Iowa Summer Institute in Biostatistics

Energy and Pearson's Distances as Metrics for Brain Region Activation Detection in Audiovisual fMRI Study

Megan Gelement: Tufts University
Ting Huang: Macalester College

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Overview

Introduction

- Brain matter
- Detecting brain activity
- Our data & research question

Methods

- Pearson's Distance
- Energy Distance

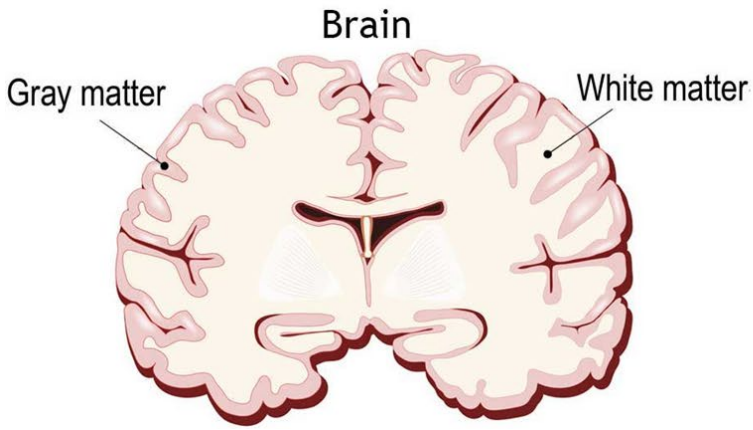
Results & Discussion

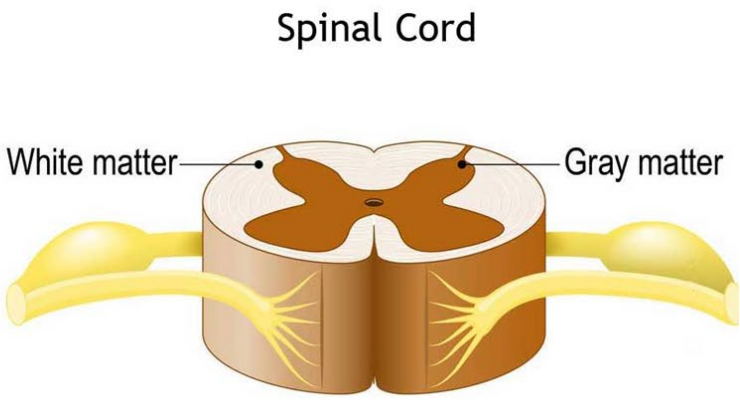
- Effectiveness of Pearson's & Energy Distances as metrics
- Regions of activity

Introduction

Brain Anatomy, BOLD fMRI, and Current Metrics for Establishing Brain Region Activation

Introduction to Brain Matter





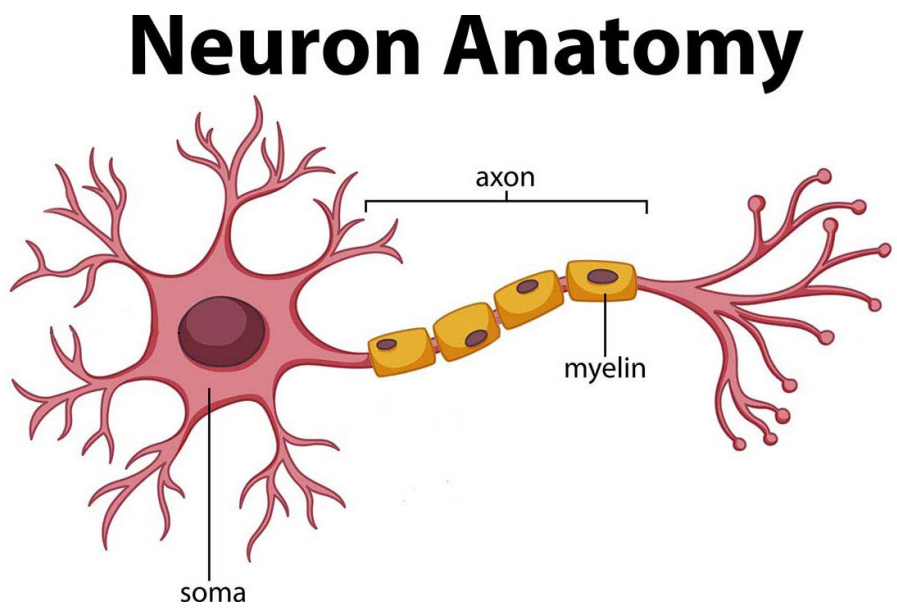


Image Source: https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-of-the-brain

BOLD fMRI

- ***Blood-oxygenation dependent (BOLD) functional magnetic resonance imaging (fMRI)*** is used to measure blood oxygen levels associated with brain regions of interest.

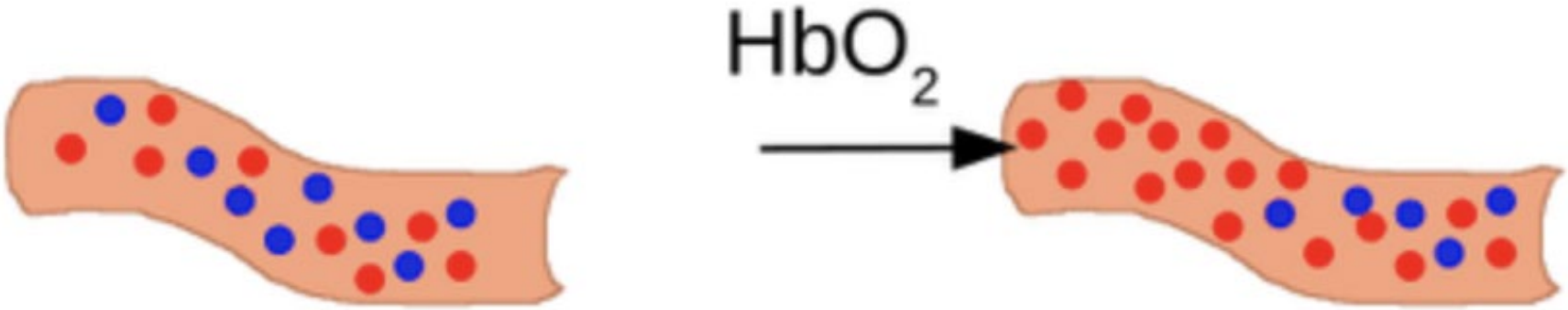


Image Source: https://www.researchgate.net/figure/fMRI-BOLD-signal-OLKT90-The-BOLD-signal-measures-the-local-changes-in-blood_fig8_318588598

