What is the dimensionality of neural representation?

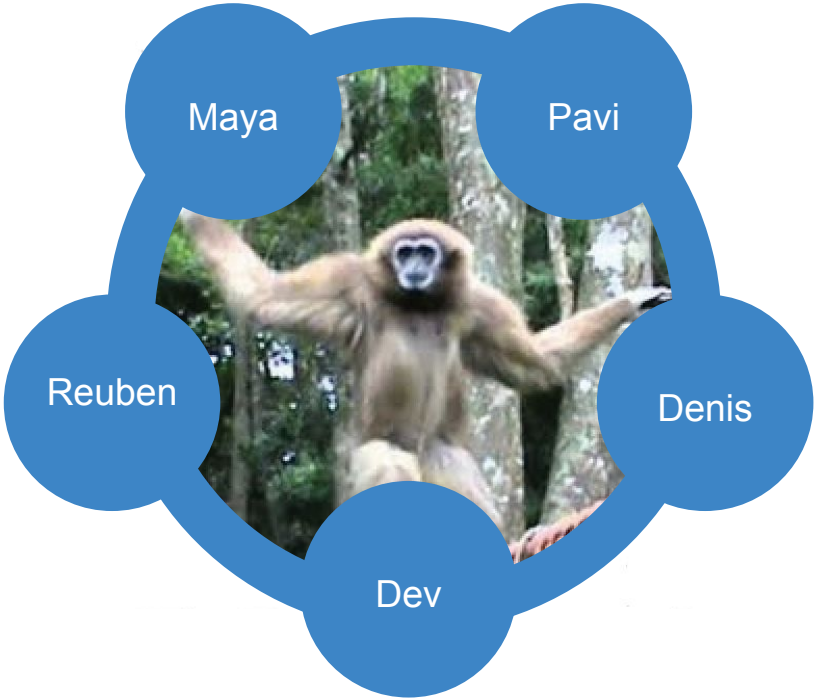
- Within a single task
- Across sensory, association, decision, & motor cortices
- Across time

Dataset: Steinmetz

Mentored by: Dr. Roozbeh Kiani

https://www.pewtrusts.org/en/trend/archive/spring-2020/roozbeh-kiani-how-the-brain-learns
https://www.npr.org/sections/13.7/2015/03/29/396140817/this-gibbon-knows-lifes-a-balancing-act

Pod-030-Judicious_Gibbon



Neuromatch Academy 2020
Group project

Hypotheses, Predictions, and Data parameters

During the inference process:

H1: gating away sensory information, using latent variables to make decisions and generate action

or

H2: combining sensory information and latent variables to make decisions and generate action

Two distinguishable **predictions**:

Across sensory, association, decision, and motor regions,

P1: neural representational dimensionality decreases.

P2: neural representational dimensionality increases .

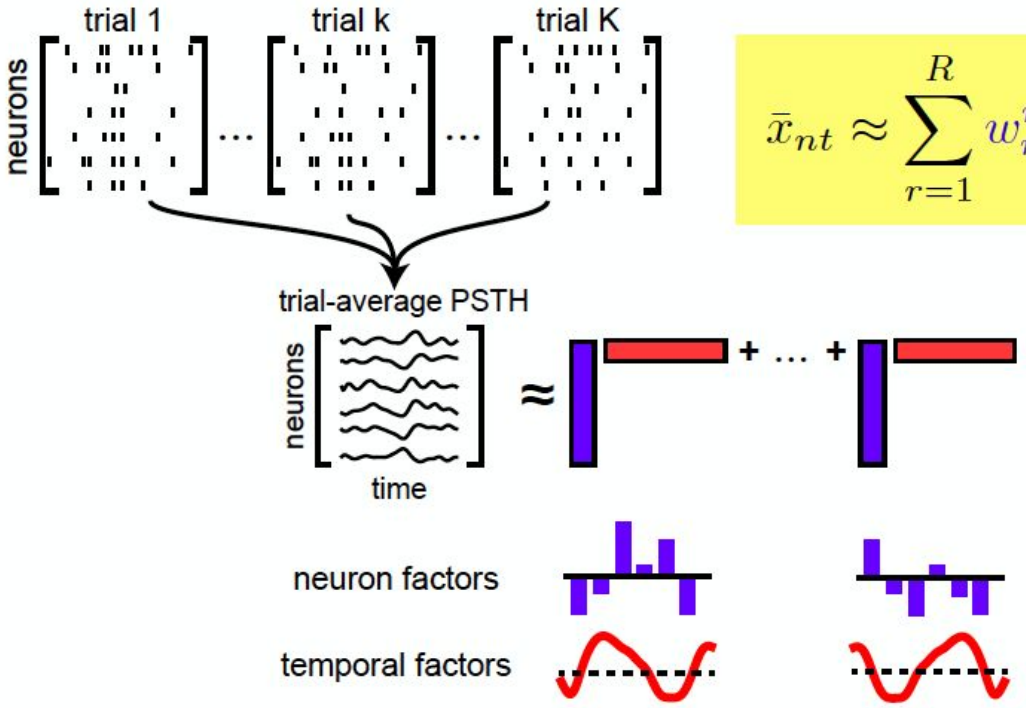
Data : Steinmetz Data
Sessions : 13 and 39
Brain Areas : VISam, CA1, PL, MOs
Task : Mice, 2 visual stimuli w/ varying contrast, choose high contrast, left - right - No-go actions

Criteria:

- Selected sessions which included recordings for all 4 areas of interest
- Minimum of 30 neurons represented in each region

Methods

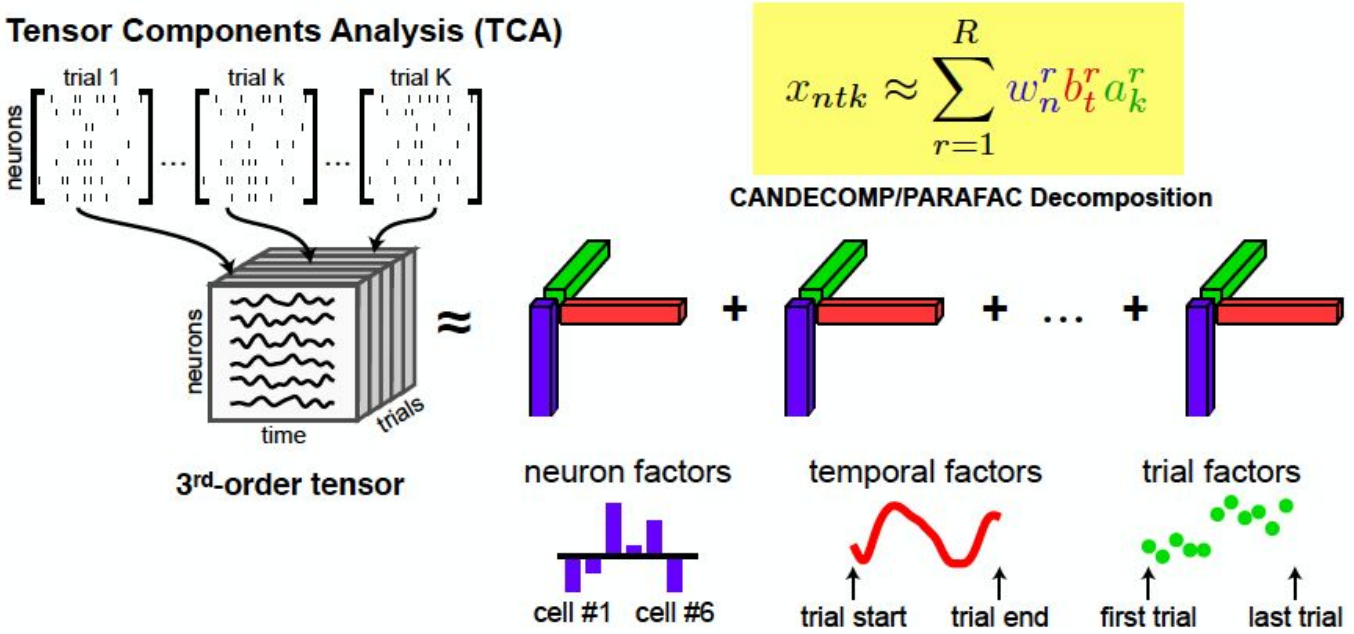
Approaches to dimensionality reduction: trial-averaged PCA



$$\bar{x}_{nt} \approx \sum_{r=1}^{R} w_n^r b_t^r$$

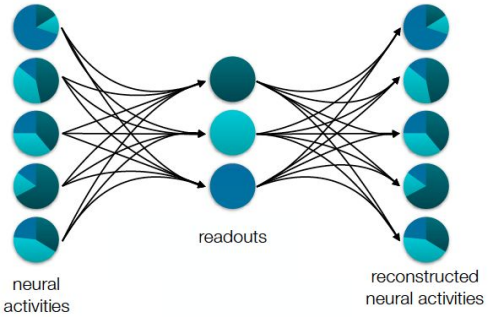
Alex H. Williams 2017

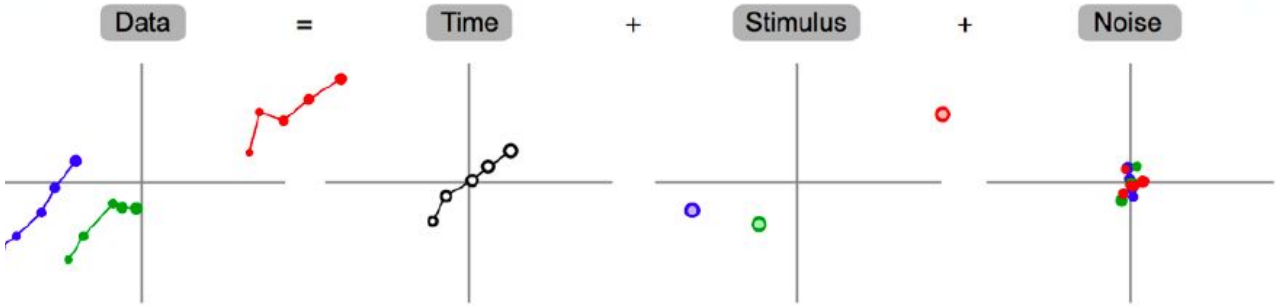
Approaches to dimensionality reduction: TCA



