Abstract:
Human cognition involves fast dynamic neural activity in distributed brain areas. To study the neural mechanisms, we can use magnetoencephalography (MEG) and electroencephalography (EEG), which are non-invasive and have high temporal resolution. MEG/EEG sensor recordings can be approximated as a linear transform of neural activity in the brain space (or source space). However, it is challenging to estimate the source activity (i.e., solve the inverse problem of the linear transform), because the number of sensors is smaller than the number of possible locations in the source space.

Typically, estimating source-space activity is not the final goal. To study what information is coded in different brain regions and temporal stages, we often regress neural activity on some external covariates; to study dynamic interaction between regions, we quantify statistical dependence of activity in those regions (i.e., “connectivity” analysis). These analyses are traditionally done in two steps. Step 1, solve the linear problem under some regularization or prior assumptions, (e.g., each source location being independent); Step 2, do the regression or connectivity analysis. However, biases induced in the regularization in Step 1 can not be adapted in Step 2, and may yield inaccurate regression or connectivity results. To tackle this issue, we present novel one-step methods on source-space regression and source-space connectivity analysis, where the dependence of source activity on covariates or cross-region dependence is explicitly modelled jointly with the source-to-sensor linear transform. In simulations as well as real data, we observed better performance by our models than a the commonly used two-step approach, when our model assumptions are reasonably satisfied.

Besides the methodological contribution, we also applied our methods in a real MEG/EEG experiment, studying the spatio-temporal neural dynamics in the visual cortex. The human visual cortex is hypothesized to have a hierarchical organization, from posterior to anterior parts; different areas encode features from low-level local edges to high-level semantic labels. However, details about the spatio-temporal dynamics is less understood. Here, using source-space regression, we correlated neural responses to naturalistic scene images, with low-level and high-level features extracted from a well-trained convolutional neural network. Additionally, we also studied the interaction between regions along the hierarchy with the source-space connectivity analysis. In these analyses, we observed early-to-late, lower- to higher-level patterns of feedforward processing, and novel evidence of feedback information flow. Finally we also compared the sensitivity between MEG and EEG in this experiment, in detecting dependence between neural responses and visual features. Our results show that the less costly EEG was able to achieve comparable sensitivity with MEG, when the number of observations was doubled.