



MRC Cognition
and Brain
Sciences Unit



UNIVERSITY OF
CAMBRIDGE

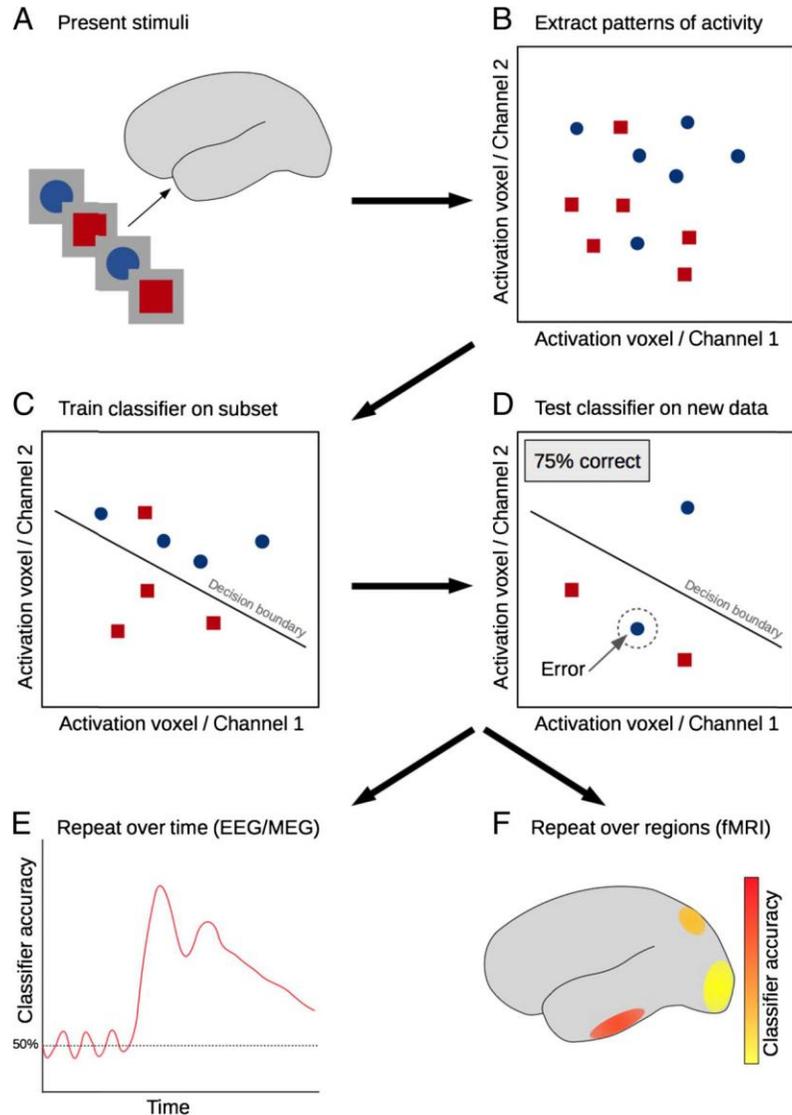
Decoding, RSA, and TRFs with EEG/MEG

Máté Aller

mate.aller@mrc-cbu.cam.ac.uk

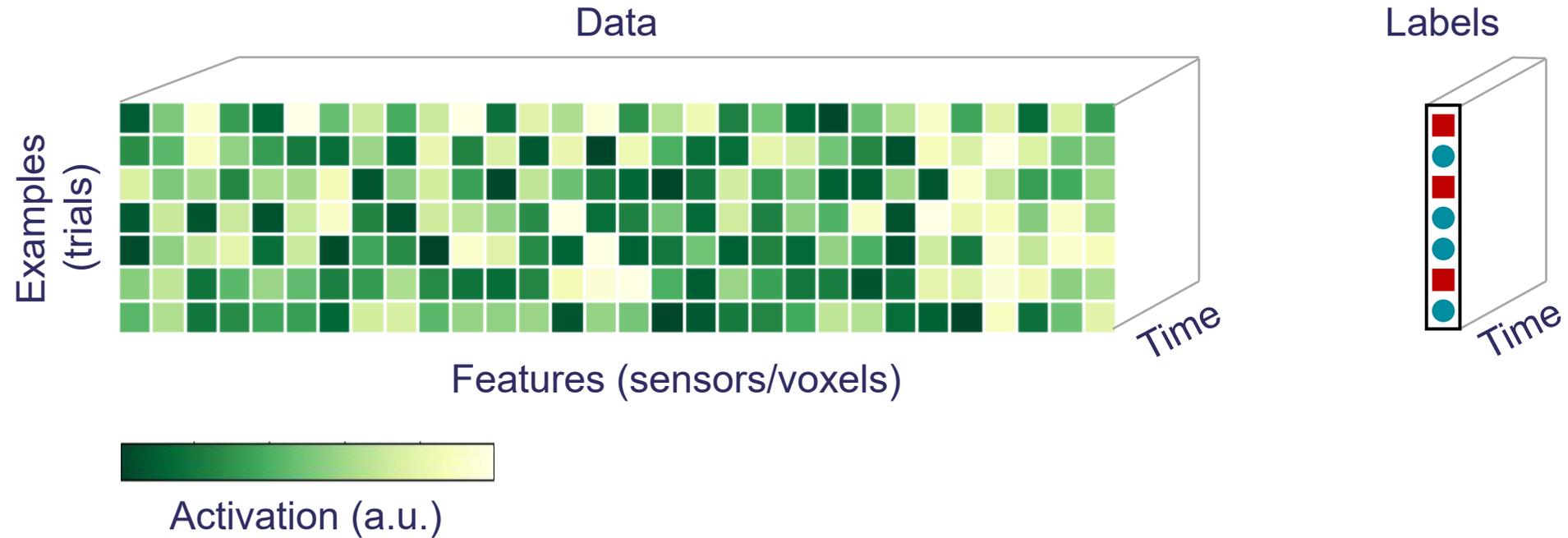