Brain Region Activation Detection with BOLD

- MR scans are made up of individual cubic elements called voxels.
- We can visualize them in 3D or in 2D as slices

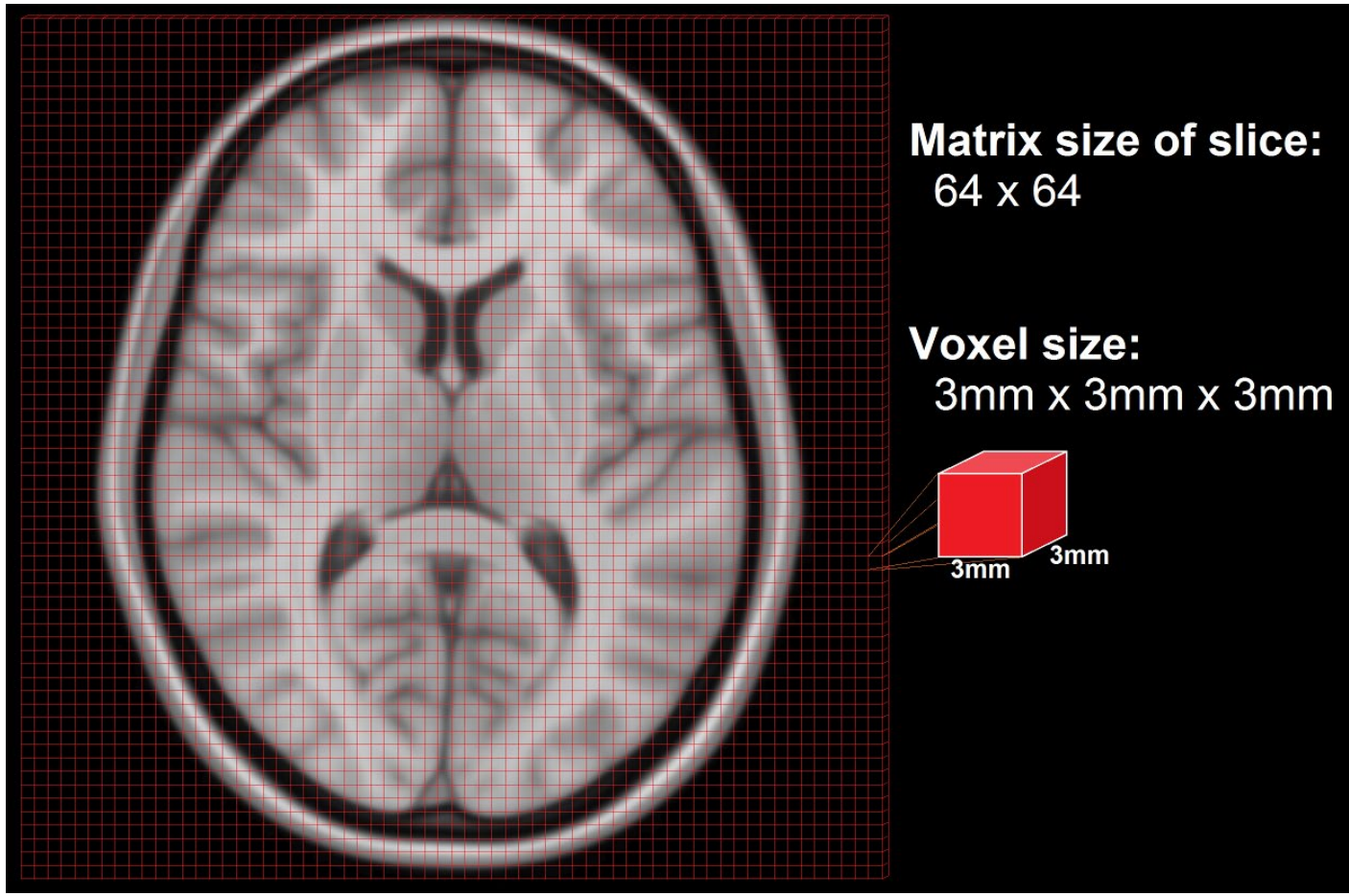
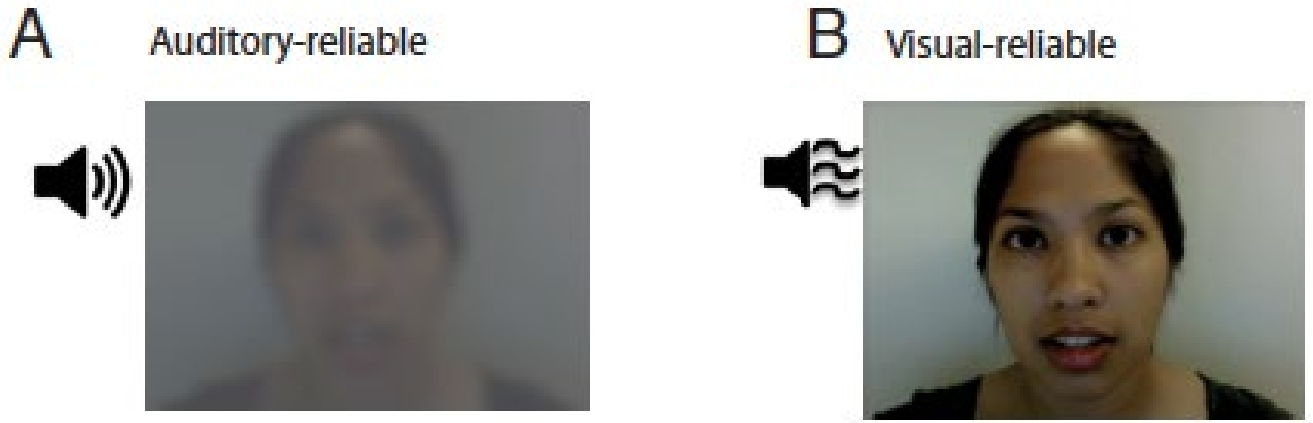