Alex H. Williams 2017

Approaches to dimensionality reduction: demixed PCA





$$\mathbf{X} = \mathbf{X}_t + \mathbf{X}_s + \mathbf{X}_{st}$$

$$L = \|\mathbf{X}_t - \mathbf{F}_t\mathbf{D}_t\mathbf{X}\|^2 + \|\mathbf{X}_s - \mathbf{F}_s\mathbf{D}_s\mathbf{X}\|^2 + \|\mathbf{X}_{st} - \mathbf{F}_{st}\mathbf{D}_{st}\mathbf{X}\|^2$$

Christian Machens 2019

Results

PCA

Number of significant dimensions slightly increased

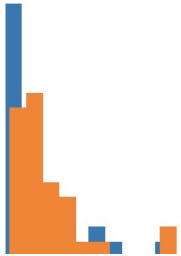
Source of neural dimensionality

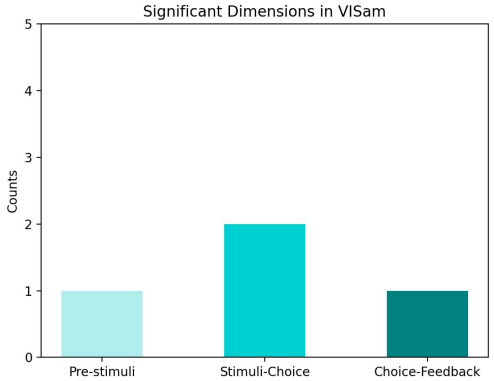
1. **Directly task-related**
2. **Latent**
3. Baseline dimension (noise, complexity, etc)

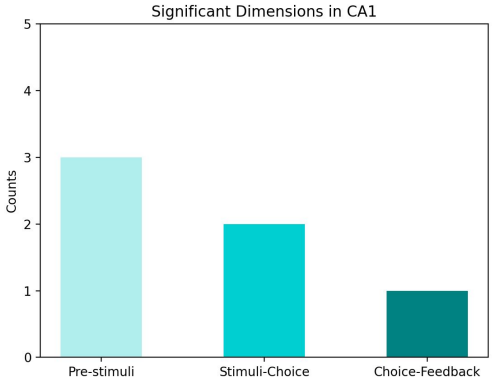
Method:

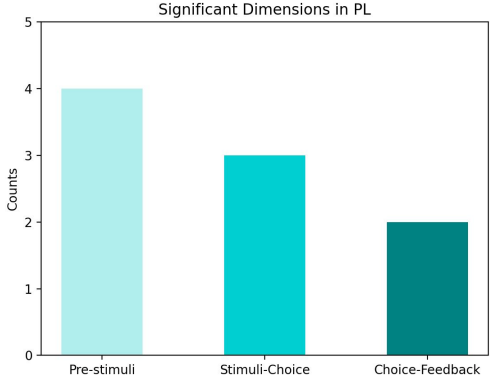
- Data dimension(**1+2**):
  Resample w/o replacement (equalizing # of cells)

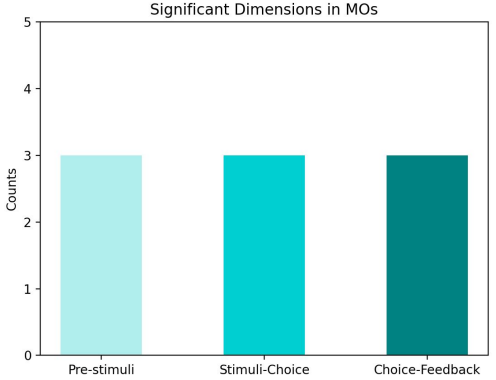
- Baseline (**3**):
  Bootstrap w/ replacement
  +
  Temporal shuffle







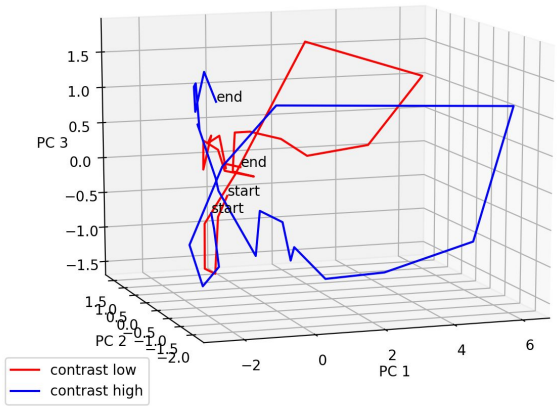




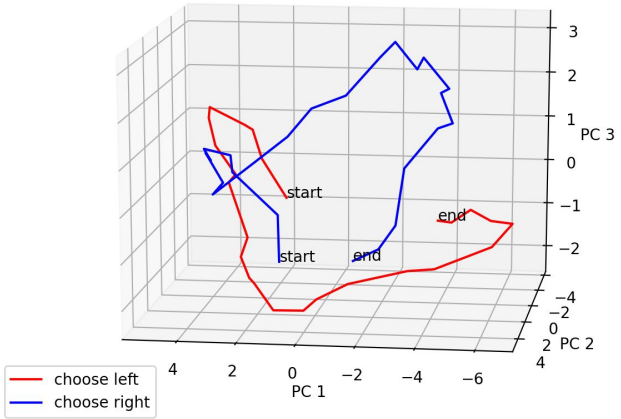
PCA

Dimensions are task-relevant

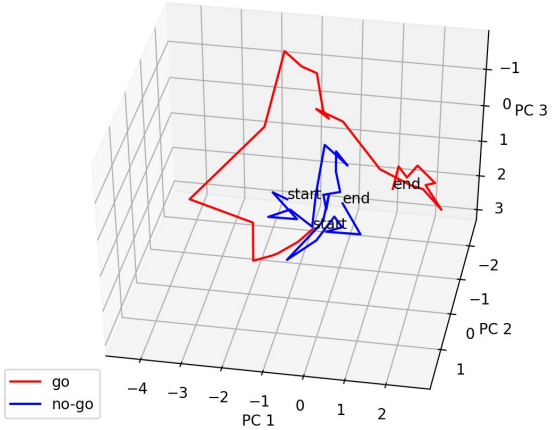
Contrast (left side stimuli)
VISam

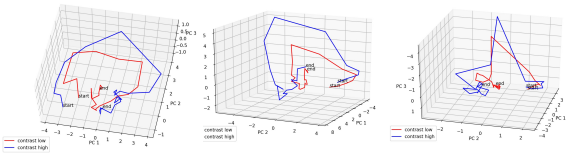


Choice (L vs. R)
PL

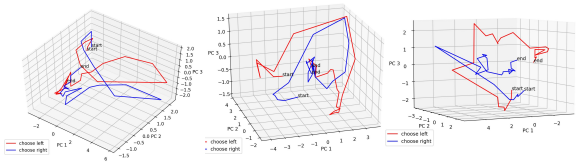


Go vs. No-Go
MOs

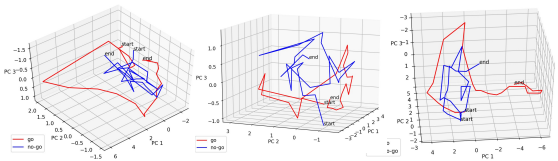




CA1 PL MOs



VISam CA1 MOs



IVSam CA1 PL

TCA components

Data Selection

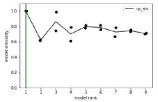
Select the brain region, session and neurons that we are interested in

Data -> Tensor

Load data into Tensor (N - no of neurons x T - no of timebins x Tr - no of trials

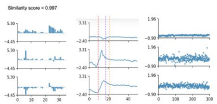
Error Plot and Similarity score

To find out the maximum rank with a similarity score ~ 1



Perform Tensor Decomposition

Components of tensor decomposition that explain variance in the data

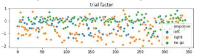


Plot Tensor Factors

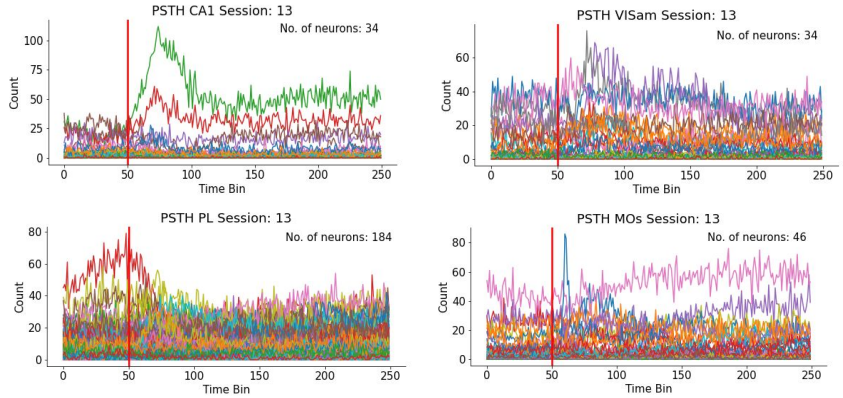
Neuron Factor. Temporal Factor, Trial Factor

