Studying Common Neural Representation of Objects Across Participants

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Abstract

I describe a novel application of a generalization of principal component analysis to study commonality of neural representation of objects across participants.

Introduction

In previous work, the category of an object a participant was viewing was identified based only on other participants’ characteristic neural activation patterns. What is the degree of overlap in neural representation of categories across participants?

In this work I propose the application of STATIS (which stands for *Structuration des Tableaux À Trois Indices de la Statistique*) to cognitive states data to study the overall consensus of neural representation of objects across participants. STATIS is a non-iterative exploratory data analysis method for comparison of multiple matrices.

STATIS

STATIS is a generalization of principal components analysis for multiple matrices. Each participant’s preprocessed data is represented in an objects by voxels matrix $X_k$, $k = 1, \ldots, p$. Let $S_k = X_kX_k'$ be a normalized cross-product matrix representing the similarity between objects for the $k$th participant. Participant cross-product matrices are aggregated into a compromise cross-product matrix, which represents the agreement in neural representation of objects across participants. The compromise matrix is a weighted average of individual cross-product matrices. Participants with neural representation of exemplars similar to other participants are assigned larger weights, and participants with neural representation of exemplars most different from others are assigned lower weights. Weights are derived from a $p \times p$ between participants cosine matrix $C$, where the $kk'$ entry is computed by an RV-coefficient (Escoufier, 1973):

$$RV(S_k, S_{k'}) = \frac{tr(S_k'S_{k'})}{\sqrt{tr(S_k'S_k)tr(S_{k'}'S_{k'})}}$$

(1)
The first principal component of the cosine matrix is proportional to the mean of the elements of $C$. Hence the weights are given by the elements of the first eigenvector of $C$, rescaled to sum up to one. Formally, the compromise matrix $S_+$ is:

$$S_+ = \sum_{k=1}^{p} \alpha_k S_k,$$

where $\alpha_k$ is the weight for the $k$th participant. The compromise matrix is analyzed by eigen-decomposition: $S_+ = Q\Lambda Q'$. The objects are represented as points with coordinates $Q\Lambda^{1/2}$ in the compromise space that is common to all participants. Furthermore, participants’ cross-product matrices are projected into the compromise space: $S_k Q\Lambda^{1/2}$.

**Neural representation of objects**

**Data**

Twelve participants viewed line drawings of ten objects, for six presentations each, from *tools* and *dwellings* categories. Preprocessed data for each participant were spatially normalized into MNI space and resampled to $3x3x6$ mm$^3$ voxels. A mask was applied to each image and only voxels inside the brain gray matter that were present in all participants were included in the analysis. Imaging data for each object were abstracted by using the mean of four images relative to fixation at each voxel. The data for each object were normalized to have mean zero and variance one to equate between participants variation in exemplars. Data were further averaged across the six presentations of each object, to get a more reliable estimate of neural activity.

**Results**

Neural representation of objects common to twelve participants was revealed by the principal components analysis of the compromise matrix. Compromise explained 62 percent of the inertia in the original data. The first principal component of the compromise matrix explained 16 percent of the total variance and represented a contrast between the two object categories. There was a commonality across participants, and category structure explained most of the differences among objects (Figure 1). The remaining components were not easy to interpret.

Participants differed in terms of their neural representation of objects. There was more agreement for some objects than others. For example, there was more agreement on *pliers* and *castle*, and less on *hut* (Figure 2). For one participant in particular (shown in red), neural representation of objects differed from the other 11 subjects.

There is a stable part of neural representation of objects across participants and it contains category structure.

**Related Work**

The STATIS method has been primarily used in sensory sciences, and has recently been described in great detail by Abdi and Valentin (2007). The RV-coefficient has been previously applied to fMRI data by Kherif et al. (2003) and Shinkareva et al. (2006).
Figure 1: Objects in the space defined by the first two principal components of the compromise matrix. The first component accounts for 16 percent, and the second component accounts for 12 percent of the inertia of the cross-product matrix.

References


Figure 2: Projection of participants into the compromise space. Each participant is shown in a unique color. Each object location is a weighted center of participant’s locations for that object.