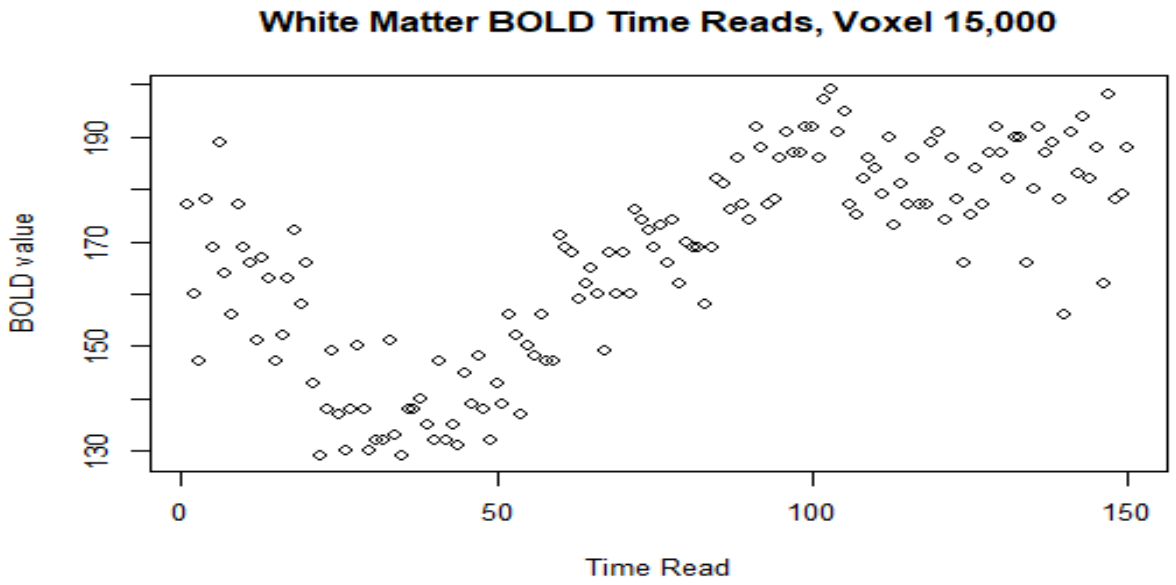
Image Source: http://miykael.github.io/nipype-beginner-s-guide/neuroimaging.html