Projection Stimulus Data on Tensor Factors

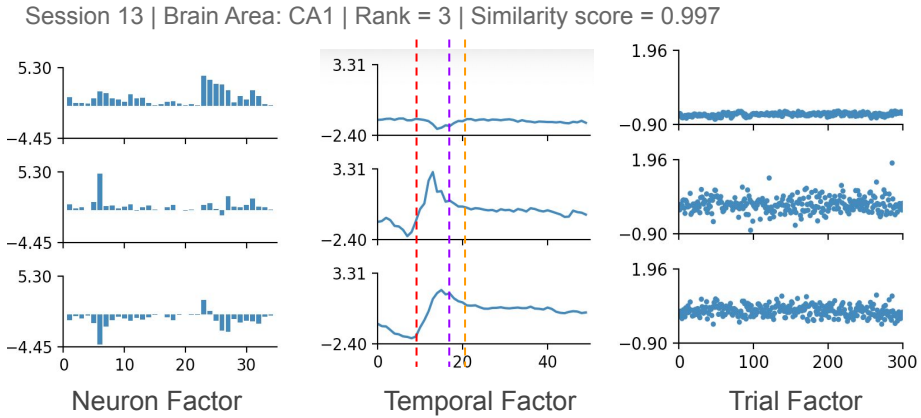
See how different stimulus components are separated



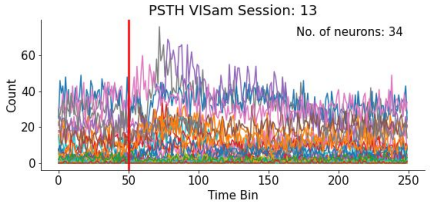
Diversity in neural representations across regions



Tensor Components

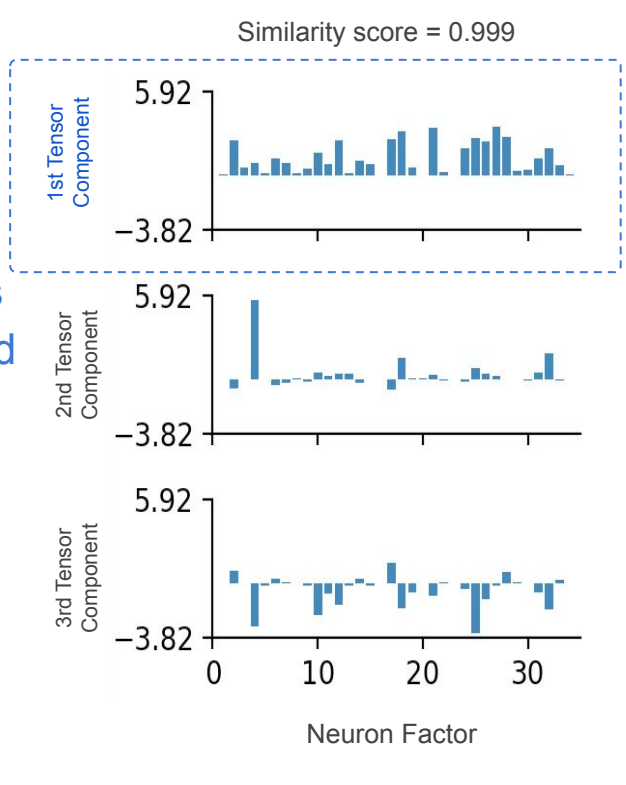


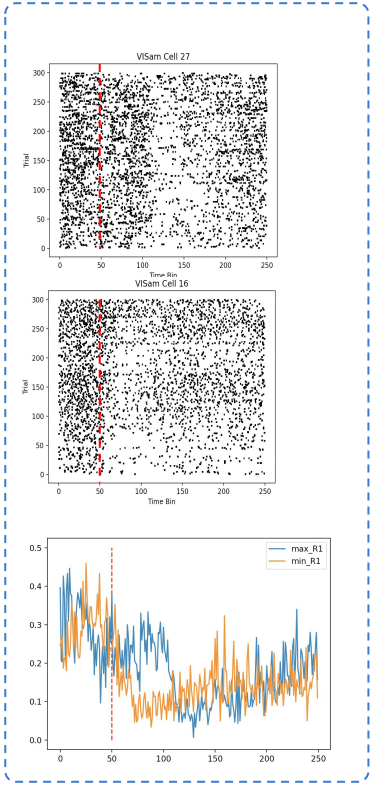
TCA- Neuron factor



Session 13 | Brain Area: VISam

Neuron Factor distinguishes whether the neuron is excited or inhibited at the presence of visual stimuli in the population





Increase firing rate to the onset of visual stimuli

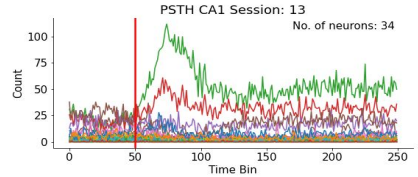
Decrease firing rate to the onset of visual stimuli

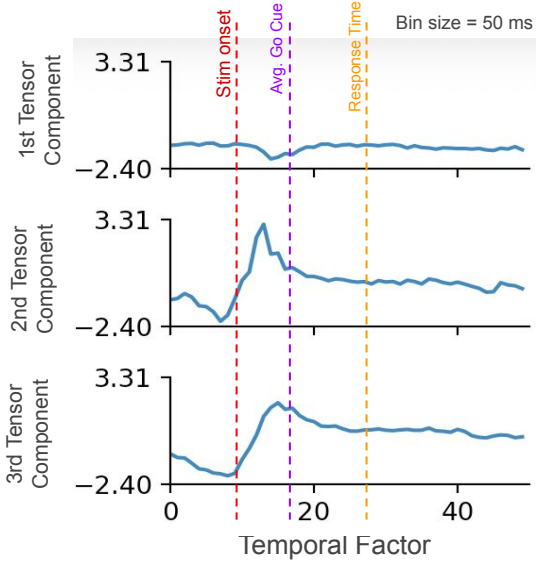
TCA - Temporal Factor

Tensor components in temporal factor reflects task events:

- the onset of visual stimuli
- the start of go cue
- the completion of choice

Session 13 | Brain Area: CA1

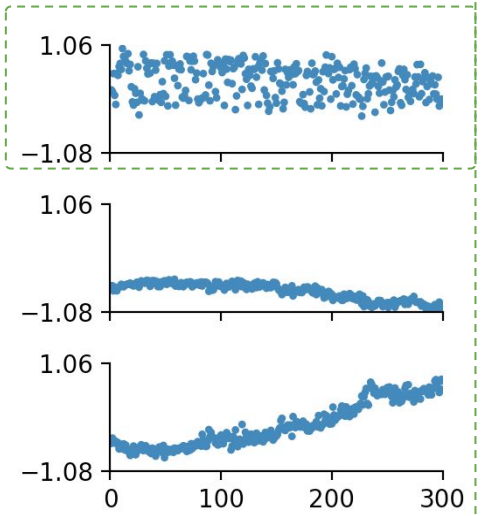


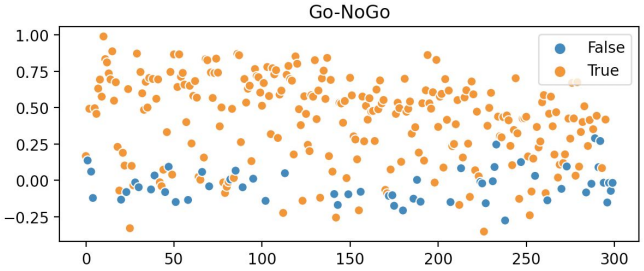


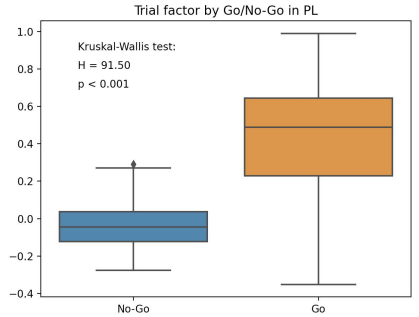
TCA - Trial factor

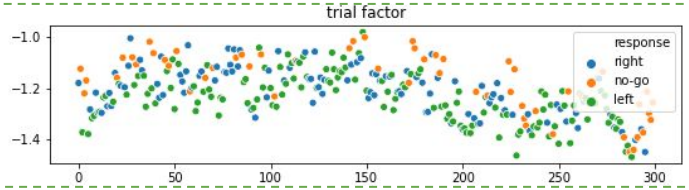
Session 13 | Brain Area: PL

Projecting stimulus conditions and response onto trial factor to observe patterns of separation

