Functional Elements and Networks in fMRI

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Methods

- Fusion of two well-known methods
  1. Independent component analysis
     * Purely data-driven
     * Spatially focal decomposition
     * Based on strict statistical independence
  2. Dependent component analysis
     * Partly hypothesis-driven
     * Temporal co-dependency between datasets
     * Based on independent components and data

ICA

- Following generative model
$$\mathbf{X} = \mathbf{A}\mathbf{S}$$
- Reliable ICA approach
  * Based on multiple runs of FastICA
  * Bootstrapping with resampled data and randomized initial conditions
- 100 runs with *tanh* nonlinearity in *symmetric* mode

DeCA

- Nonparametric dependent component analysis
- Mutual information-based generalization of classical CCA
  * Uses Parzen estimators q
 * Maximizes dependency estimate between datasets y and z

$$f(\mathbf{w}_y, \mathbf{w}_z) = \sum_{i=1}^{N} \log \frac{q_{yz}(i)}{q_y(i) q_z(i)}$$

Abstract ICA is commonly used in fMRI studies to identify, in a blind manner, spatially independent functional elements of brain activity. With complex stimuli, or complex brain functions, individual elements may not be directly relatable to the stimulus goals. We propose a two-step approach for the analysis of functional magnetic resonance images, in the context of natural stimuli. In the first step, elements of functional brain activity emerge, based on spatial independence assumptions. The second step exploits temporal covariation between the elements and given features of the natural stimuli to identify functional networks. The networks can have complex activation patterns related to common task goals.
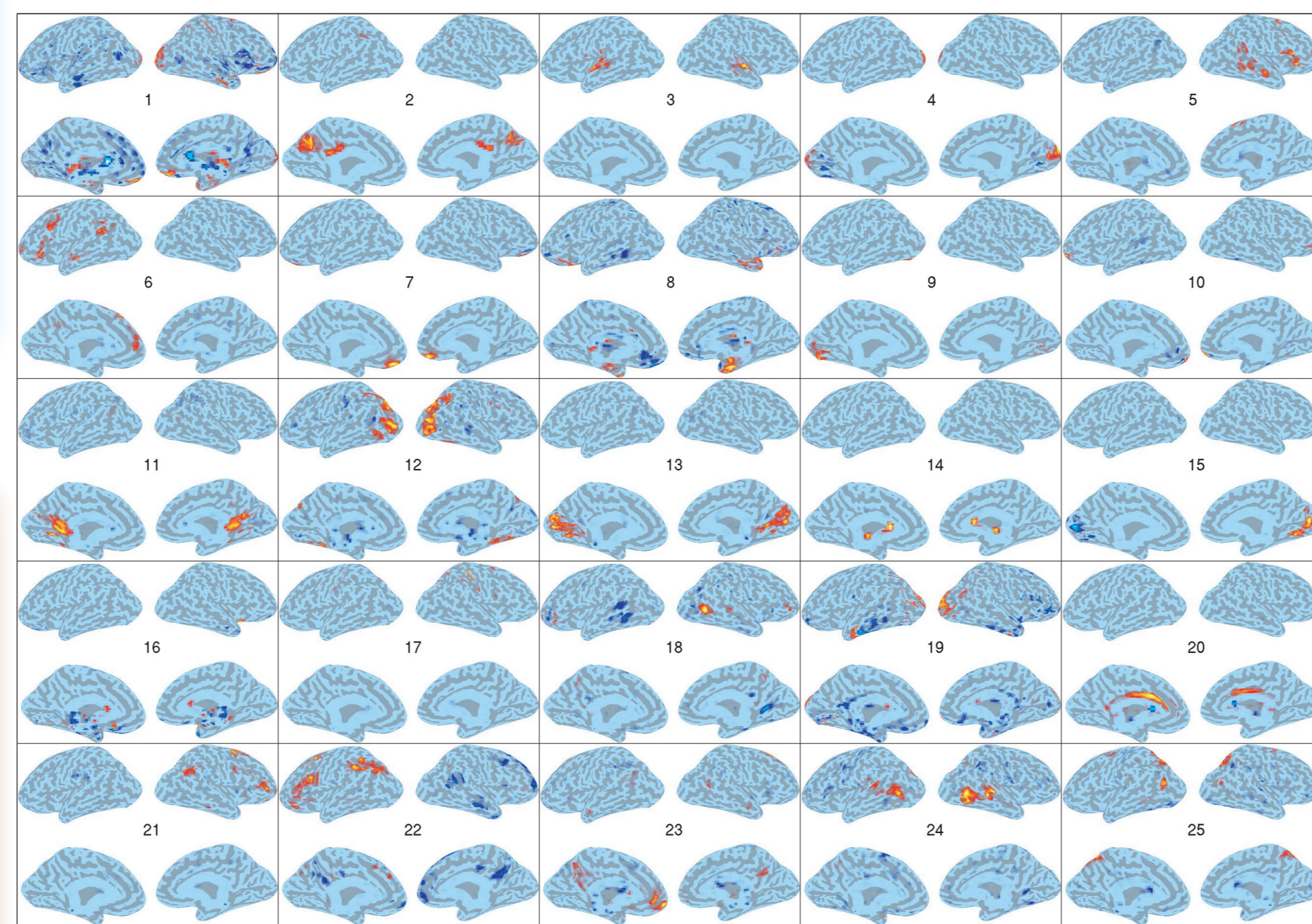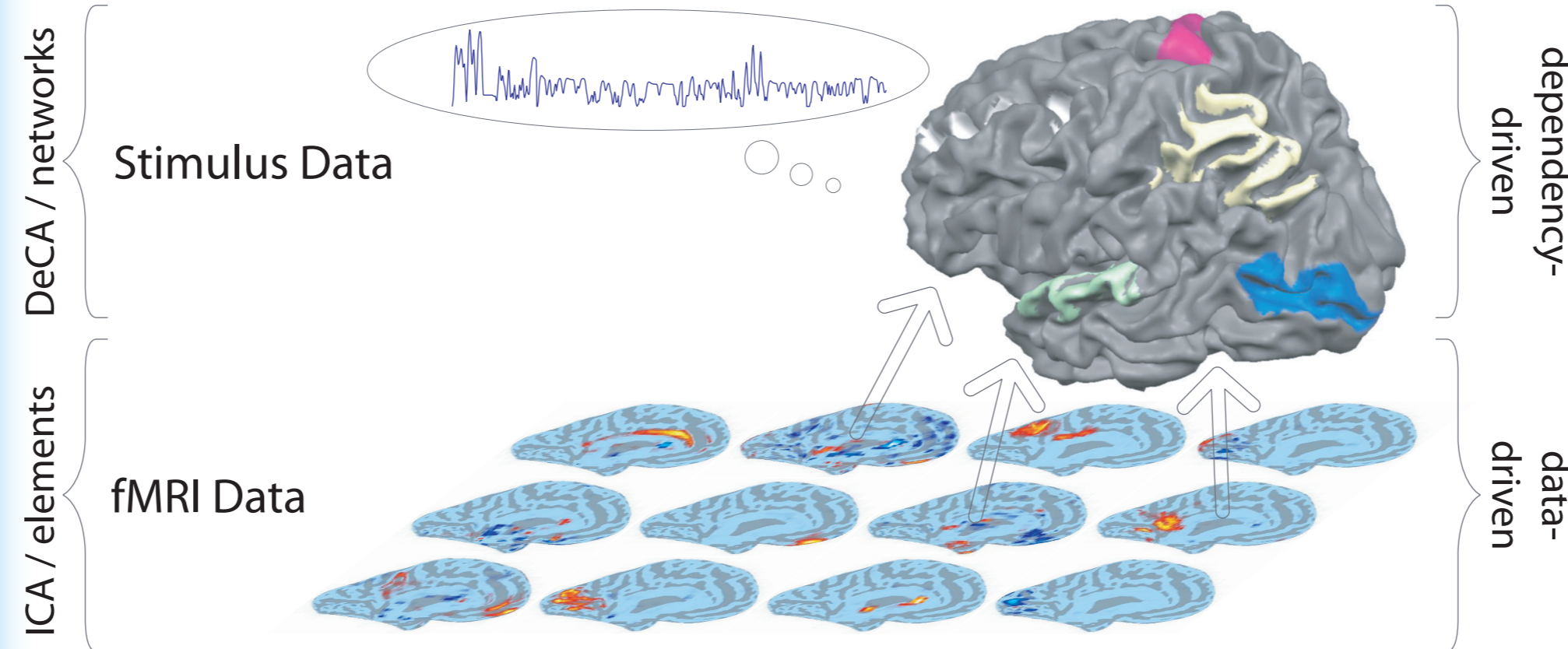
Materials