Decoding from EEG/MEG

Decoding recap



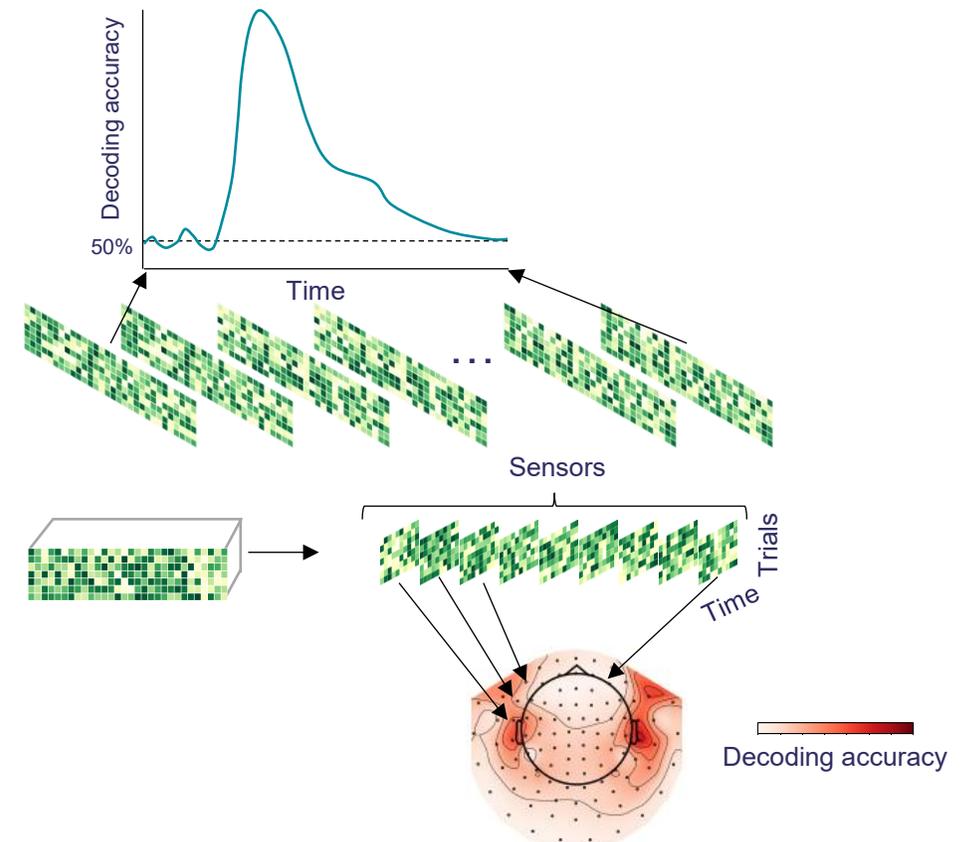
	fMRI	EEG/MEG
Spatial resolution	Few millimetres	Few centimetres
Temporal resolution	1-2 seconds	0.5 – 1 milliseconds