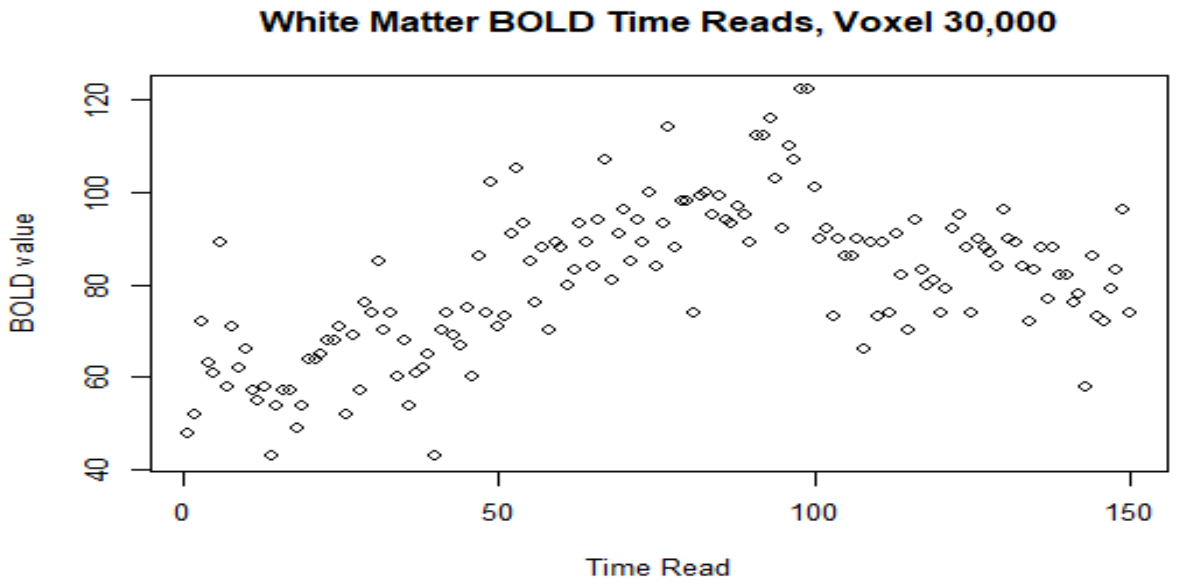
Our Data

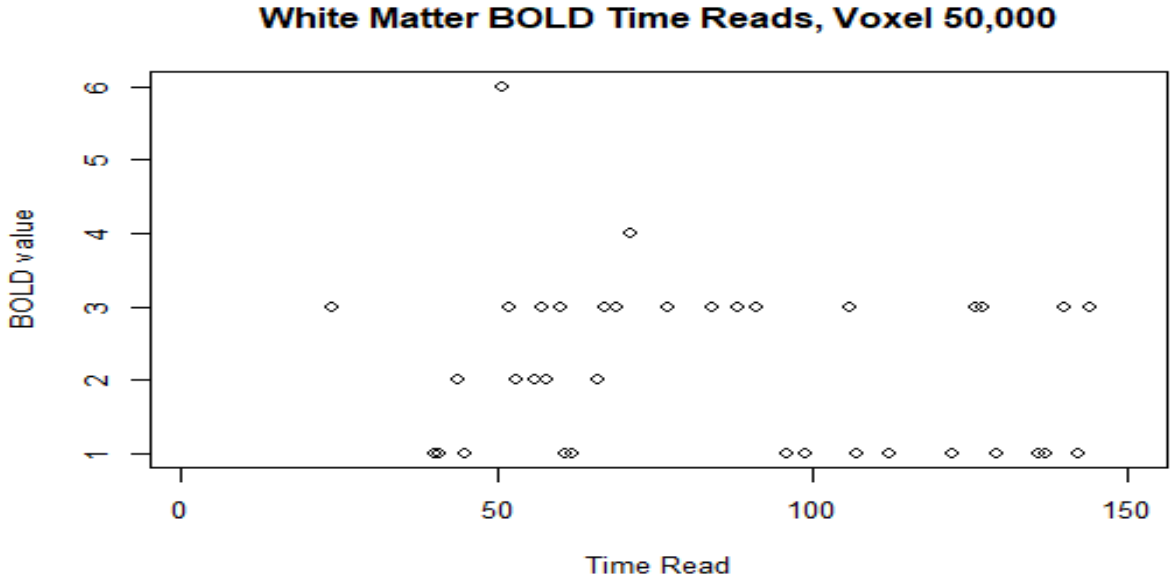


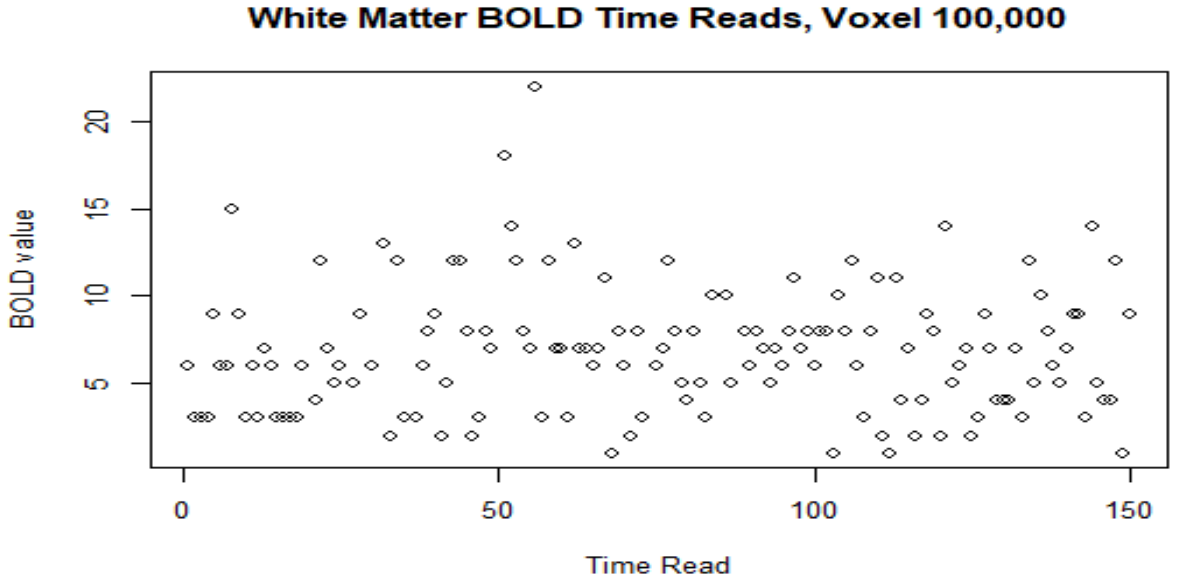
- We looked at BOLD activity from a single subject exposed to various audiovisual stimuli in a previous study
- 211,200 voxels
  - 150 time points per series
- We used the medical recommendation for the area of no activity
- Some studies employ linear regression analysis to identify regions of interest

Image source: Nath & Beauchamp 2011, “Dynamic Changes in Superior Temporal Sulcus Connectivity During Perception of Noisy Audiovisual Speech,” The Journal of Neuroscience,


White Matter BOLD Time Reads, Voxel 15,000
BOLD value
130
150
170
190
0
50
100
150
Time Read


White Matter BOLD Time Reads, Voxel 30,000
BOLD value
40
60
80
100
120
0
50
100
150
Time Read


White Matter BOLD Time Reads, Voxel 50,000
BOLD value
1
2
3
4
5
6
0
50
100
150
Time Read


White Matter BOLD Time Reads, Voxel 100,000
BOLD value
5
10
15
20
0
50
100
150
Time Read

Methods

Pearson’s Distance and Energy Distance

Pearson's Distance

$$r = \frac{\Sigma(X_i - \bar{X})\,(Y_i - \bar{Y})}{[\Sigma(X_i - \bar{X})^2\,\Sigma(Y_i - \bar{Y})^2]^{1/2}}$$

Pearson's Distance Formulas

$$\begin{cases} 1 - r \\ 1 - |r| \\ \sqrt{1 - r} \\ \sqrt{1 - r^2} \end{cases}$$

Energy Distance

$$X \sim \mathcal{F} \quad \text{and} \quad Y \sim \mathcal{G}$$

Samples $x_1, x_2, \ldots, x_n$; and $y_1, y_2, \ldots, y_m$.

$$E(X,Y) = 2E_1 - E_2 - E_3,$$

where

$$E_1 = \frac{1}{nm} \sum_{i=1}^{n} \sum_{j=1}^{m} \|x_i - y_j\|$$

$$E_2 = \frac{1}{n^2} \sum_{(i,j)=1}^{n} \|x_i - x_j\|$$

$$E_3 = \frac{1}{m^2} \sum_{(i,j)=1}^{m} \|y_i - y_j\|$$

Image credit: ESA/Hubble & NASA, A. Riess et. al w/ acknowledgement to Mahdi Zamani; source: scitechdaily.com

