How to improve the functional alignment of data using spatial brain information?

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Introduction: Procrustes problem in fMRI data

Multi-subjects fMRI studies permit to **compare** studies across subject.

The anatomical and functional structure of brains vary across subjects even in response to identical sensory inputs.

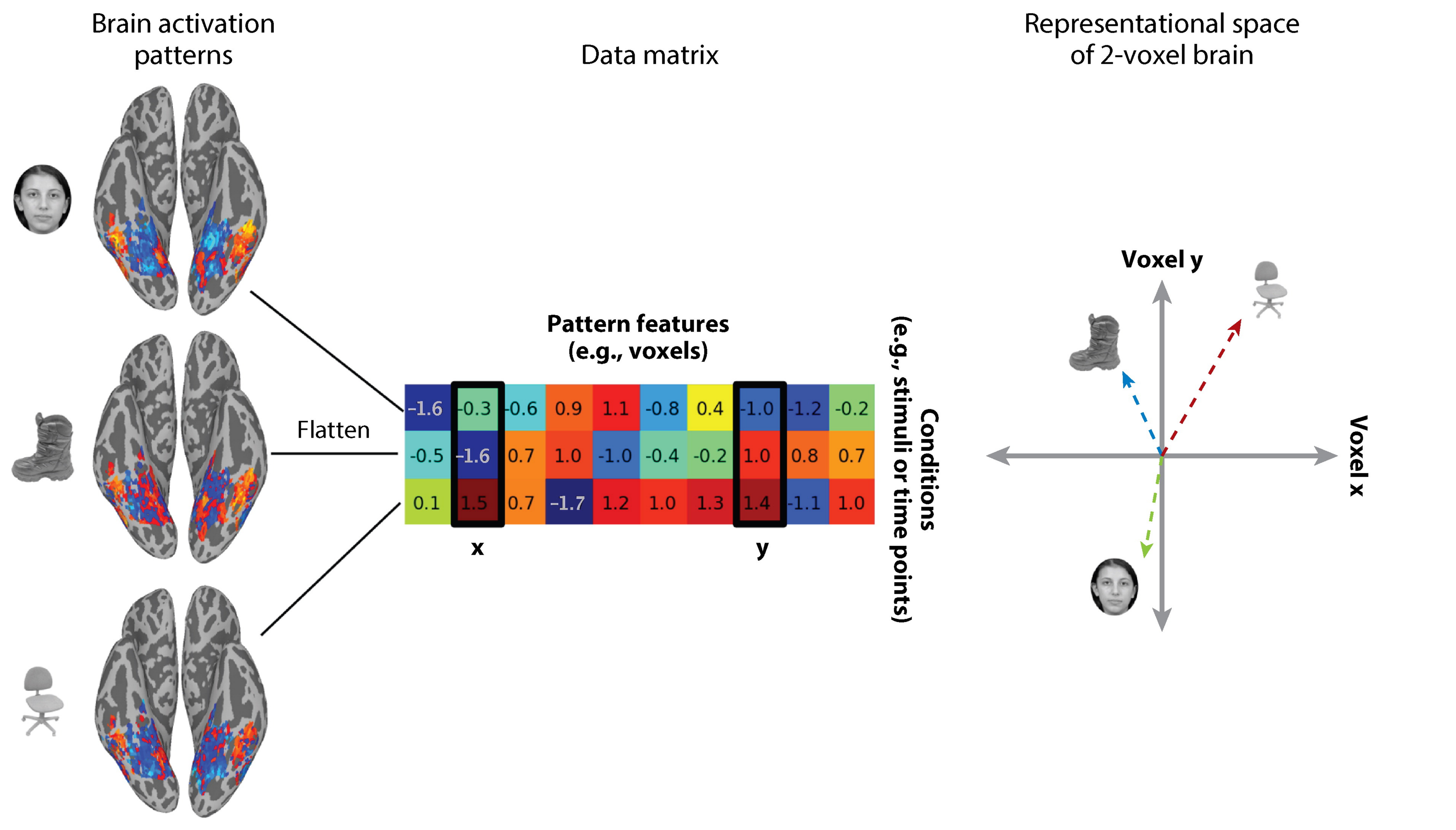
ALIGNMENT STEP

- **Anatomical Alignment** $\rightarrow$ Talairach space;
- **Functional Alignment** $\rightarrow$ Hyperalignment (Haxby et al., 2011).