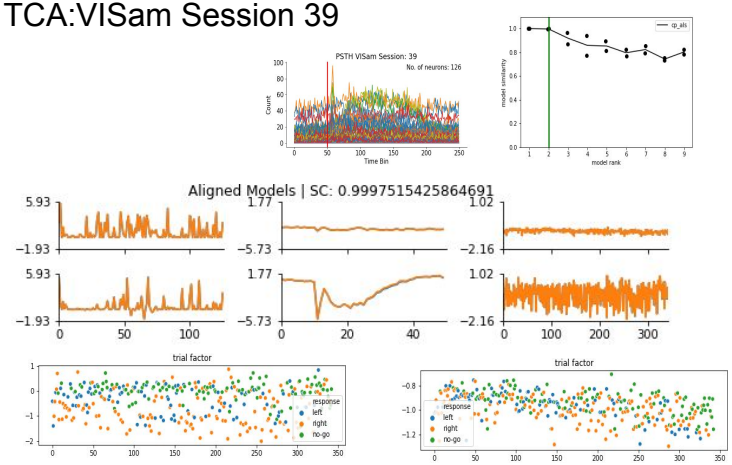




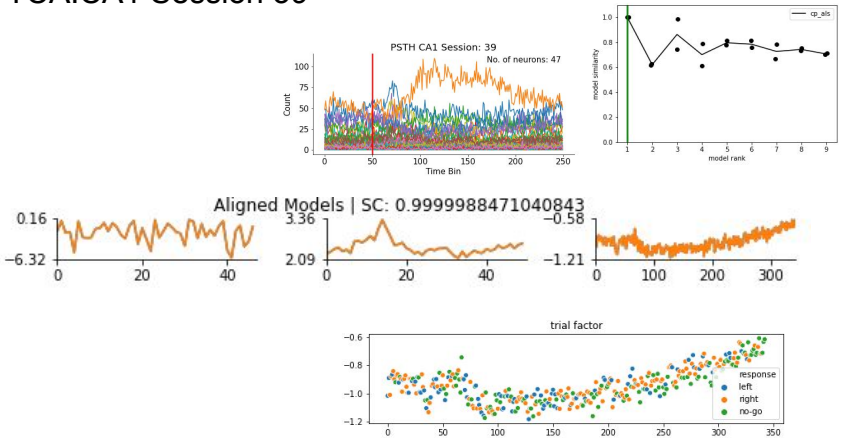




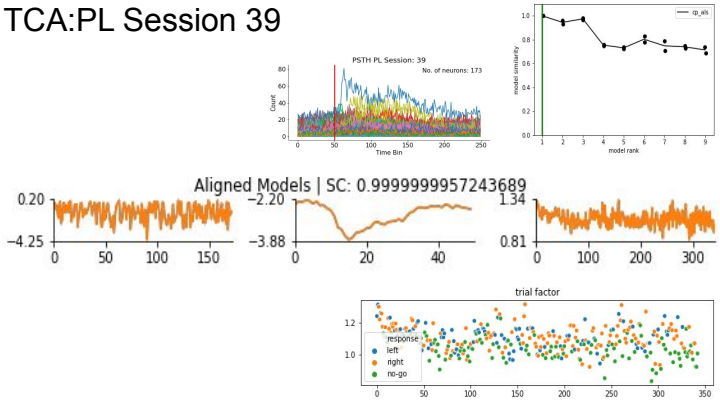
TCA:VISam Session 39



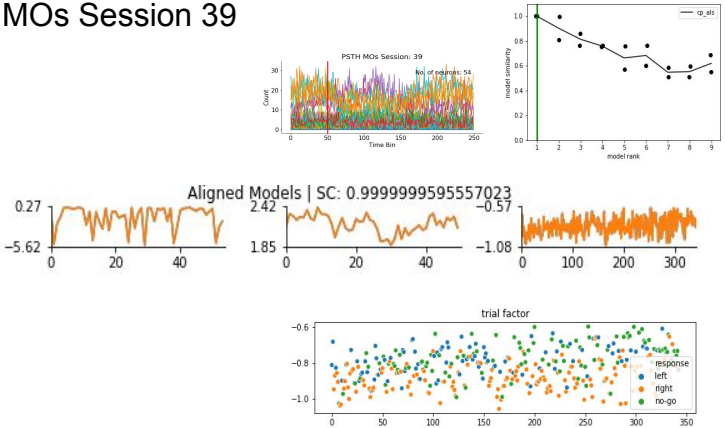
TCA:CA1 Session 39



TCA:PL Session 39

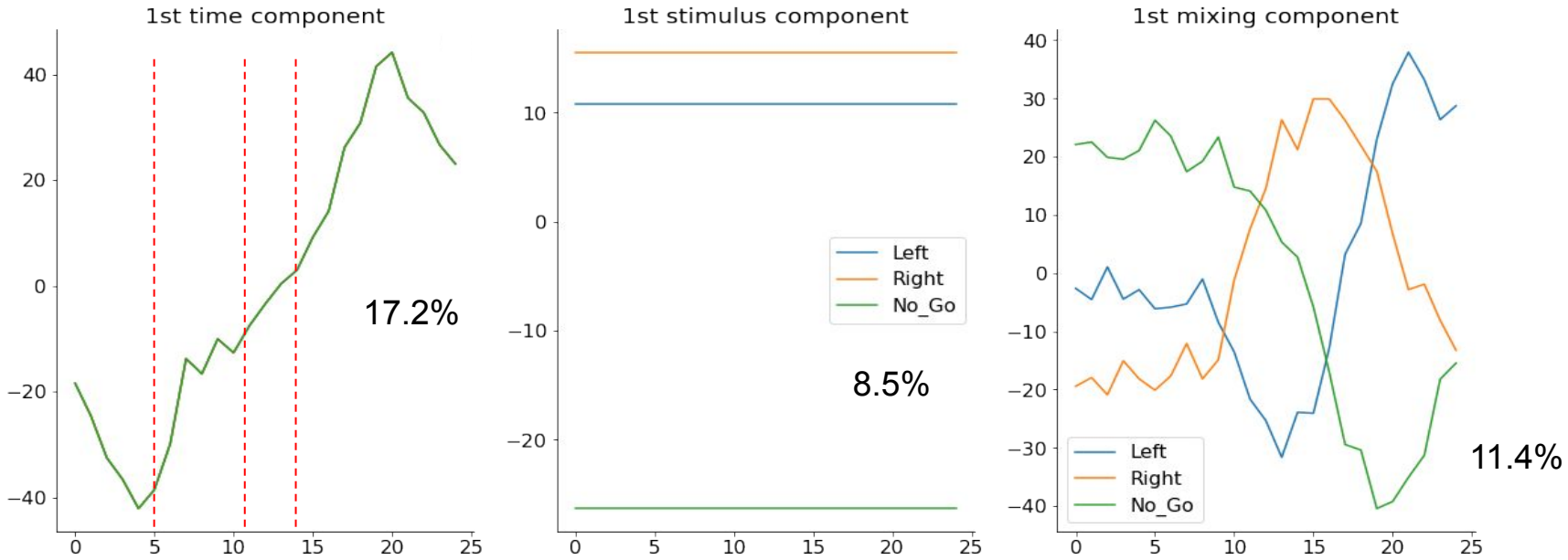


TCA:MOs Session 39



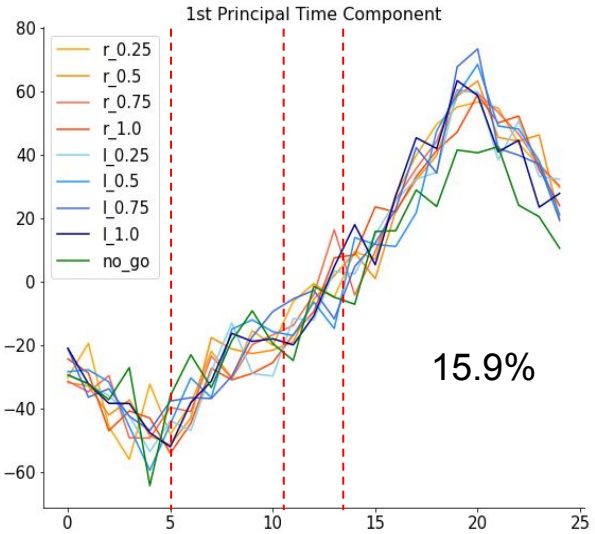
dPCA (demixed PCA) plots

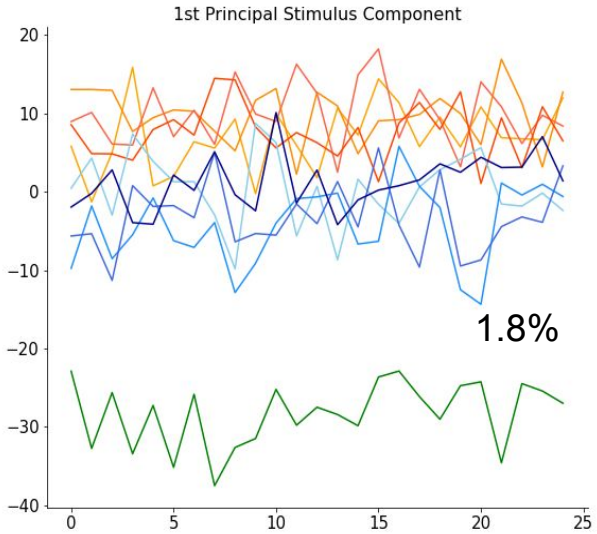
PL session 13

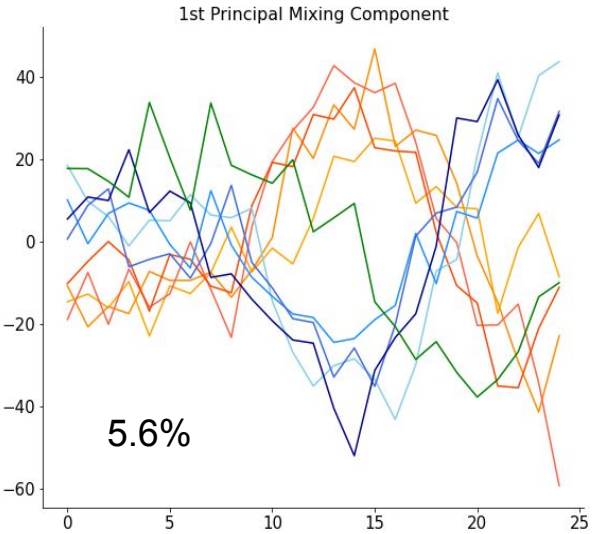


Choice & contrast values

PL session 13



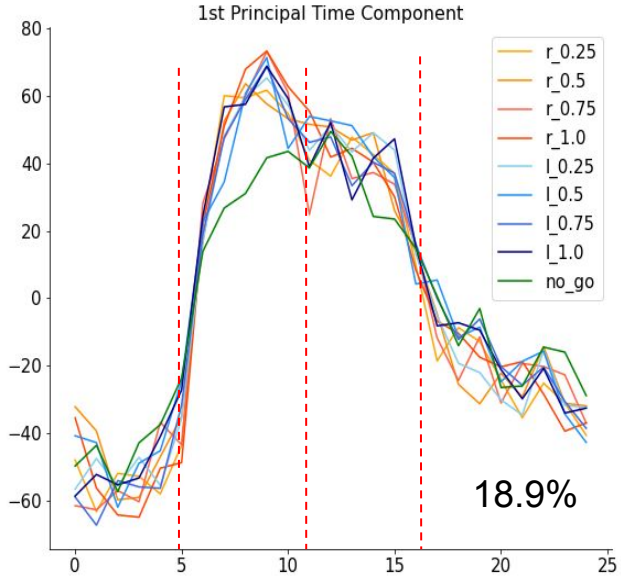


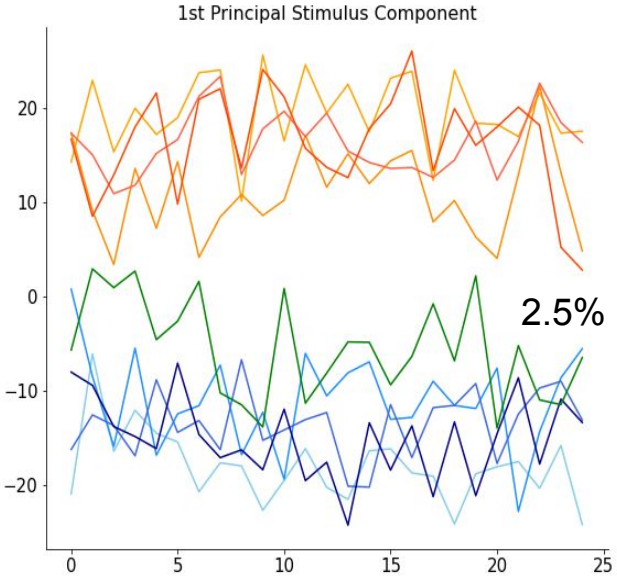


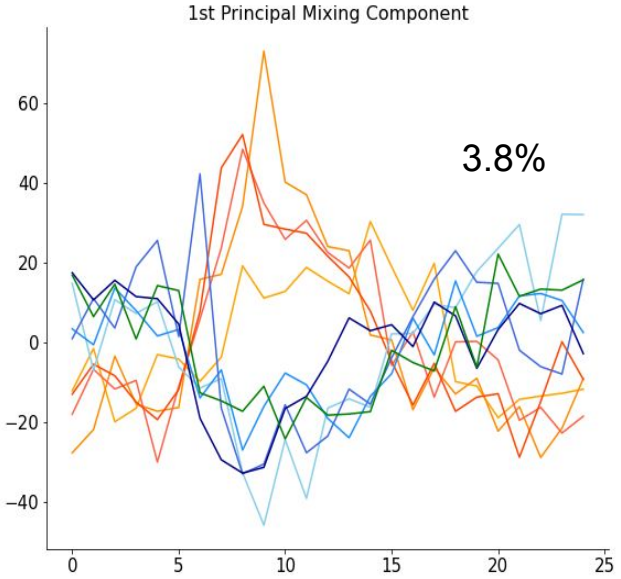
Time (100 ms bins)

Choice separation seen across different sessions

PL session 39





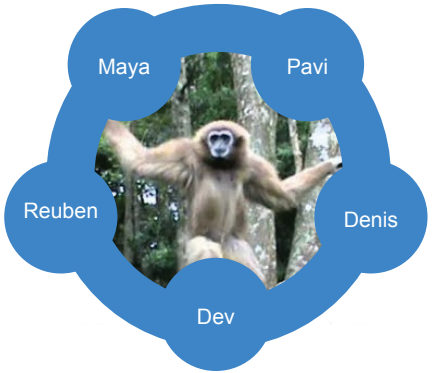


Time (100 ms bins)

Thanks!

Authors and Acknowledgements

Pod-030-Judicious Gibbon

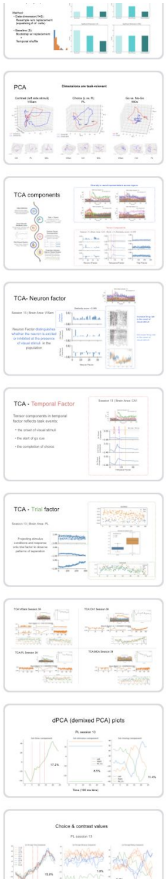


We thank:

- Neuromatch Academy: all the organizers, mentors, volunteers, TAs and our peers!