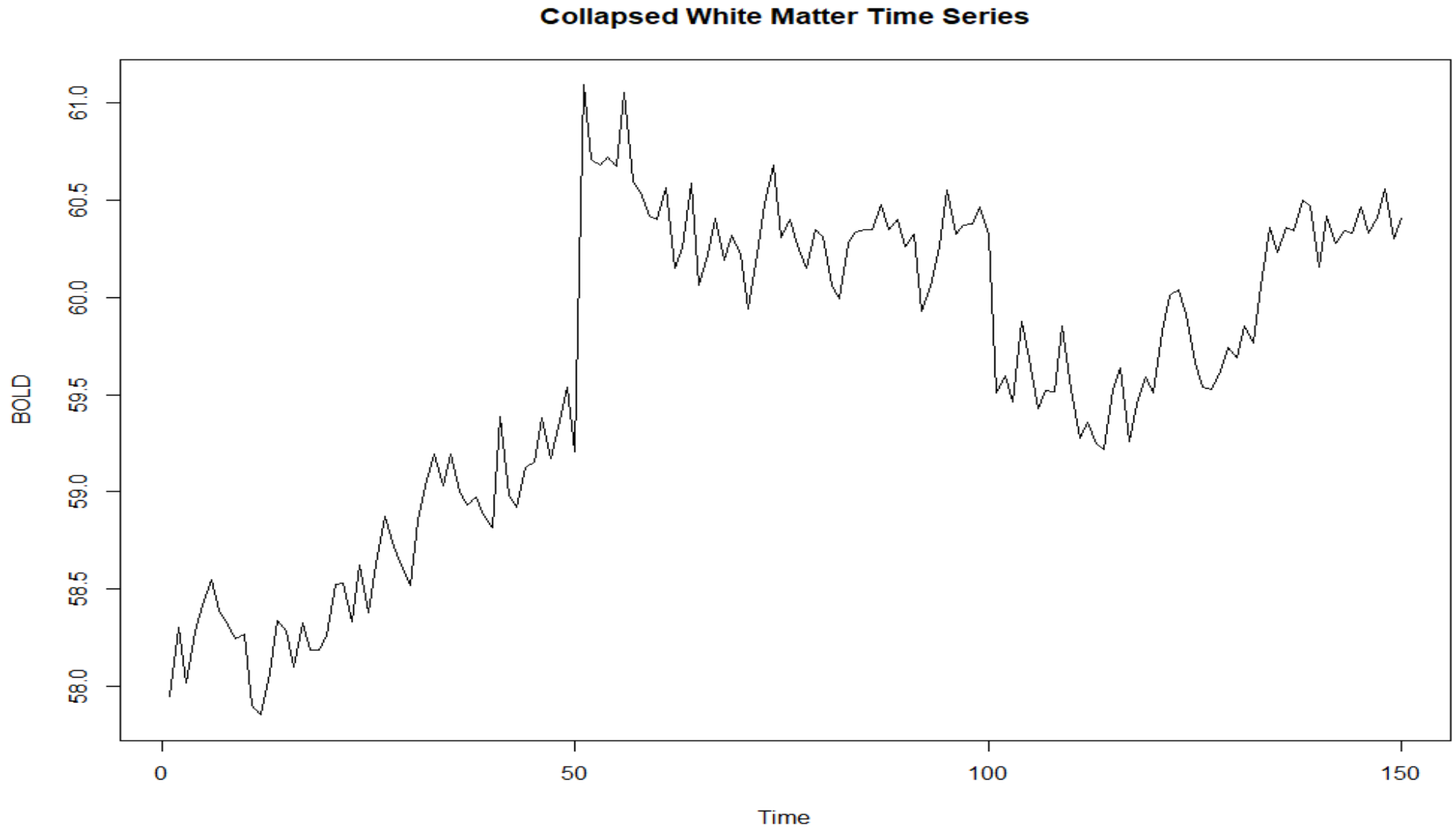
Our Algorithm

- We employ a strategy known as profile monitoring

- Step 1: Using the medical recommendation for no activity
  - Summarize each white matter time series by computing the mean
    - Compute the Pearson's and Energy distances between each white matter voxel measurements and the collapsed mean series
      - Obtain the 5% upper threshold representing our decision benchmark

- Step 2: For each distance
  - Apply the benchmark found in Step 1 to the series from each voxel
  - Display the results

