The neural basis of intelligence in fine-grained cortical topographies

Summary

1. Problem

Previous research on the neural basis of intelligence has focused on coarse-grained features of brain anatomy and function and overlooked fine-grained architecture in that existing models could not resolve idiosyncratic topographies, that is to say, no principled method could investigate how the information embedded in these topographies differs across individuals.

2. Solution in this article

This article uses hyperalignment to model the fine-grained architectural differences by resolving idiosyncratic interindividual variation of fine-grained topographies of functional connectivity. This model has been proven to improve the predictions of general intelligence, especially in the cortical systems associated with self-generated thought.

3. Future direction

The bases for the organization of its fine-grained topographies and the transformations of representational geometries between default regions are unknow, but the keys to understanding it may reside in the information processing embedded in these topographies.

The neural basis of intelligence in fine–grained cortical topographies

Introduction

Previous Research

- **Cox et al., 2019; Schmitt et al., 2019; Kong et al., 2019**: The size and shape of the brain and its parts
- **Dubois et al., 2018; Finn et al., 2015; Luders et al., 2007:** the size and strength of connections between large cortical fields
- **Haxby et al., 2001, 2014:** Intelligence is encoded in fine-grained cortical topographies
- **Guntupalli et al., 2016, 2018; Haxby et al., 2011:** Different brains encode the same information in idiosyncratic topographic patterns
- **Guntupalli et al., 2018:** Functional connectivity shows fine-grained variation vertex-by-vertex within a cortical field and even neuron-by-neuron within an fMRI voxel **(Park et al., 2017)**

New method

Hyperalignment

- **Feilong et al., 2018; Guntupalli et al., 2016, 2018; Haxby et al., 2011, 2020:** a computational framework that models how shared information is encoded in idiosyncratic, fine-grained topographies
- **Guntupalli et al., 2018:** connectivity hyperalignment — **remixes the connectivity profiles of loci in a cortical field to maximize the similarity across brains in fine-grained, vertex-by-vertex patterns.**

Results

Data

- **876 participants of HCP**
- **Each**
  - **47 min task fMRI**
  - **1 h resting fMRI**
  - Hyperaligned
- **Scores on 10 cognitive tests**

Method

- **Fine-Grained (Full)= Coarse-Grained + Fine-Grained (Residual)**
- **Build models based on regional connectivity profiles using cross-validated principal component regression with ridge regularization.**
  - **Test: k=1-6**
  - **Training: 876-k**
- **Assess the performance by using a coefficient of determination (R^2) to denote the percent of intelligence score variance accounted for (VAF) by the prediction models**

To measure general intelligence as a general factor

Models

- **Fined-grained > Coarse-grained**
- **Task fMRI > Resting fMRI**
- **Hyperaligned data > MSM-aligned data**

Discussion

The results show that individual differences in fine-grained patterns of functional connectivity are a markedly better predictor of general intelligence than are coarse-grained patterns.

Results also show that fMRI data collected during performance of cognitive tasks better predict intelligence than resting state fMRI data

The results show further that the neural basis of intelligence resides mostly in the fine-grained structure of connectivity in the **default mode and frontoparietal networks**. (small in the dorsal & ventral attention; less in the visual system; none in the auditory/ somatosensory/motor/limbic function system)

- The predominance of the **default mode network** was found for both task connectivity and resting connectivity, suggesting that the efficiency of these connections is evident in both.
  - Internally-driven cognition
- A strong role for the **frontoparietal network** was more evident in task connectivity, suggesting that efficiency of this system's connections is better revealed during performance of tasks that increase its activity.
  - Self-directed thought/regulation of introspective process

The predominant role of the default and frontoparietal systems suggests that intelligence rests on self-generated and stimulus-independent thinking for finding correct solutions to problems and generating novel insights.