**Emotion-Cognition Modeling with Interoception**

**Overview of the fMRI data**

Columns are:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Patient ID | Time | Condition1 | Scan-in-condition1 | Condition2 | Condition3 | Ignore | brain |
| ID in [2000,2999] is control  ID in [3000,3999] is ruminative population  ID in [1000,1999] is pilot group |  |  |  | Condition2==2 is criticism  Condition2==3 is neutral  Condition2==5 is rest |  |  |  |

There are two variables of interest:

1. Patient population (control or ruminative)
2. Scan condition (neutral statement vs critical statement)

Both groups (control and ruminative) were introduced to neutral and critical conditions

**Generated data profiles**

I have organized the data profiles as follows:

There are two folders called “criticism\_rest\_76\_scans” and “neutral\_rest\_76\_scans”.

* In the “criticism\_rest\_76\_scans” folder
  + Each individual has three files associated with them, each containing fMRI data for a different brain region: Executive network, salience network, interoceptive network
  + Each of these files is 76 rows (1 row = 1 scan)
  + 18 scans criticism + 18 scans rest + 18 scans criticism + 18 scans rest
* In the “neutral\_rest\_76\_scans” folder
  + Each individual has three files associated with them, each containing fMRI data for a different brain region: Executive network, salience network, interoceptive network
  + Each of these files is 76 rows (1 row = 1 scan)
  + 18 scans neutral + 18 scans rest + 18 scans neutral + 18 scans rest

Sample file: “2303\_executive\_criticism\_76\_scans.csv”

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| patient ID | time | condition1 | scan-in-condition1 | condition2 | condition3 | ignore | brain |
| 2303 | 199 | 3 | 1 | 2 | 2 | -999 | 9854.46 |
| 2303 | 200 | 3 | 2 | 2 | 2 | -999 | 9854.83 |
| 2303 | 201 | 3 | 3 | 2 | 2 | -999 | 9848.97 |
| 2303 | 202 | 3 | 4 | 2 | 2 | -999 | 9837.81 |
| 2303 | 203 | 3 | 5 | 2 | 2 | -999 | 9830.68 |
| 2303 | 204 | 3 | 6 | 2 | 2 | -999 | 9822.79 |
| 2303 | 205 | 3 | 7 | 2 | 2 | -999 | 9819.05 |
| 2303 | 206 | 3 | 8 | 2 | 2 | -999 | 9826.48 |
| 2303 | 207 | 3 | 9 | 2 | 2 | -999 | 9834.02 |
| 2303 | 208 | 3 | 10 | 2 | 2 | -999 | 9836.9 |
| 2303 | 209 | 3 | 11 | 2 | 2 | -999 | 9834.65 |

**The dynamical connectionist model**

The dynamical connectionist model is defined in the file “bada\_nn\_1999\_2.m”. This model is a fully connected graph with four nodes. Each node represents a brain region:

* Executive (prefrontal cortex)
* Salience (amygdala)
* Interoceptive (insula)
* Incoming threat (external perception)

A 4x4 weight matrix, *A*, defines the strength of the connections between these regions. An input vector, u, defines any input to one of the nodes/brain regions at a given time.

e.g.

A picture containing circle, diagram, line, screenshot

Description automatically generated A = A picture containing black, darkness

Description automatically generated, u = 

For the weight matrix, A, the values over the principal diagonal are feed forward, and values under the principal diagonal are feed backward. Values along the diagonal define self-referential connections for each node.

Take the following matrix as an example:

%threat %sal. %exec. %int.

%healthywmat=[ 1 2 3 4 ; % external threat

% 5 6 7 8 ; % salience/vigilance/rum

% 9 10 11 12 ; % executive

% 13 14 15 16 ]; % interoception

Taking the first row as an example, the connection from the external threat node to the external threat node is 1. Connection from external threat to salience network is 2. Connection from external threat to executive network is 3. Connection from external threat to interoceptive network is 4.

In other words, connections are defined from rows to columns.

Let the weight matrix be:

wmat=[ .9 .15 0 0 ; % external threat

0 .9 .25 .25 ; % vigilance/salience

-.25 -.04 .9 -.1 ; % avoidance/control

0 .25 .15 .9 ]; % interoception

This weight matrix produces the following dynamics:

A picture containing text, diagram, line, plot

Description automatically generated

**Fitting model to data: Description**

The weight matrix that defines the connectionist model has 16 parameters. We want to “fit” the weight matrix to each individua’s fMRI data. In other words, we want to find the exact 16 parameters that make the model behave as close as possible to an individual’s brain.

Thus, we will find the 16 parameters for individual A, then find a new set of 16 parameters for individual B, then for individual C, and so on until we have found model parameters for all the individuals that were scanned.

Once we have found these model parameters, we can average the values and ask questions like: How does the connection strength between the amygdala and insula in ruminative patients compare to the control population?

Want: spreadsheet with columns:

* Id#
* Overall model fit (best possible parameters, how close are we to modeling timeseries for each network)
  + 3 correlations for criticism
  + 3 correlations for neutral
* 16 model parameters for criticism
* 16 parameters for neutral

To fit the models to data, we start

TODO: Ask Greg about what sort of questions do we want to answer for our paper?

* Are we comparing normal populations vs ruminative?
* Are we comparing connectivity differences in criticism vs neutral for each individual?