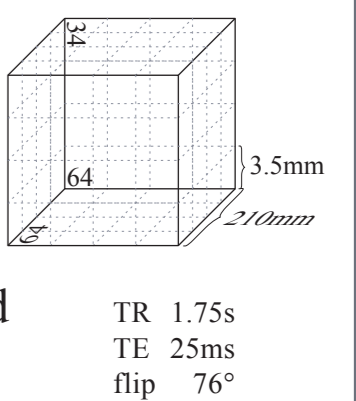- Pittsburgh Brain Activity Interpretation Competition
  * http://www.ebc.pitt.edu/2006/competition.html

Natural Stimuli

- Viewing 20 minutes of movie
  * Described by subjective feature ratings

fMRI

- 858 time points
- Whole head volumes
  * Corrected and normalized
  * Cortex extracted and morphed
- Inflated cortical surface
  * Containing 238735 vertices

TR 1.75s
TE 25ms
flip 76°

3.5mm
210mm

Stimulus Data — DeCA / networks — dependency-driven
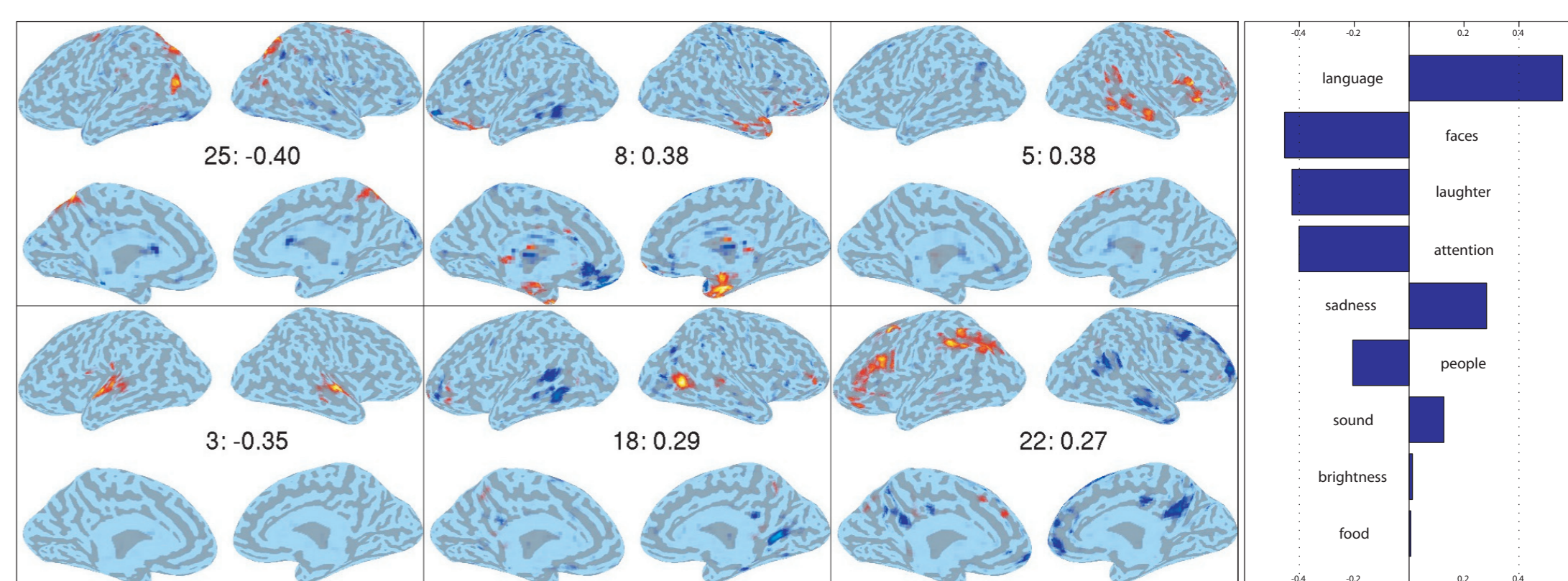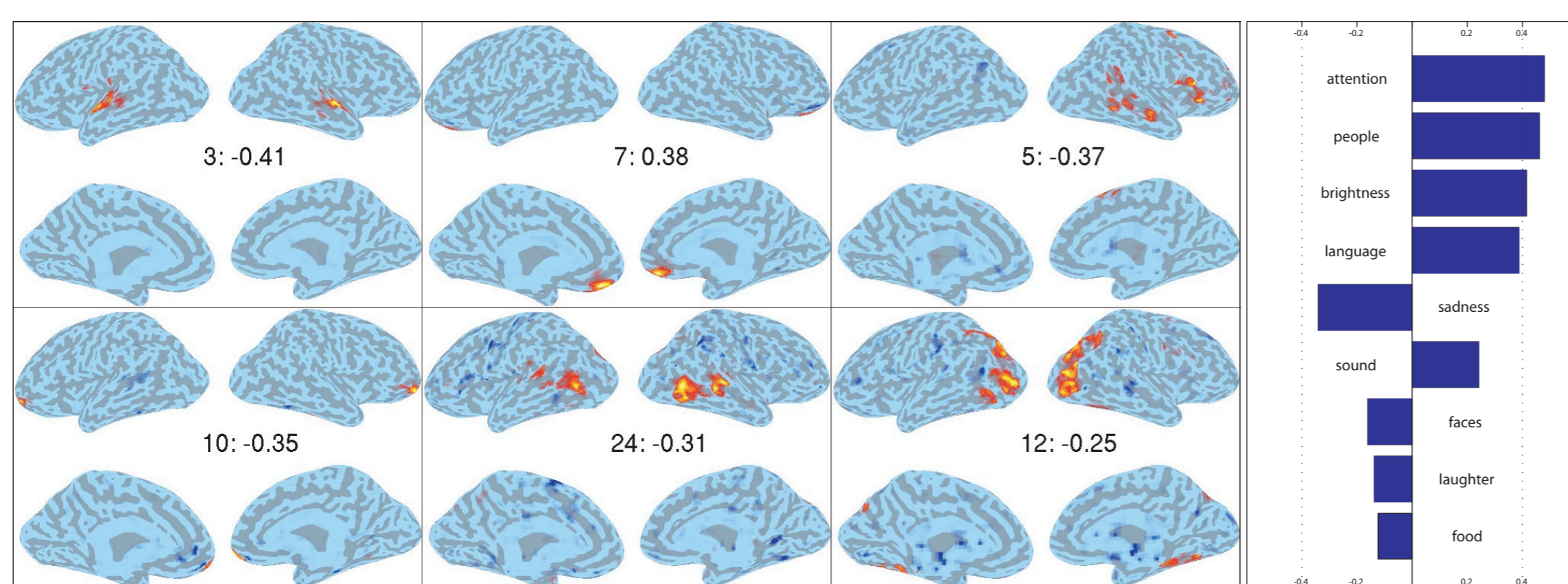
fMRI Data — ICA / elements — data-driven