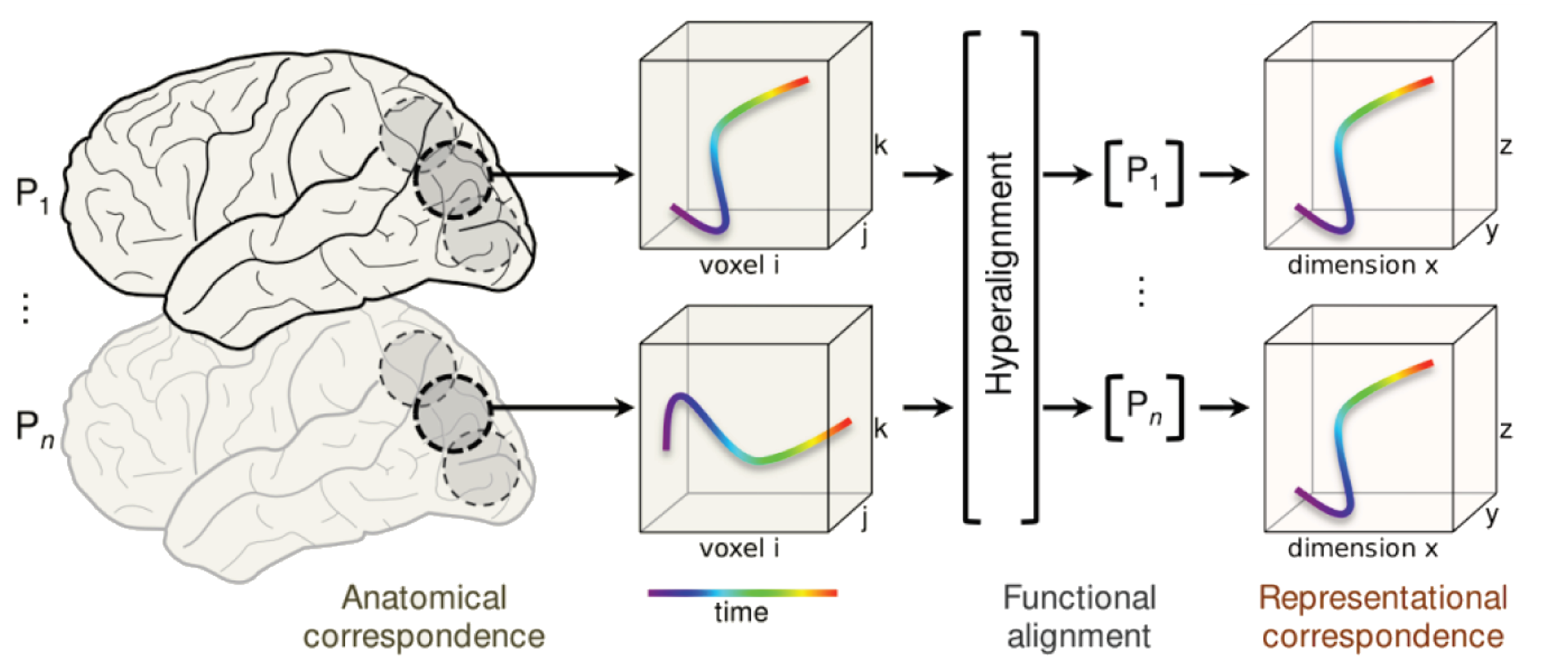
Let $X_i \in \mathbb{R}^{n \times v}$, $i = 1, \dots, N$ represents the subject, v voxels and n time points. The **Orthogonal Procrustes problem** is expressed as:

$$\boxed{\min_{R} ||X_i - X_j R||_F^2 \quad \text{subject to} \quad R^T R = I_v}$$

Data



Hyperalignment



The von Mises-Fisher-Procrustes model

Hyperalignment is a sequential approach of the Procrustes solution $\rightarrow$ No statistical approach and optimization criteria.

We rephrase it as **statistical model**:

$$\boxed{X_i = M R_i + E_i \qquad \vec{E}_i \sim \mathcal{N}_{nv}(0, \Sigma)}$$

Also the **anatomical features** are important!

Impose a **prior distribution**, for $\boxed{R_i}$.

Prior distribution

Analyze the most plausible rotation $\rightarrow$ **Prior information** into R_i.

IDEA: closer voxels have similar rotation loadings

The Matrix von Mises-Fisher distribution was introduced by Down(1972):

