates on the local scale. The searchlight decoding technique has furthermore been found to be prone to spatial inaccuracies. For instance, the spatial extent of informative areas is generally exaggerated, and their spatial configuration is distorted. In this thesis, I compare searchlight decoding with linear classifier weight mapping, both using the formerly proposed non-parametric statistical framework using a simulation and ultra-high-field 7T experimental data. It was found that the searchlight method led to spatial inaccuracies that are especially noticeable in high-resolution fMRI data. In contrast, the weight mapping method was more spatially precise, revealing both informative anatomical structures as well as the direction by which voxels contribute to the classification. By maximizing the spatial accuracy of ultra-high-field fMRI results, such global multivariate methods provide a substantial improvement for characterizing structure-function relationships.