Brain Activity

- Functional Elements
  * "Individual" processing task
  * Identified as independent components
- Functional Networks
  * Combined processing of several elements
  * Common goal related to external stimuli
  * Represented by dependent components

Network I

- Comprises brain areas often associated with, *e.g.*:
  * Auditory (IC3)
  * Visual (IC12)
  * Multi-modal integration (IC24)
- High scoring stimulus features include:
  * *attention*, *people*, *brightness* and *language*

Network II

- Comprises brain areas often associated with, *e.g.*:
  * Language processing (IC3 & IC5)
  * Face recognition (IC8)
- High scoring stimulus features include:
  * *language*, *faces*, *laughter* and *attention*

3: -0.41 | 7: 0.38 | 5: -0.37
10: -0.35 | 24: -0.31 | 12: -0.25

attention, people, brightness, language, sadness, sound, faces, laughter, food

25: -0.40 | 8: 0.38 | 5: 0.38
3: -0.35 | 18: 0.29 | 22: 0.27

language, faces, laughter, attention, sadness, people, sound, brightness, food

Discussion

We introduced a two-step approach using ICA and DeCA to construct networks of functional brain activity, based on covariation between the networked activity and combinations of stimulus features. Interpretation of the functional role of the complex network is based on its constituent spatial elements, as well as on relations between the network's global temporal activity and the stimulus features. The method was tested on fMRI recordings of brain responses to natural stimuli. The found networks seem plausible, considering the limited and very subjective nature of the available stimulus features. Some elements were a part of several networks, with different functional contribution to each network's common task. More controlled studies are being planned to verify the results and to further develop the approach.