Data structure and notation



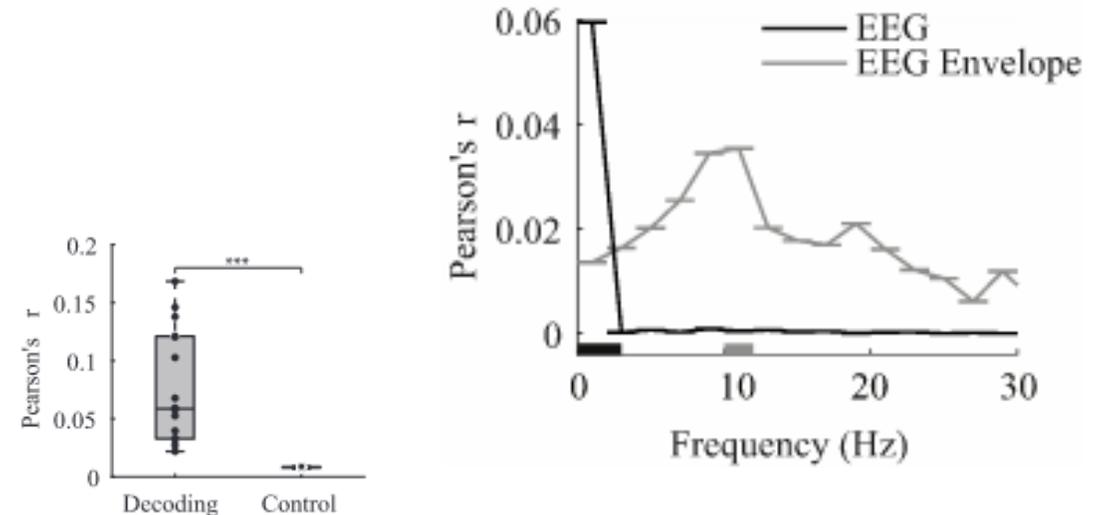
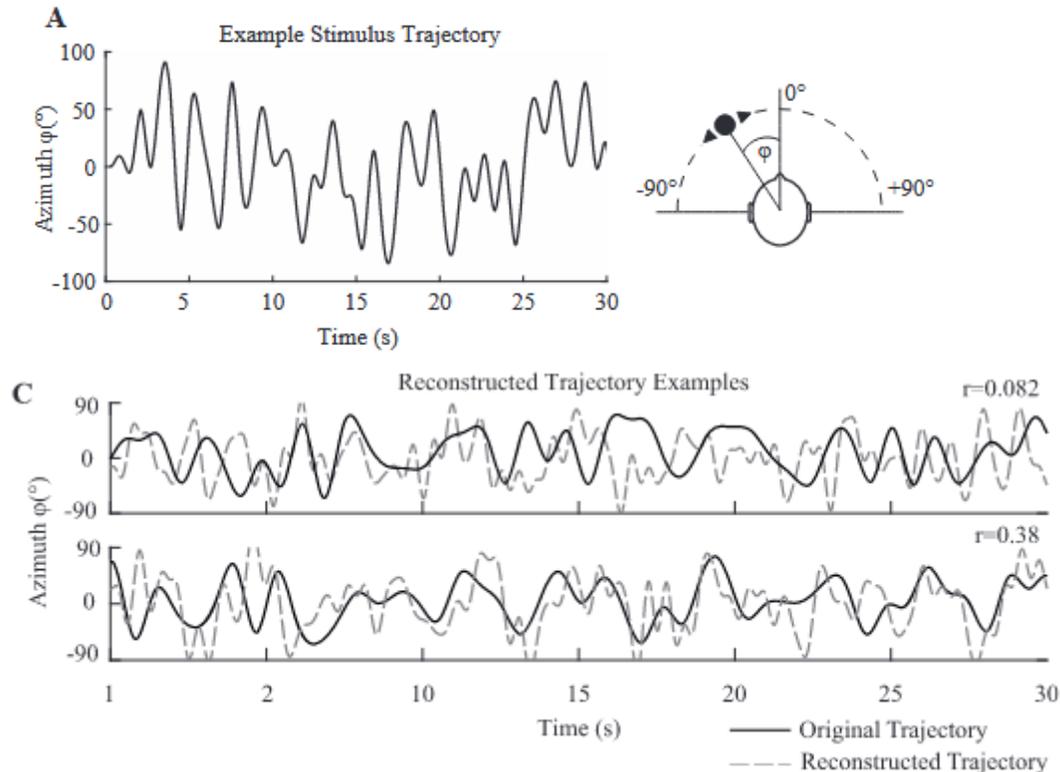
How to leverage the additional time dimension?

1. Concatenate across time
 - Number of features increase by number of time points
 - Most sensitive
 - No timing information left
2. Time resolved decoding
 - Decode separately at each time point
 - Time course of spatial information
3. Use time dimension as features
 - Decode separately at each sensor
 - Spatial map of temporal information
 - See also Temporal Response Functions