- Our project mentor: Dr. Roozbeh Kiani
- Our TA: Brian Zhexin Xu
- Dr. Nick Steinmetz
- The funding agencies

Members:

Maya Zhe Wang, University of Minnesota, mayawangz@gmail.com
Pavithra Rajeswaran, University of Washington Seattle, pavir@uw.edu
Dev Laxman Subramanian, Cornell University, sdevlaxman@yahoo.co.in
Denis Matrov, Tallinn University, jazzhole@gmail.com
Reuben Addison, Louisiana State University, reuben.addison@gmail.com



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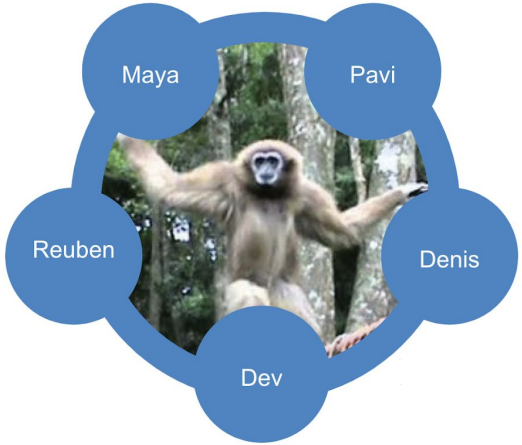
Pod-030-Judicious_Gibbon



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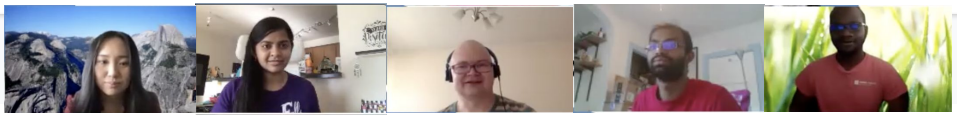
Group project



Notes

Hypothesis/project idea/ methods (area selection, no. of neurons, etc.) -2 slides? -- Denis

PCA- figure will change - 1 slide - Maya

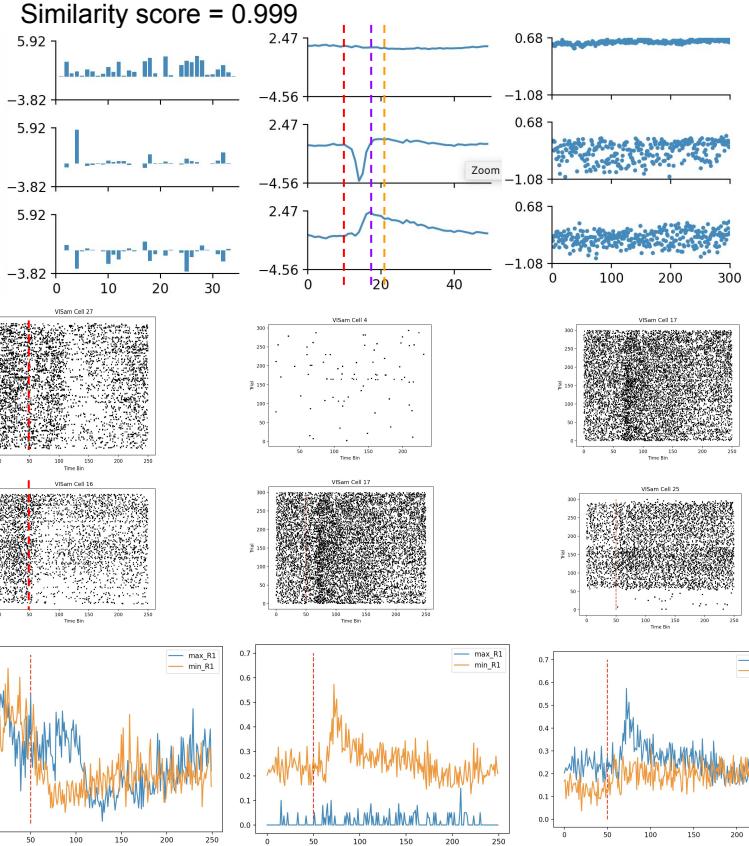
dPCA - 2 slides | 1- methods (Alex williams - fig 1), 2 - highlight results