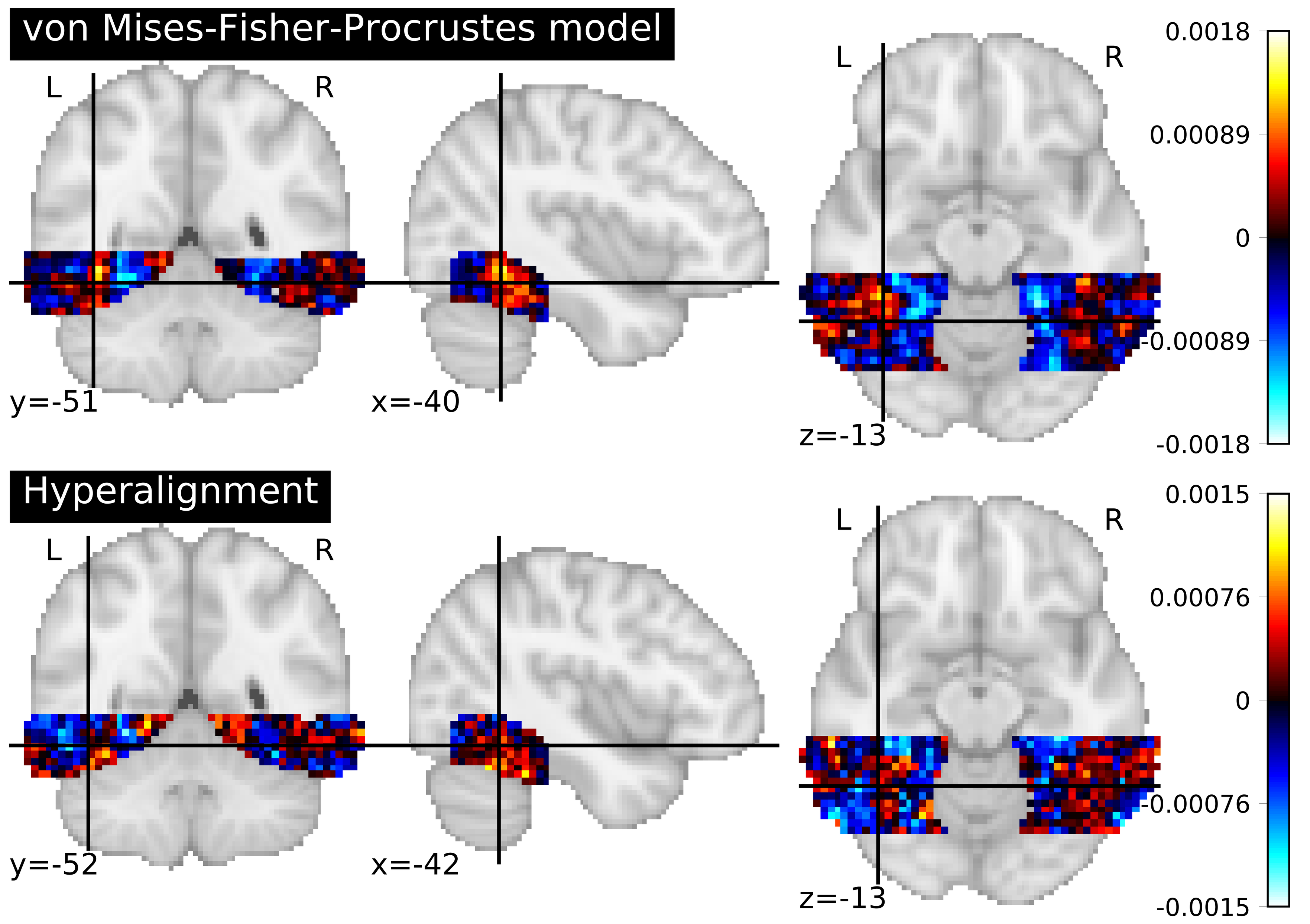
$$\boxed{f(R_i) \sim C \exp(k_0 \, tr(Q^\top R_i))}$$

where C normalizing constant, k_0 **concentration** parameter and Q matrix **location** parameter $v \times v$.

The matrix Q can be expressed as a **similarity matrix** considering the euclidean distance of the 3d **coordinates** of the voxels.

We modify the Procrustes solution in the **SVD** step $\rightarrow$ we decompose $\boxed{X_i^\top M + k \cdot Q}$ instead of $X_i^\top M$.

Experiments



Take Home message

- It doesn't depend on the **order of the subjects** as Hyperalignment;
- It returns a **unique solution** having **anatomical information**;
- It reaches the **global minimum** imposed by GP;
- It improves the **between-subjects classification**;
- leads to a **smoother map** of classifier coefficients.

Experiments

We align the images of the Ventral Temporal Cortex of 10 subjects watching static, gray-scale images of faces and objects. The **Linear Support Vector Machine** is used as classifier.

	Anatomical	GPA with prior
Accuracy	0.31	0.67

Error of classification reduction: **10%** respect to the Hyperalignment method; **17%** respect to the classical GP solution.

References

[1] Down, T. D. *et al.* (1972)Orientation statistics. Biometrika, 59(3): 665-676;

[2] Haxby, V. J. *et al.* (2011) A common model of representational spaces in human cortex. Neuron, 72(2): 404-416;

[3] Schonemann, P. H. (1966). A generalized solution of the orthogonal Procrustes problem. Psychometrika, 31(1):1-10.