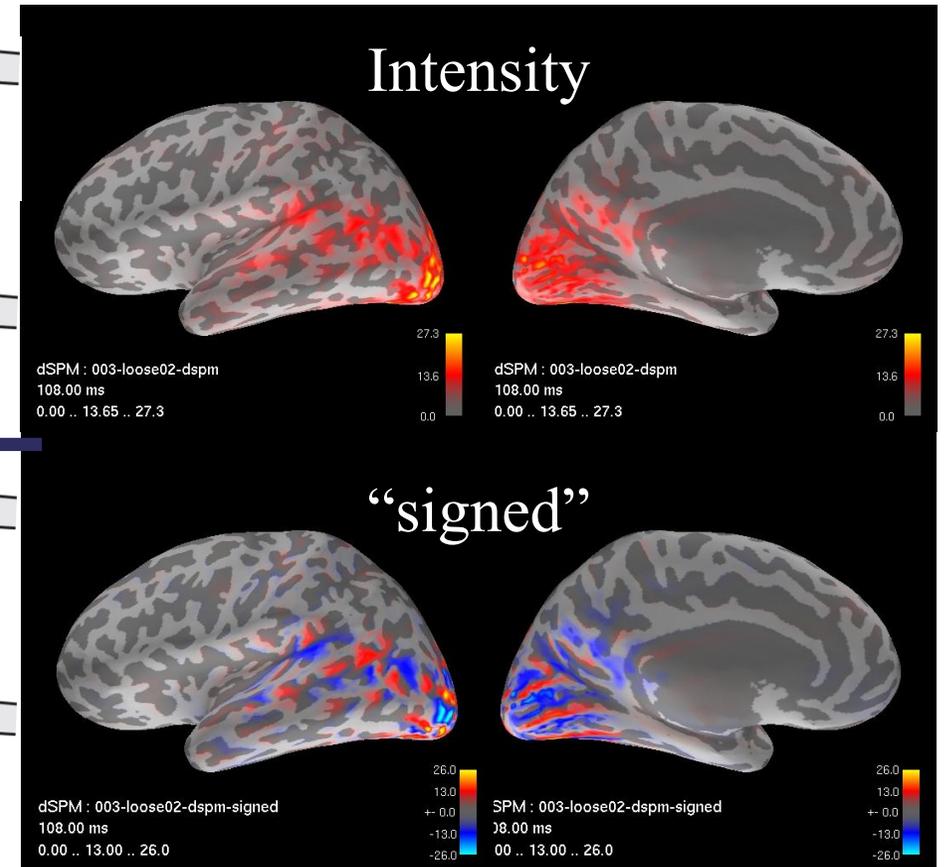
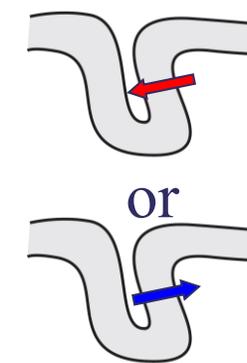
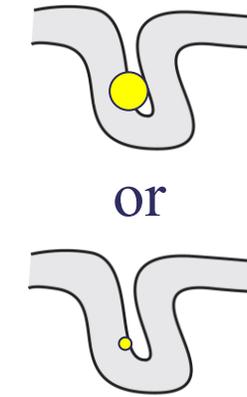
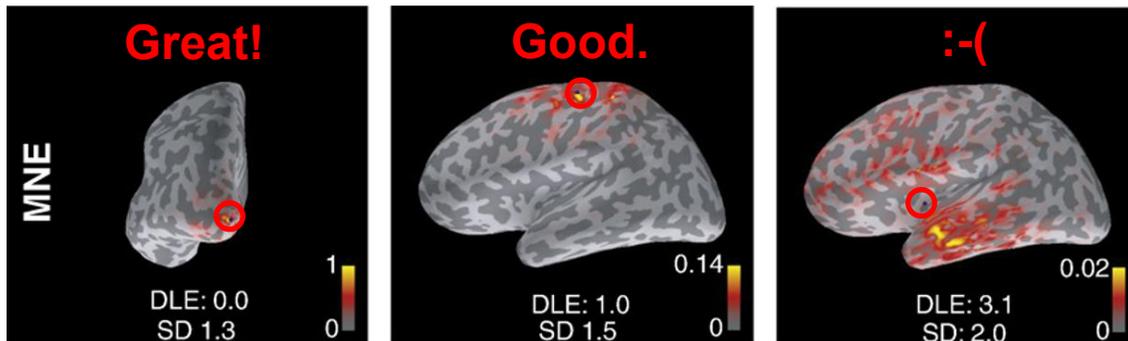
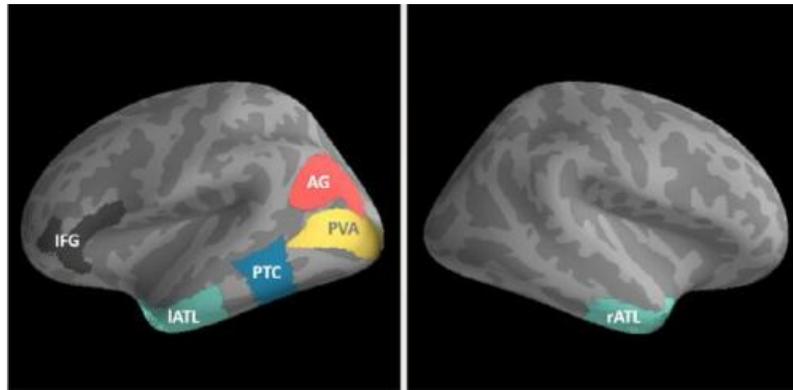


Feature selection: Broadband signal or TF decomposition?