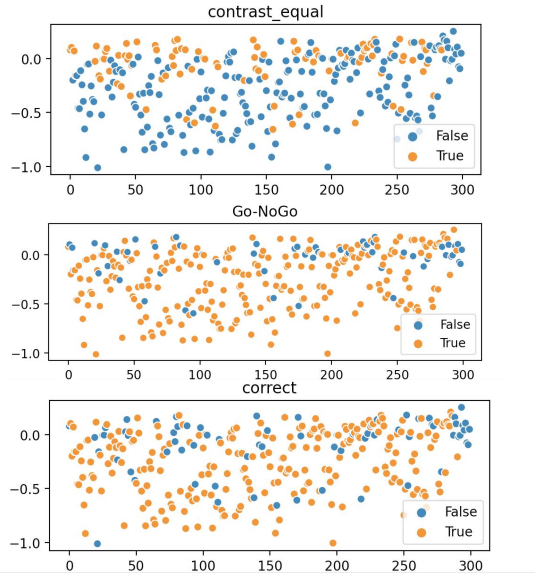
- Figure modifications: significance, stimulus conditions along with choice
- Select the main brain area we want to highlight (Dev, Reuban, Pavi)

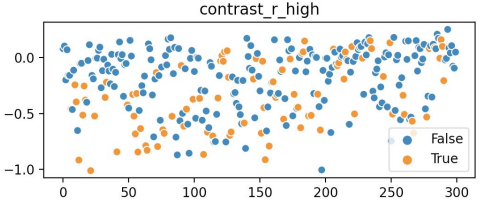
TCA - 5 slides | 1 - Tensor decomposition, 2 - neuron factor, 3 - temporal factor, 4 - trail factor , 5 - TCA analysis for other regions/sessions - Pavi, Maya

Color code: 

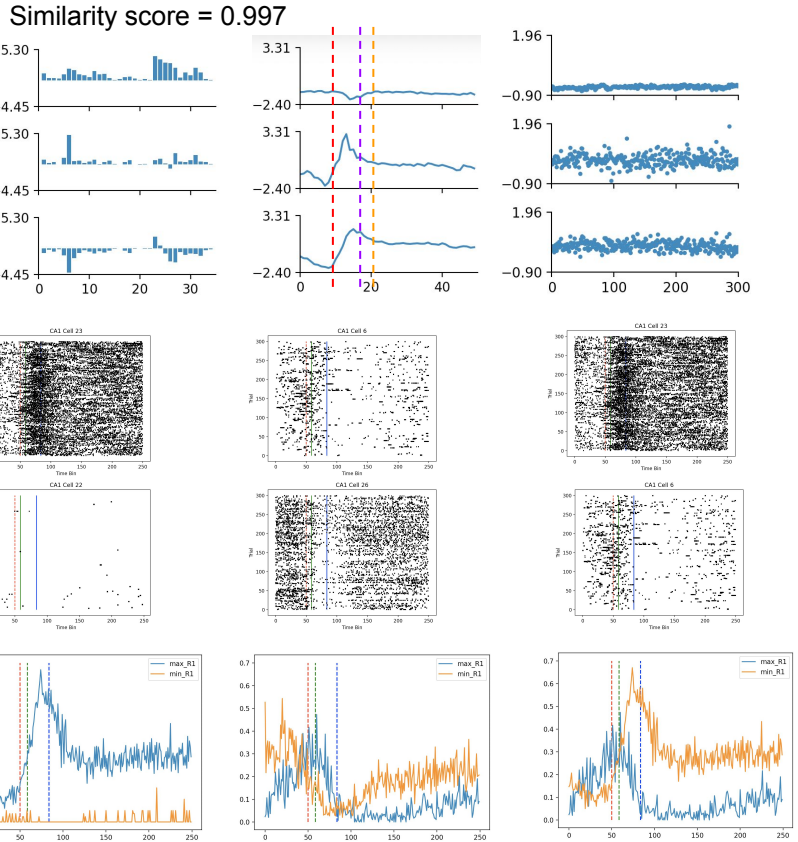
TCA: VISam, session 13

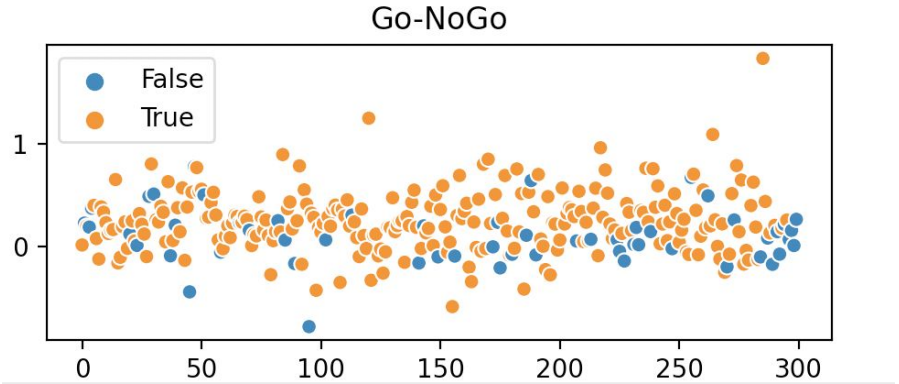




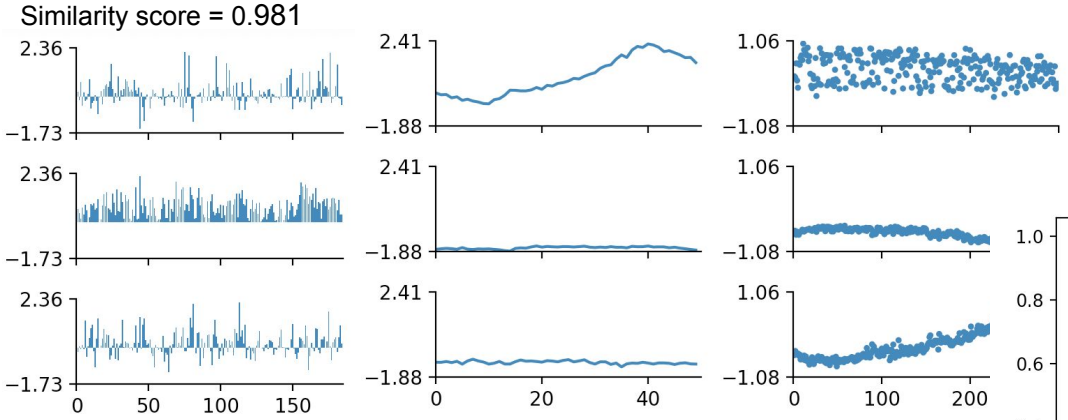


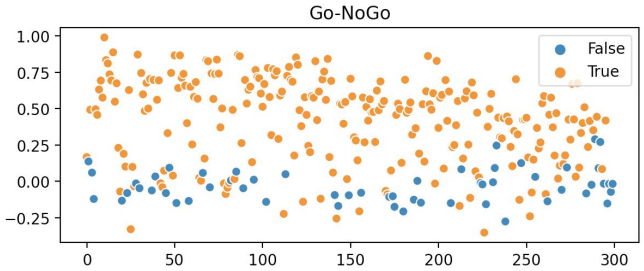
TCA: CA1, session 13

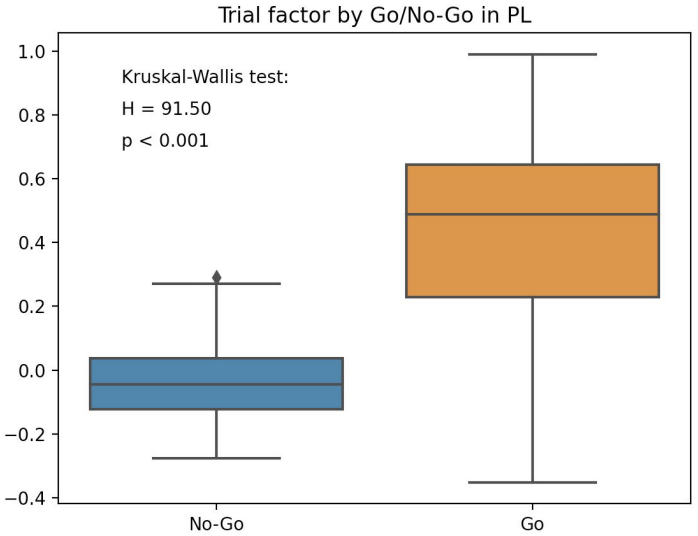




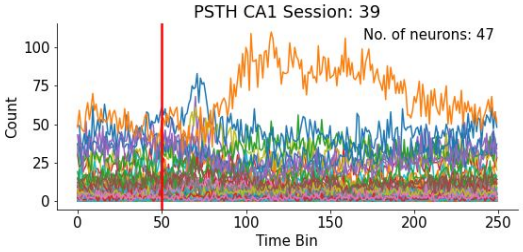
TCA: PL

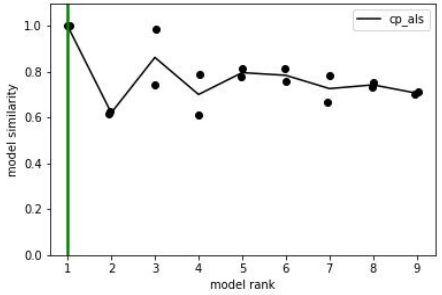

Similarity score = 0.981
2.36
−1.73
2.41
−1.88
1.06
−1.08
0
50
100
150
0
20
40
0
100
200