Primary question: It appears that according to simulations, one can regulate network response by either:

1. Decreased interoceptive connectivity
2. Increased control connectivity

Question: is there evidence that people do one or the other of these to regulate their responses?

* Is it the case that when ruminative ppl have more runaway salience processing
  + If they don’t… is it through:
    - Decreased int
    - Increased control
* In controls
  + If they don’t have runaway salience, is the mechanism:
    - Decreased interoceptive int
    - Increased control

t- test between groups for each of 16 parameters to say what’s different.

TODO: Ask Greg about the criticism models….

% PROBLEM: Originally, if type='criticism' there would be an addition of

% criticism vector just at time=1 and time = 30000. However, in the fMRI

% study, criticism was presented for 18 scans, then 18 of rest, then 18

% criticism, then 18scans rest. So criticism vector should be added for

% time = [1,15000] and time= [30000,45000].

**ANSWER**: We could add an additional parameter for how long the stimulus is presented, to make the model fit more empirically sound.

TODO: Should the ‘criticism’ vector be constant?

Right now, the criticism that is added at each time point in the criticism condition is [ 0.05 0 0 0] \* momentum. However, should this criticism value be a variable that is also fit to the data?

Not everyone perceives the same criticism equally.

**Fitting model to data: Process**

Three files of code are utilized:

1. bada\_nn\_1999\_2.m
2. indmodelparameters.m
3. find\_model\_parameters.m

indmodelparameters.m is the starting point for fitting model to patient data. Basically, this file calls find\_model\_parameters.m and builds a struct called weight\_matrix\_fit\_to\_data.mat, which has the following hierarchy:

* **Struct**
  + **Neutral**
    - **Individual A**
      * **Weights** (1x16 matrix containing the fitted model parameters to neutral condition)
      * **Exec**\_**corr** (pearson correlation between simulated executive activity and fMRI executive activity)
      * **Sal**\_**corr** (pearson correlation between simulated salience activity and fMRI executive activity)
      * **Int**\_**corr** (pearson correlation between simulated interoceptive activity and fMRI executive activity)
      * **Timeseries**
        + **fMRI** (60000x3 fMRI data for executive, salience, interoceptive region)
        + **simulation** (60000 x 3 simulation data for executive, salience, interoceptive regions)
        + **labels** (1x3 corresponds to the column titles for fMRI and simulation timeseries data)
    - …
    - **Individual Z**
      * **Weights**
      * **Exec**\_**corr**
      * **Sal**\_**corr**
      * **Int**\_**corr**
      * **Timeseries**
        + **fMRI**
        + **simulation**
        + **labels**
  + **Criticism** 
    - **Individual A**
      * **Weights** (1x16 matrix containing the fitted model parameters to criticism condition)
      * **Exec**\_**corr** (pearson correlation between simulated executive activity and fMRI executive activity)
      * **Sal**\_**corr** (pearson correlation between simulated salience activity and fMRI executive activity)
      * **Int**\_**corr** (pearson correlation between simulated interoceptive activity and fMRI executive activity)
      * **Timeseries**
        + **fMRI** (60000x3 fMRI data for executive, salience, interoceptive region)
        + **simulation** (60000 x 3 simulation data for executive, salience, interoceptive regions)
        + **labels** (1x3 corresponds to the column titles for fMRI and simulation timeseries data)
    - …
    - **Individual Z**
      * **Weights**
      * **Exec**\_**corr**
      * **Sal**\_**corr**
      * **Int**\_**corr**
      * **Timeseries**
        + **fMRI**
        + **simulation**
        + **labels**

indmodelparameters.m

* Loop through all patients in fMRI recording files.
  + For each patient:
    - Find the model parameters (i.e., the 16 values of weight matrix) for neutral condition.
      * Save these values (fMRI data, simulated data, correlations between simulated vs actual brain regions, and weight matrix) to the struct.
    - Find the model parameters for criticism condition.
      * Save these values to the struct.

find\_model\_parameters.m

* Load the brain data for the given patient and the given condition (neutral or criticism)
  + This involves loading three files from the generated data profiles
  + E.g. For patient 2303 in the criticism condition, we read in:
    - 2303\_executive\_criticism\_76\_scans
    - 2303\_salience\_forward\_criticism\_76\_scans
    - 2303\_interoceptive\_forward\_criticism\_76\_scans
  + Interpolate brain data to be 60000 in length
* use fminsearch to find model parameters, with the function weightsearch as the function that is being optimized
* Inside weightsearch:
  + call bada\_nn\_1999\_2.m with either neutral or criticism condition to get simulated data
  + Perform convolution of simulated data with the current weight matrix (hemodynamic fMRI)
    - All convolved data is 60000 in length
  + Find the correlation between convolved and interpolated data for each region
  + Calculate loss
  + Once loss < 0.0003, we end

**Discussion – 7/5/2023**

Symmetry criterion: connection from A to b is not equal to connection from b to a

Lower auto-corr and higher noise should make it more tolerable of higher duration presentations.

When there are low fits, play around with initial auto-correlation, noise levels, stimulus duration. OR empirically fit them as parameters.

Hamming window: discount / cutoff the first and last bits.

e.g. A graph of a graph

Description automatically generated

how often is this happening? ^