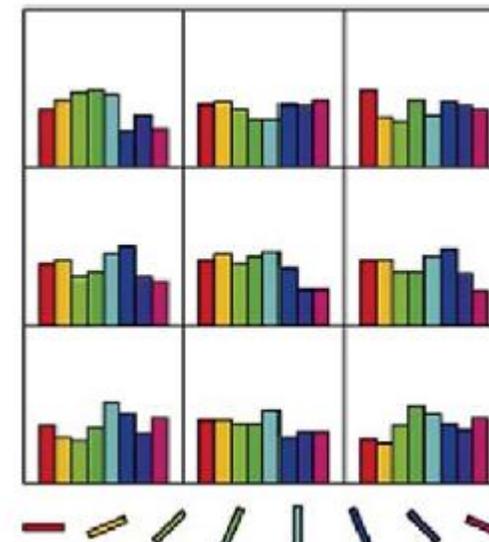
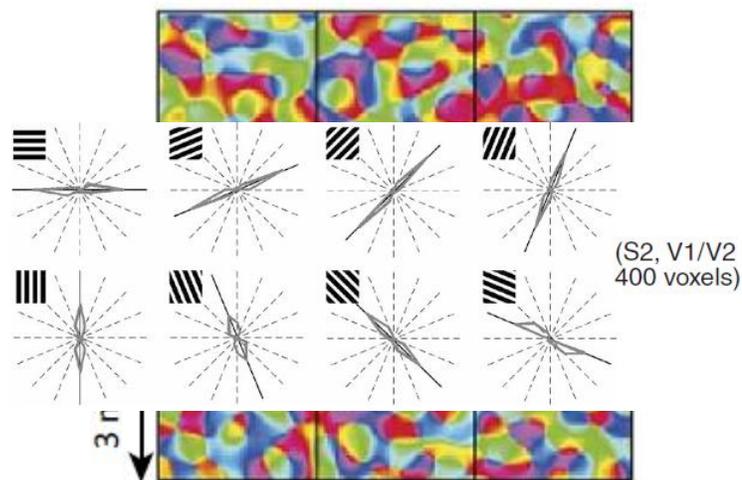
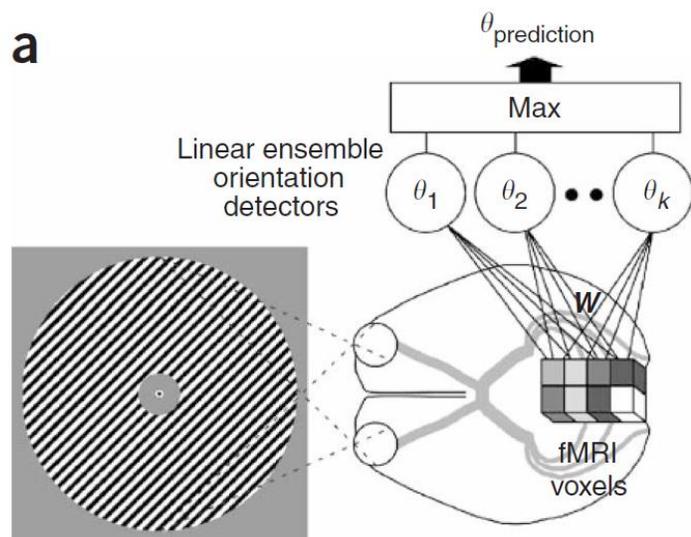
- Generally broadband is preferred
- Opportunity to investigate frequency band or power or phase