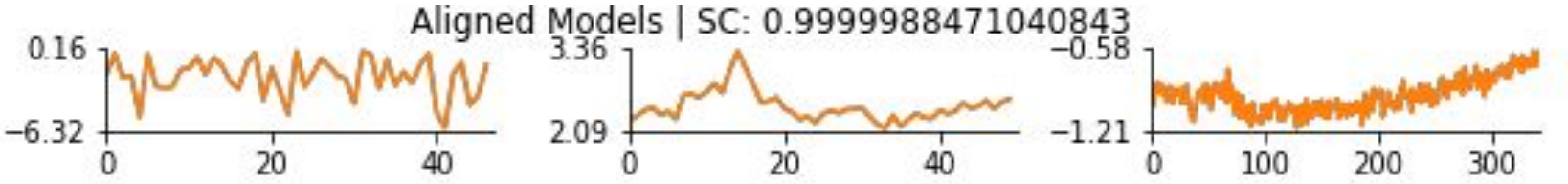

Go-NoGo
False
True
1.00
0.75
0.50
0.25
0.00
−0.25
0
50
100
150
200
250
300

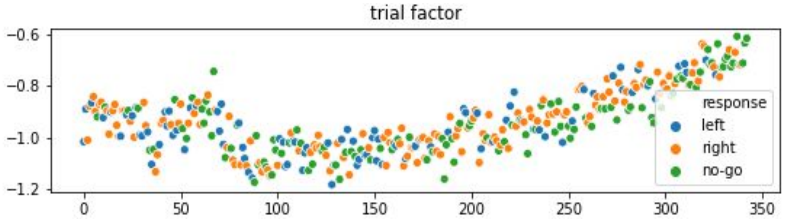

Trial factor by Go/No-Go in PL
Kruskal-Wallis test:
H = 91.50
p < 0.001
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
No-Go
Go