Our Working Model

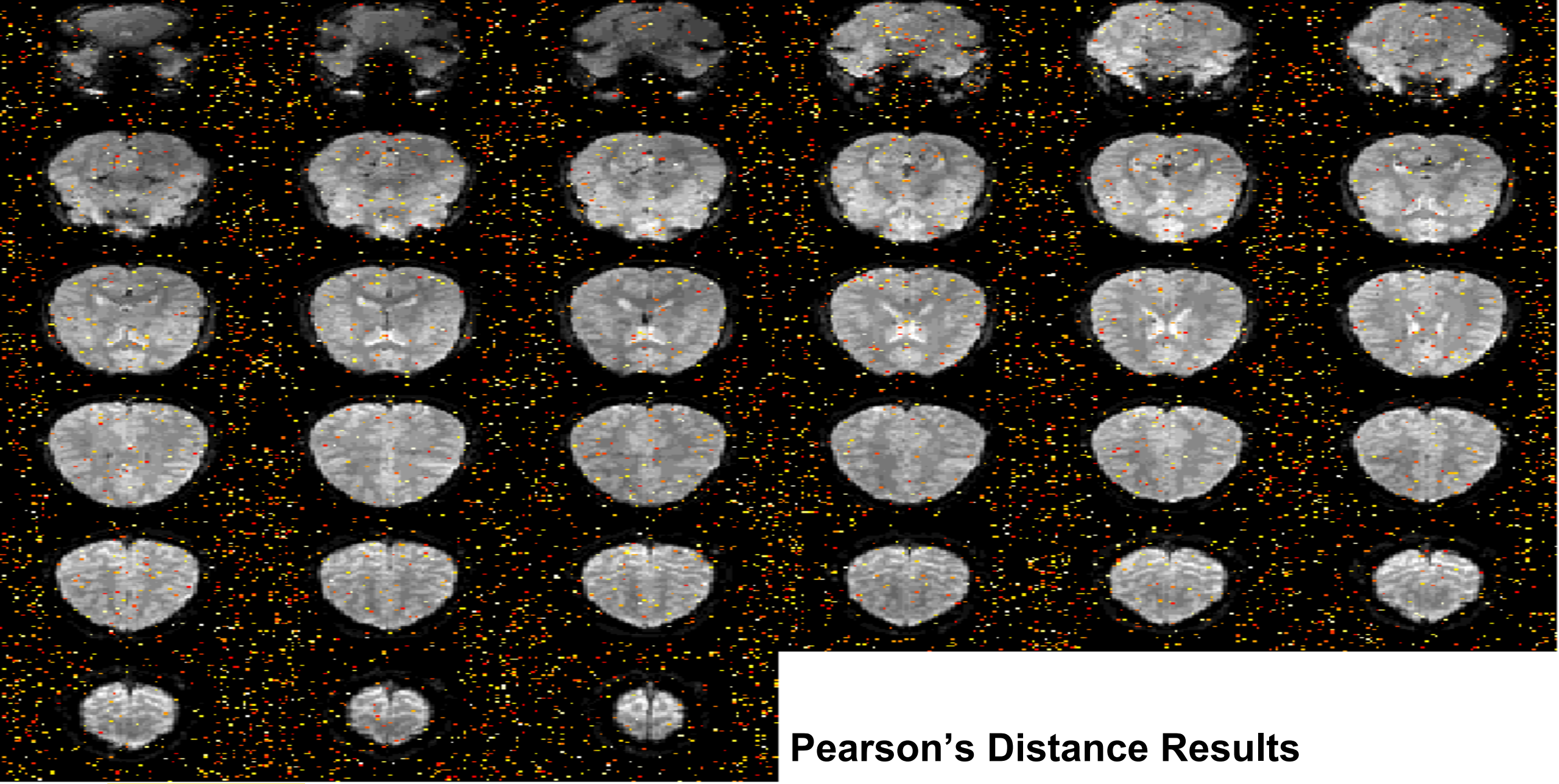


Results & Discussion

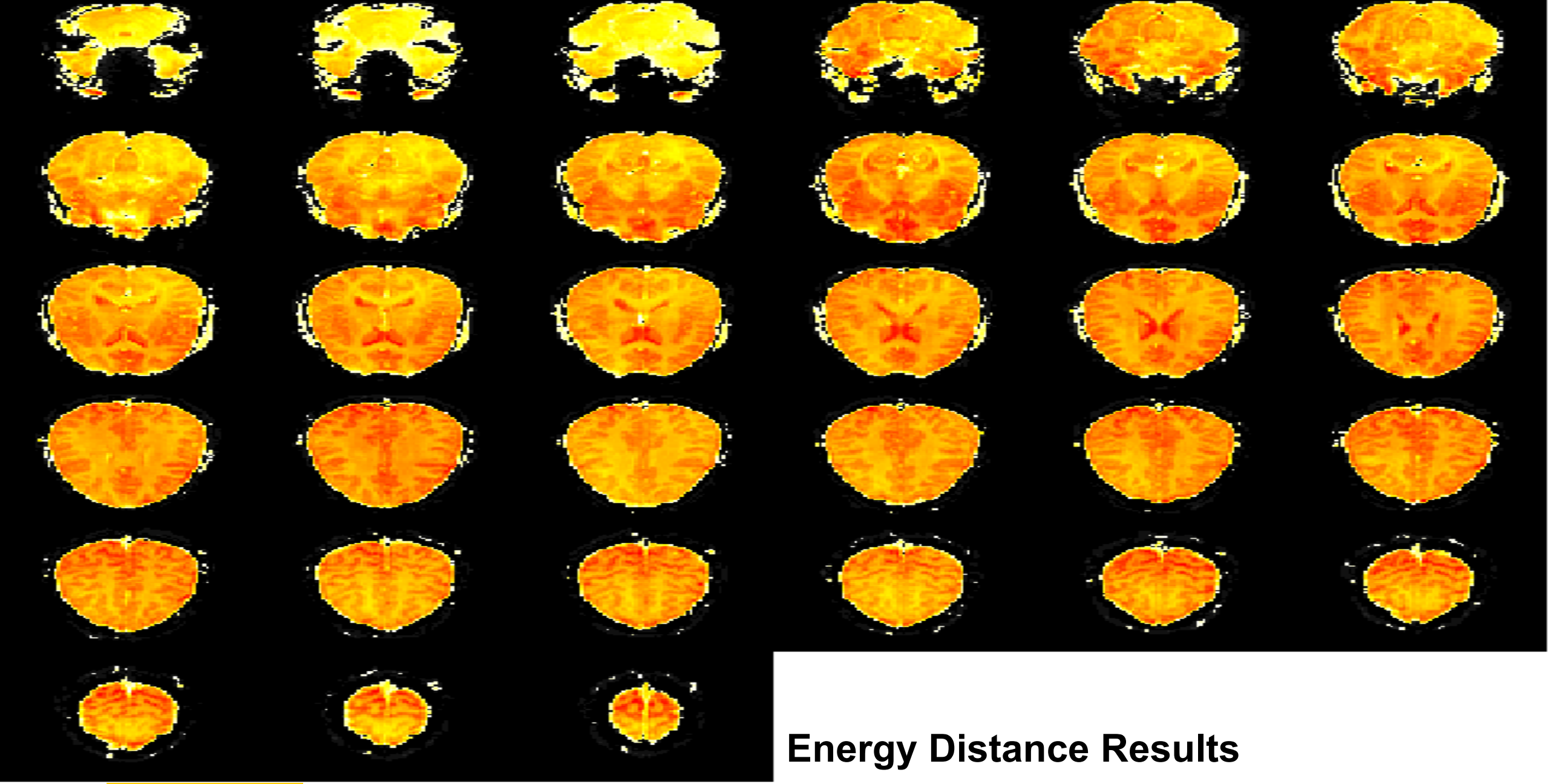
Mapping the Brain Using Pearson’s and Energy Distances

Regions of Interest

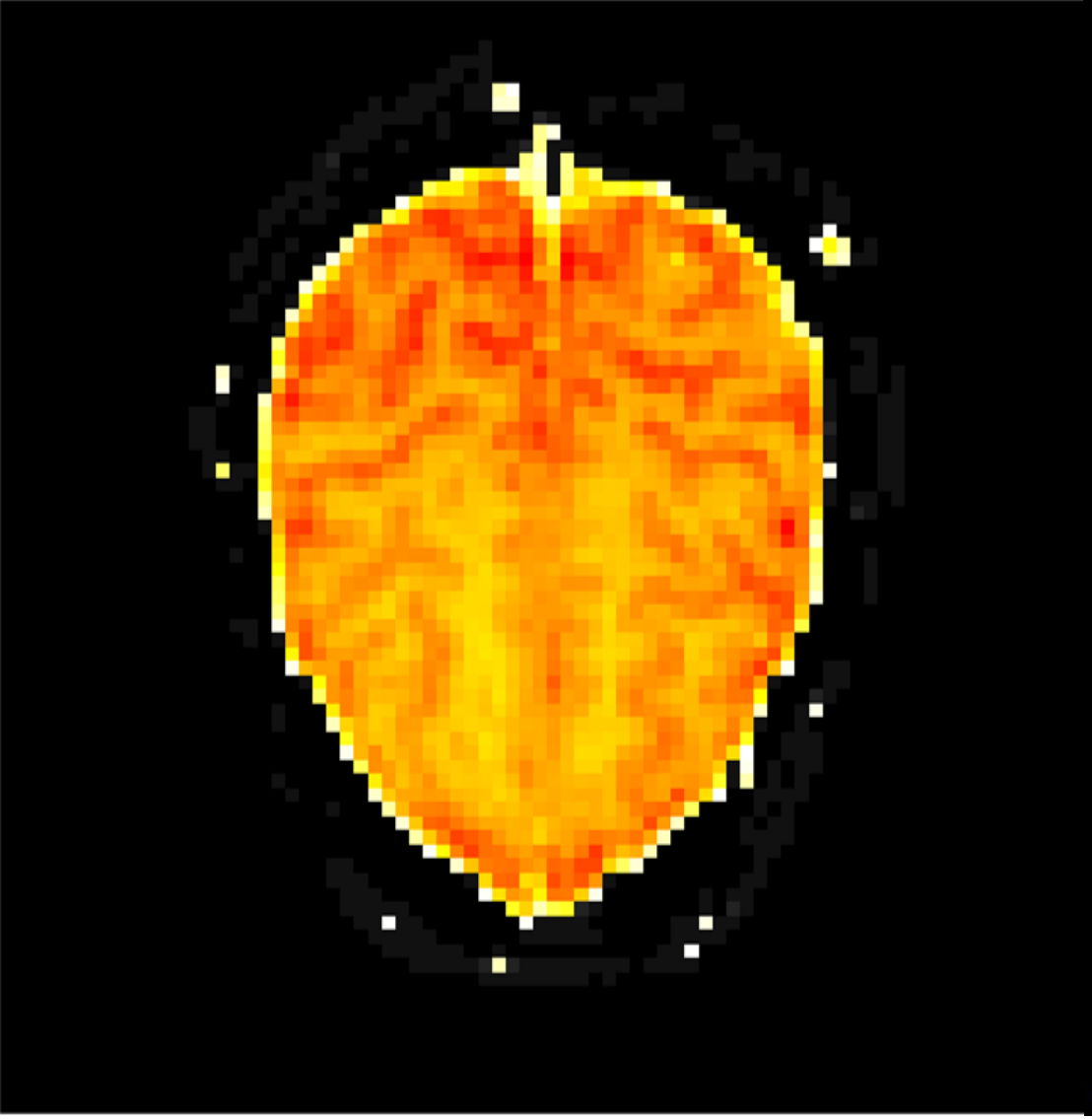
- **Temporal lobe**: contains **auditory cortex**, which is mostly found in a fissure known as the **lateral sulcus**
- **Superior temporal gyrus:** involved in word recognition
- **Thalamus** (specifically, **medial geniculate nucleus**): sends information to auditory cortex
- **Parietal lobe**: Integrates sensory information (particularly spatial); visual, some auditory