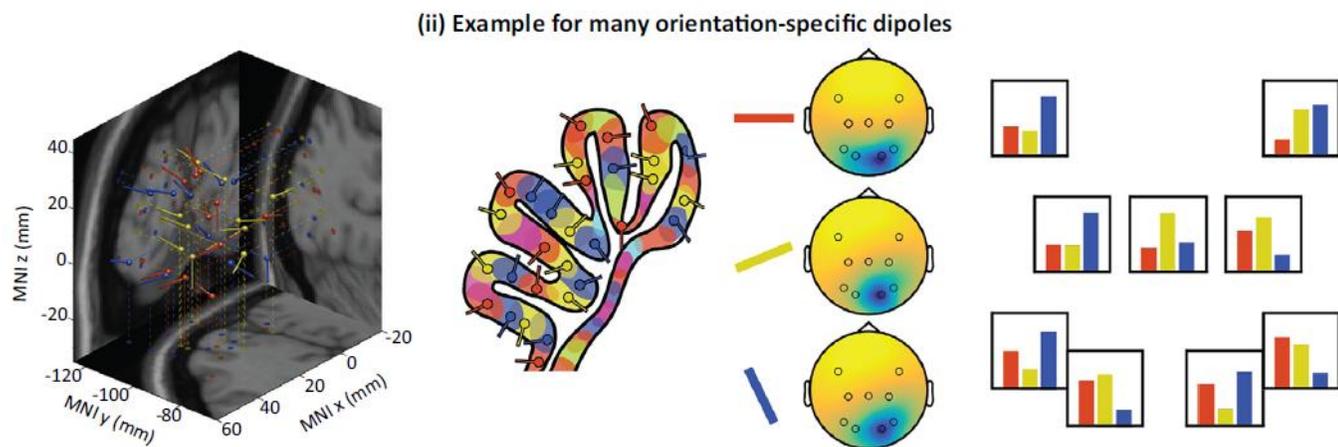
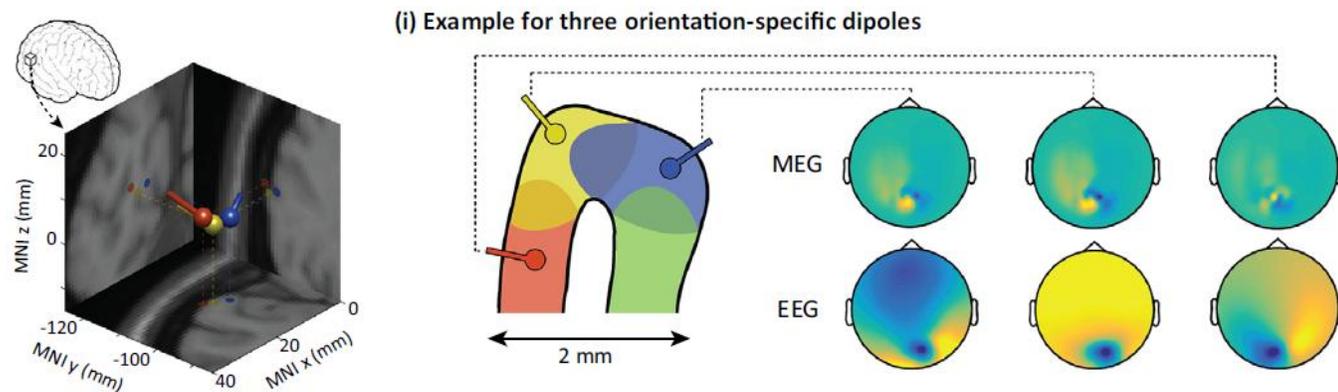
Feature selection: Sensor space or source space?