TCA:CA1 Session 39

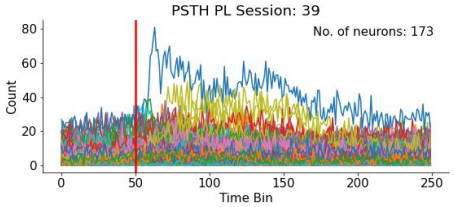


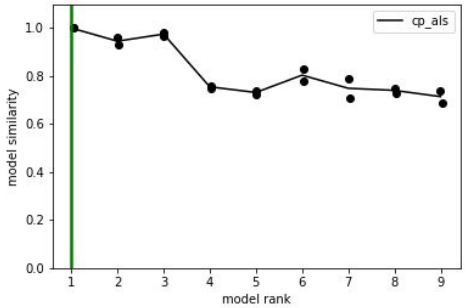


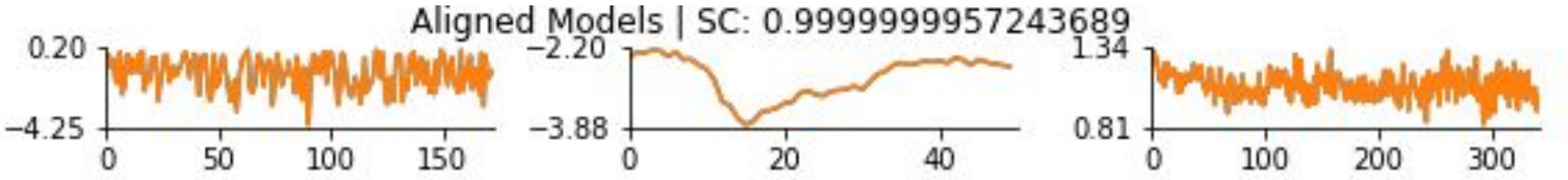


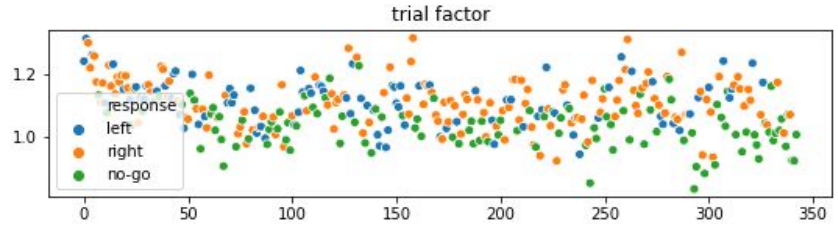


TCA:PL Session 39

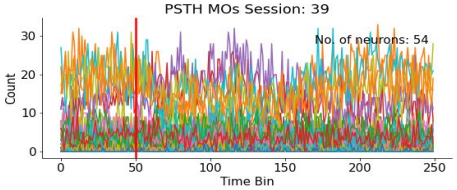


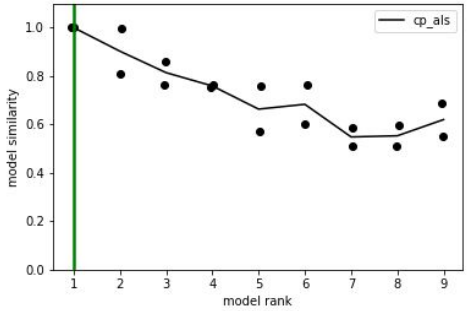


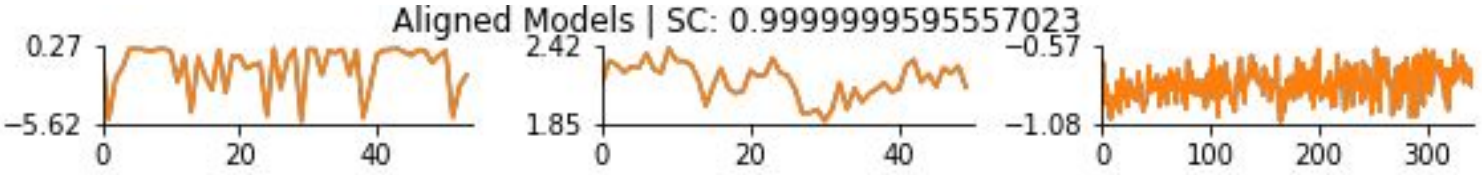


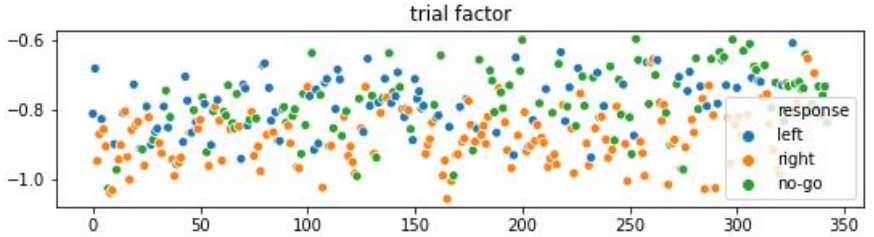


TCA:MOs Session 39





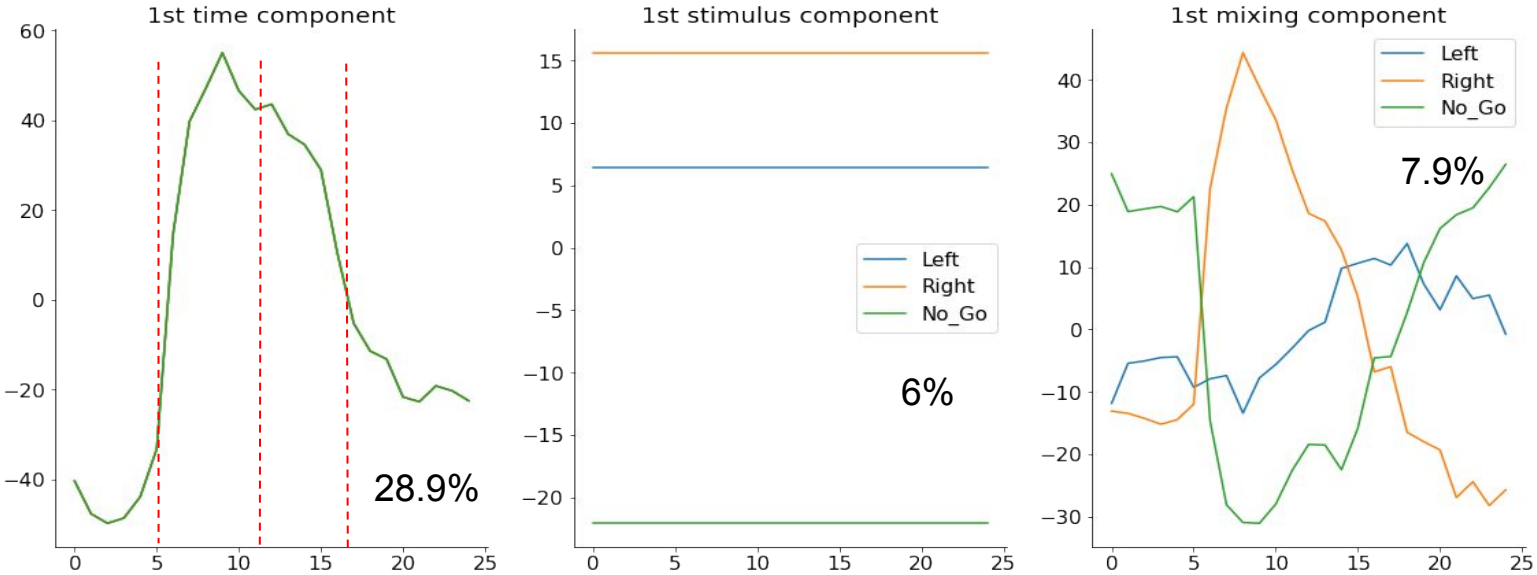




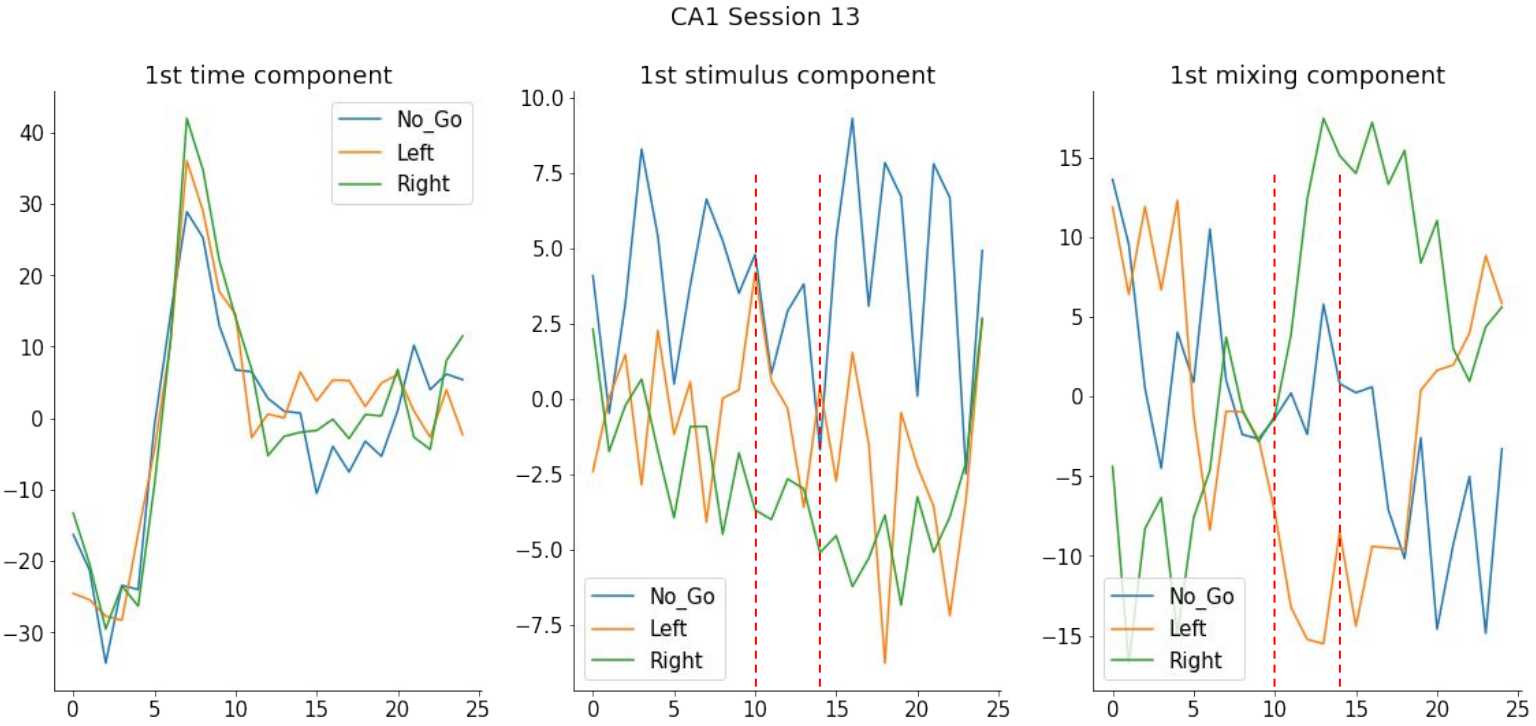
Members:

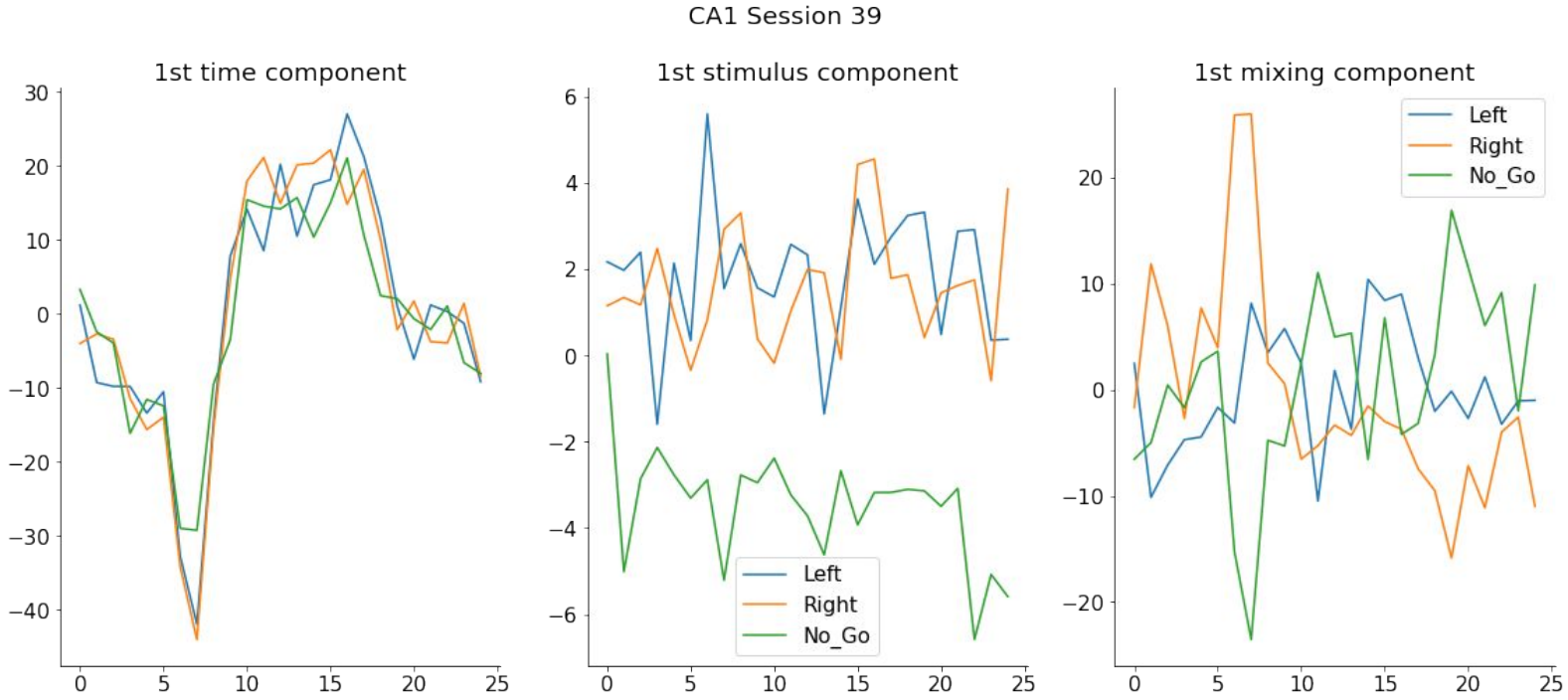
Maya Zhe Wang, University of Minnesota, mayawangz@gmail.com
Pavithra Rajeswaran, University of Washington Seattle, pavir@uw.edu
Dev Laxman Subramanian, Cornell University, sdevlaxman@yahoo.co.in
Denis Matrov, Tallinn University, jazzhole@gmail.com
Reuben Addison, Louisiana State University, reuben.addison@gmail.com

PL session 39



Extras


CA1 Session 13
1st time component
1st stimulus component
1st mixing component
No_Go
Left
Right


CA1 Session 39
1st time component
1st stimulus component
1st mixing component
Left
Right
No_Go

CA1 session 39