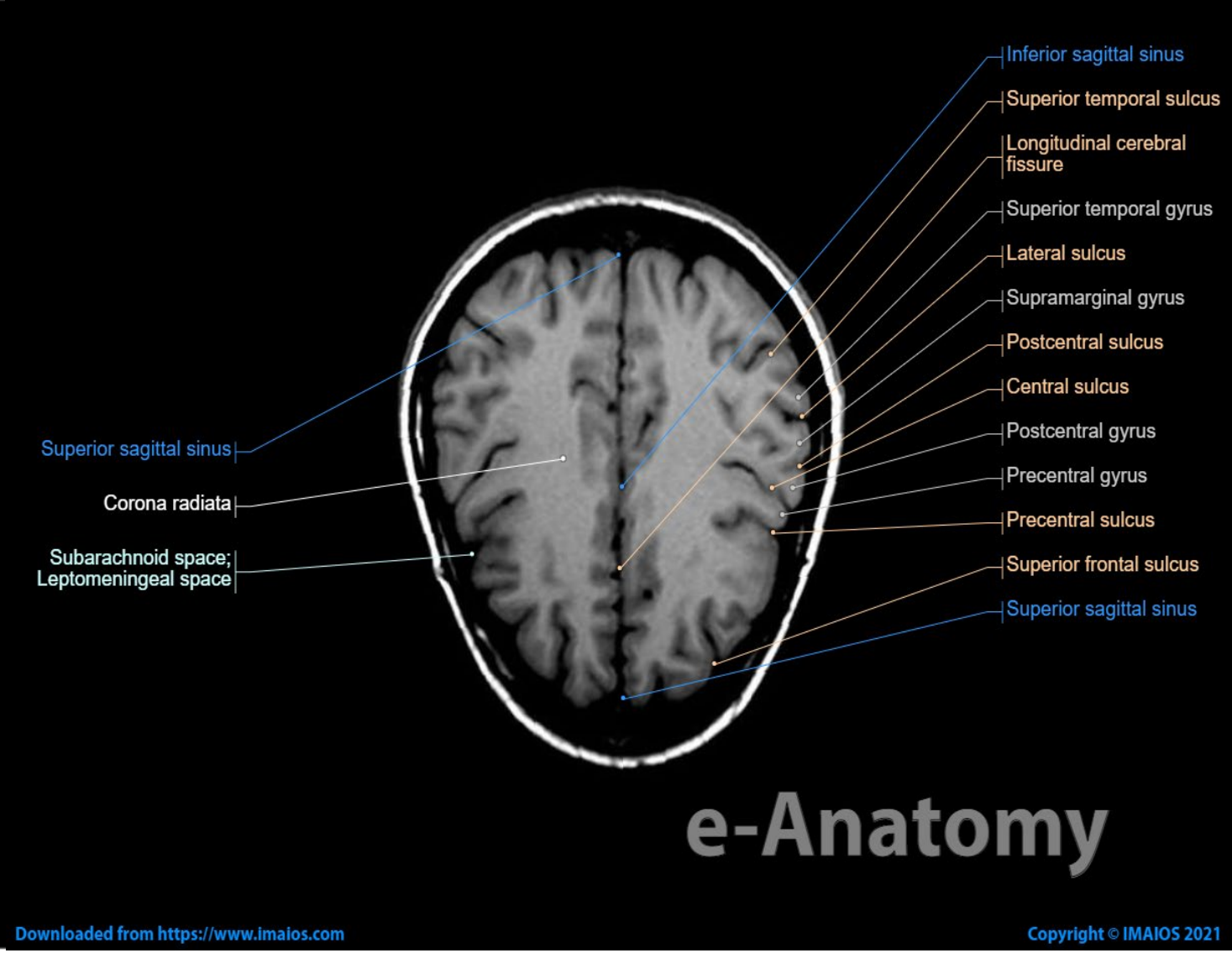


Pearson's Distance Results



Energy Distance Results




Inferior sagittal sinus
Superior temporal sulcus
Longitudinal cerebral fissure
Superior temporal gyrus
Lateral sulcus
Supramarginal gyrus
Postcentral sulcus
Central sulcus
Postcentral gyrus
Precentral gyrus
Precentral sulcus
Superior frontal sulcus
Superior sagittal sinus
Superior sagittal sinus
Corona radiata
Subarachnoid space;
Leptomeningeal space
e-Anatomy
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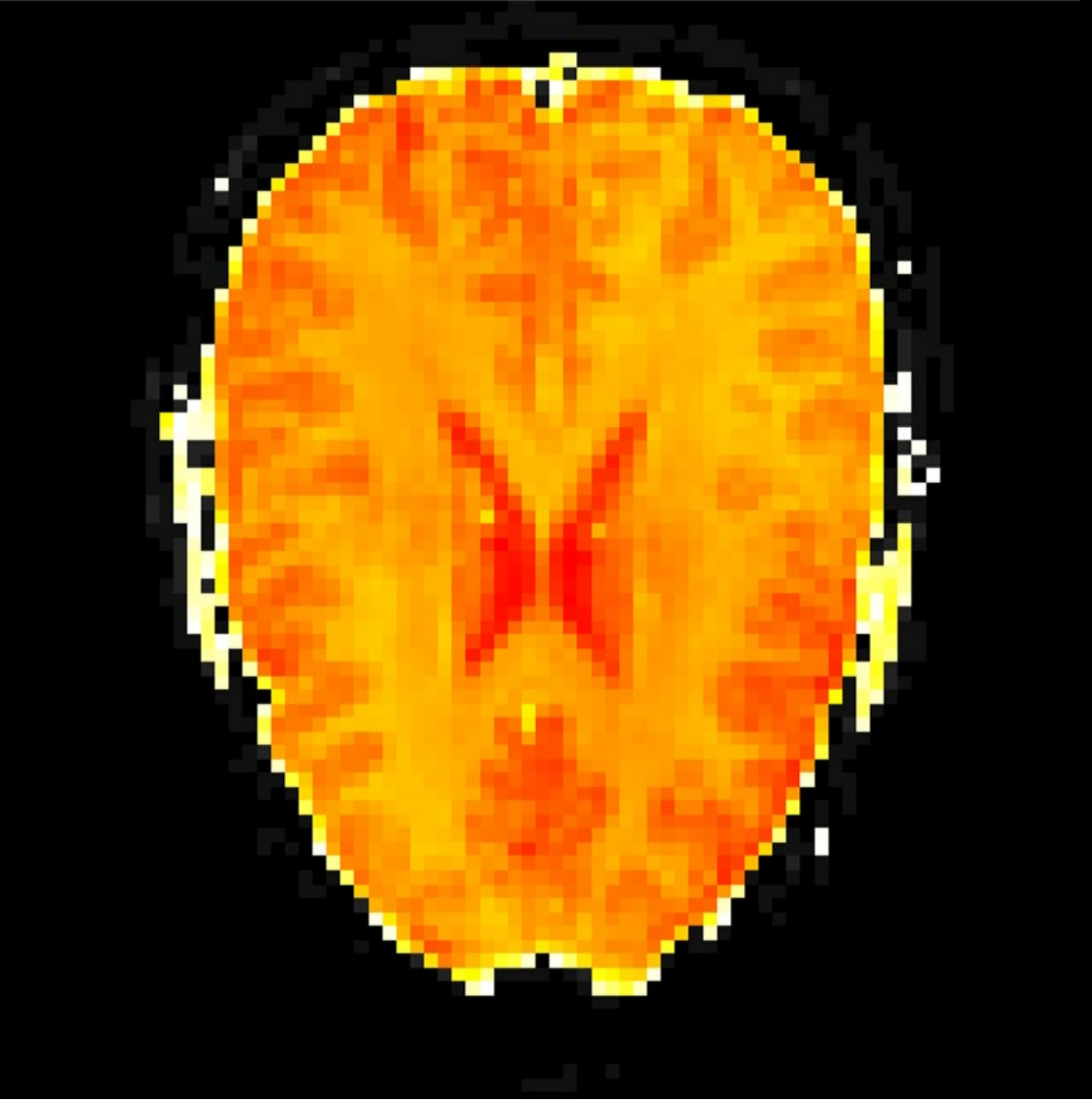

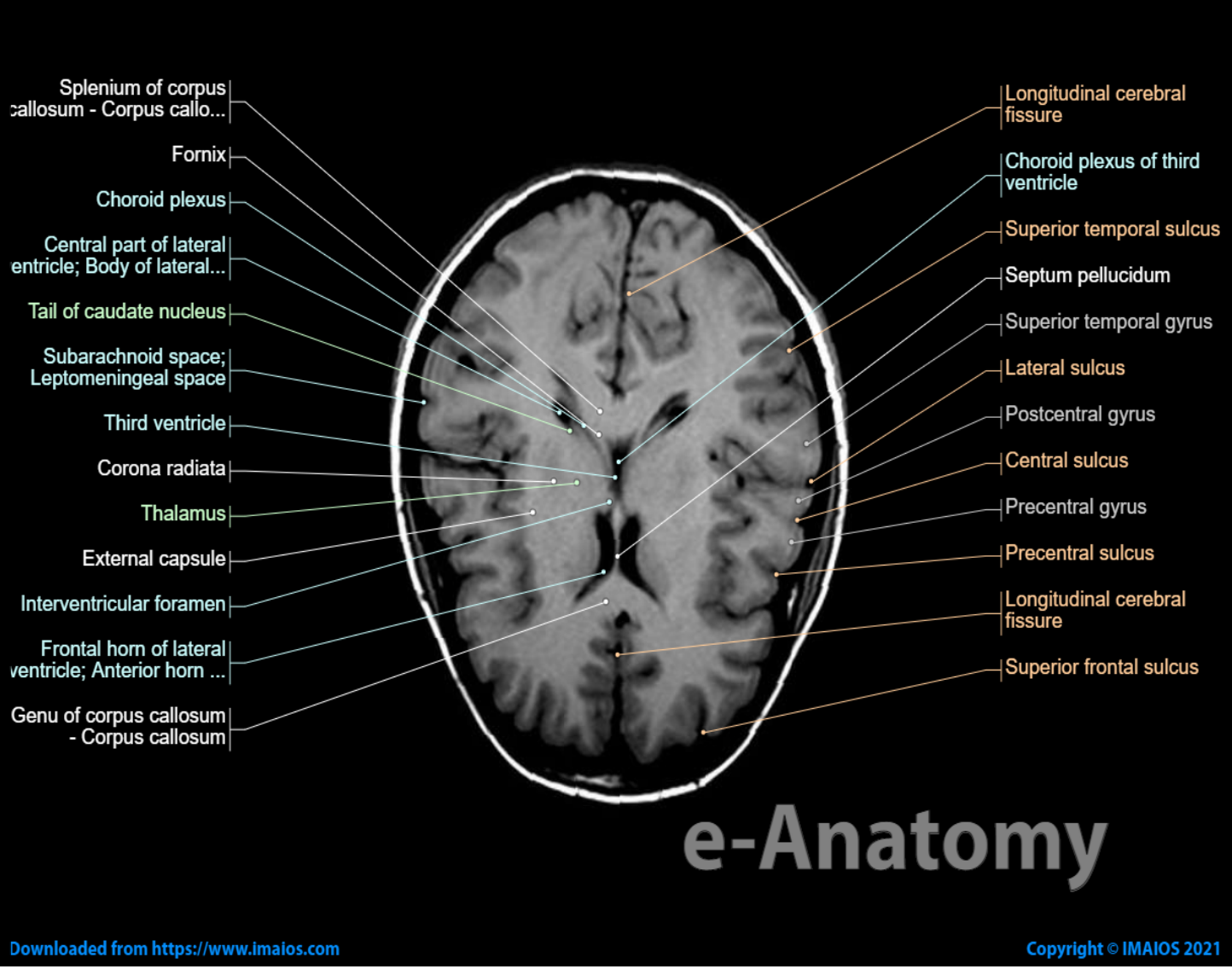

Conclusions, Limitations & Future Research

- Energy distance suggests areas of activation consistent with published literature
- Pearson's distance hasn't shown ability to capture activation regions
- Though 211,200 x 150 observations are used, they belong to a single subject
- Future research:
  - Explore energy distance as a metric for determining activity across a larger sample of subjects to validate findings
  - Use unsupervised tools in the absence of medical recommendations

Acknowledgements & Collaborators

- Dr. Gideon Zamba, ISIB Program Director, project mentor
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Questions?