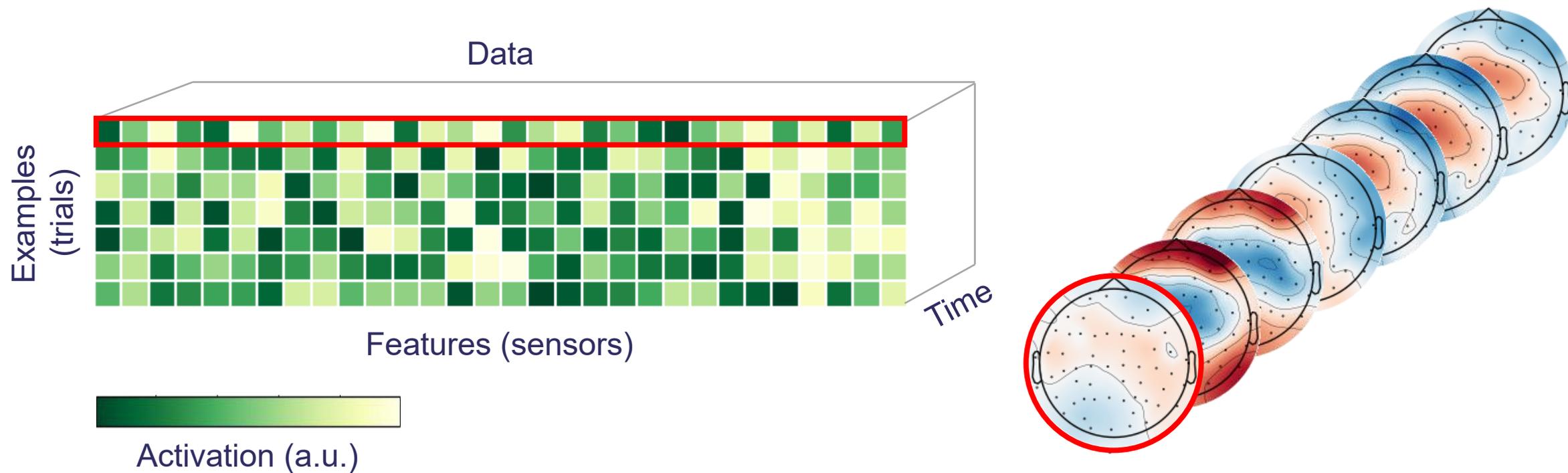
Decoding from mass signals - fMRI



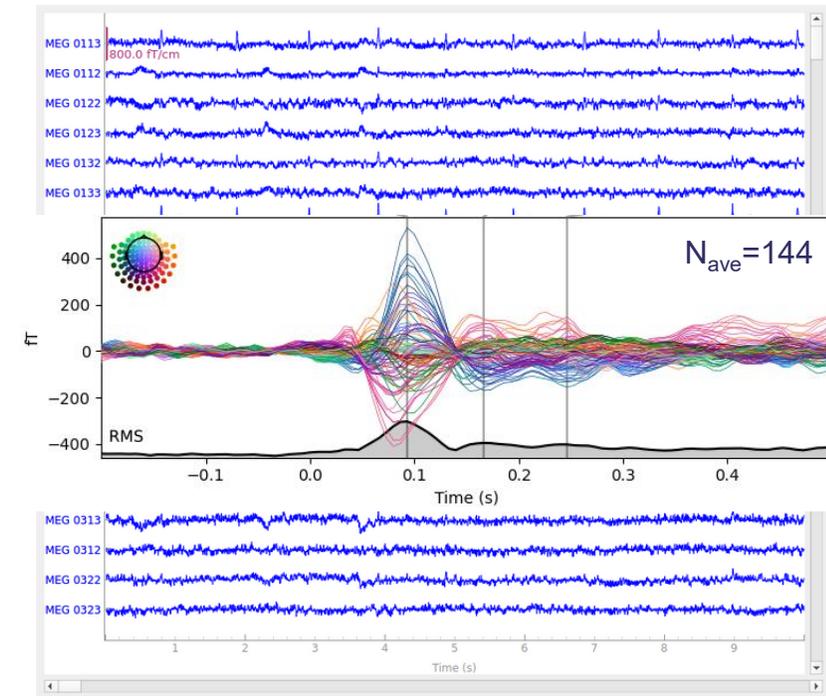
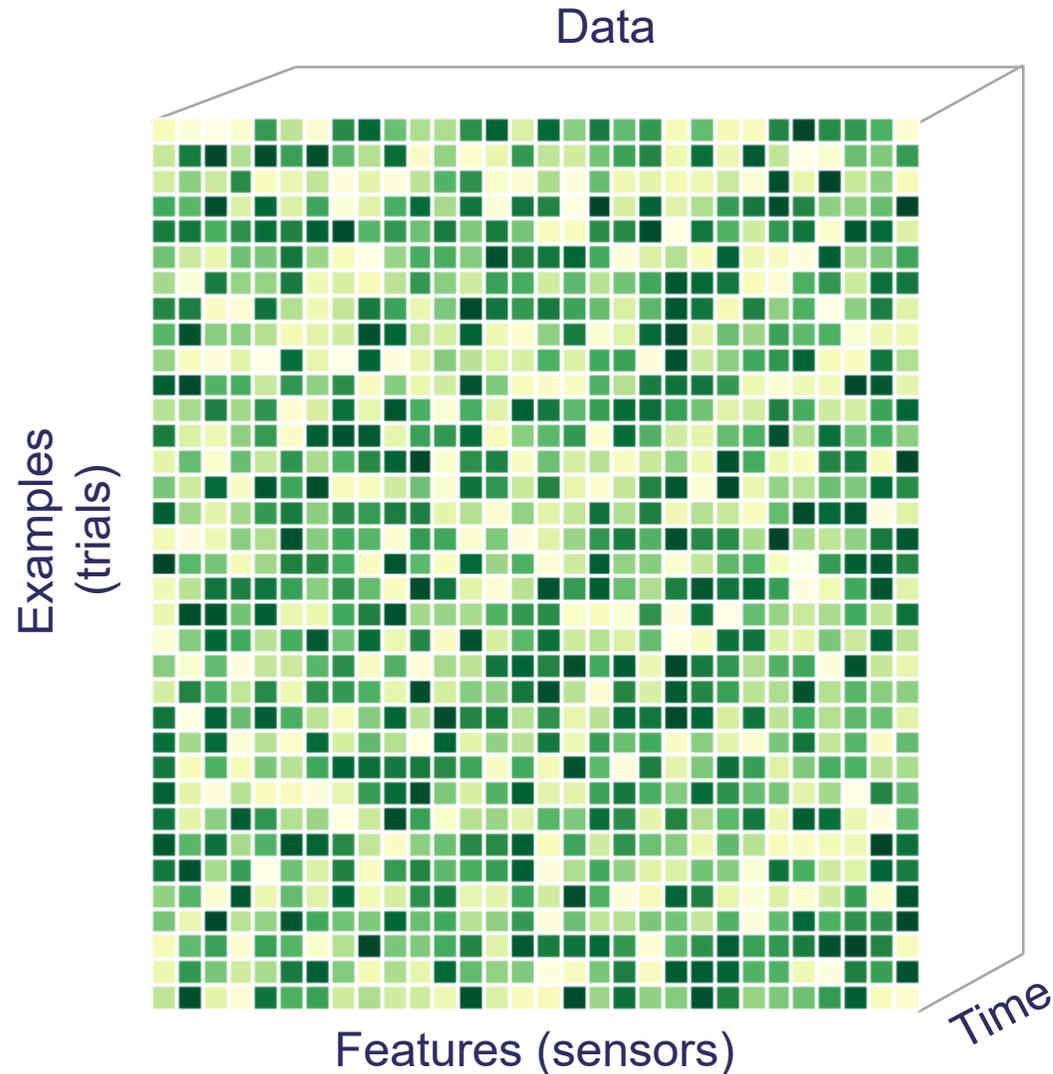
Decoding from mass signals – EEG/MEG



Time resolved decoding - intuition

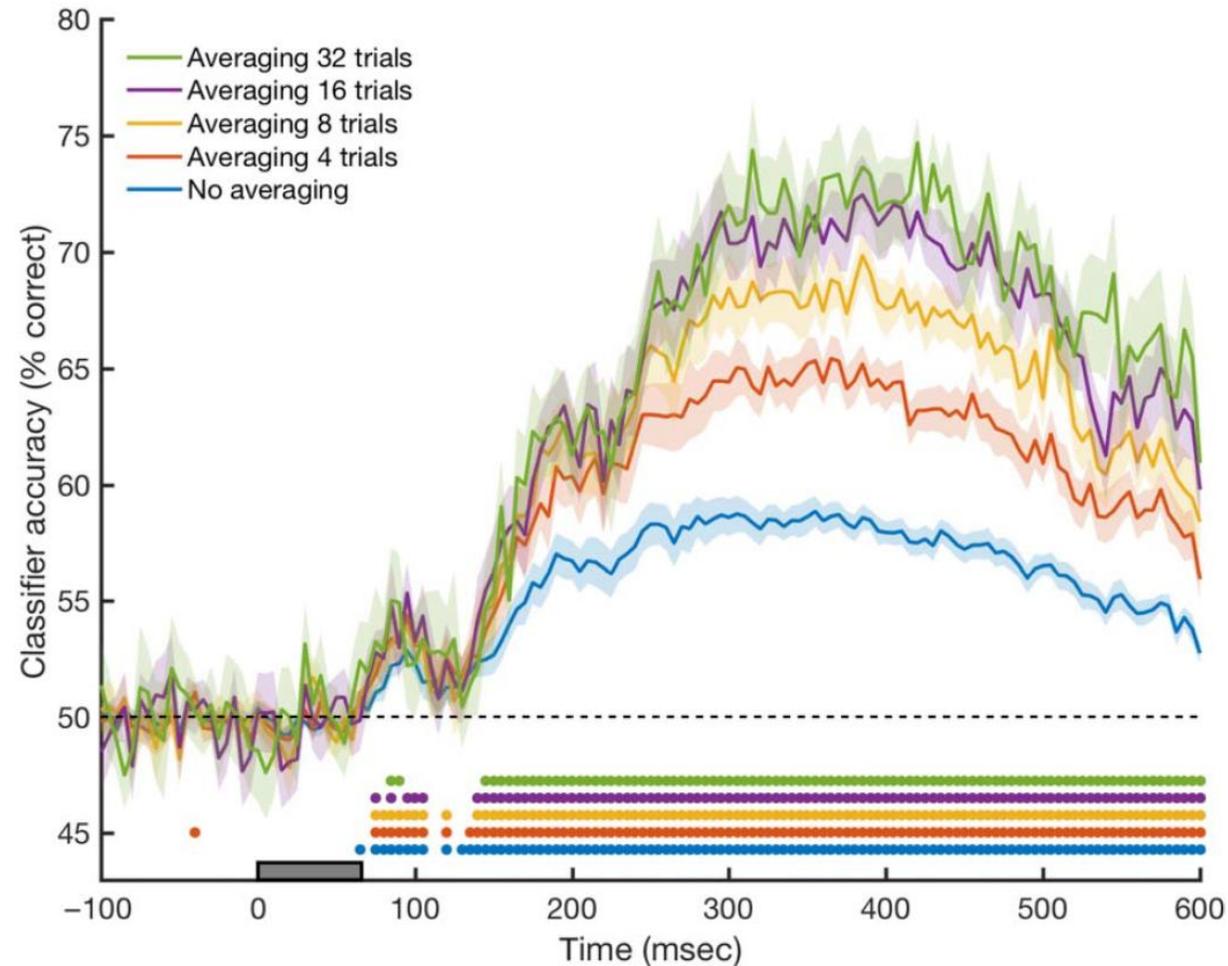


Time resolved decoding practicalities: Single trials vs pseudo-trials

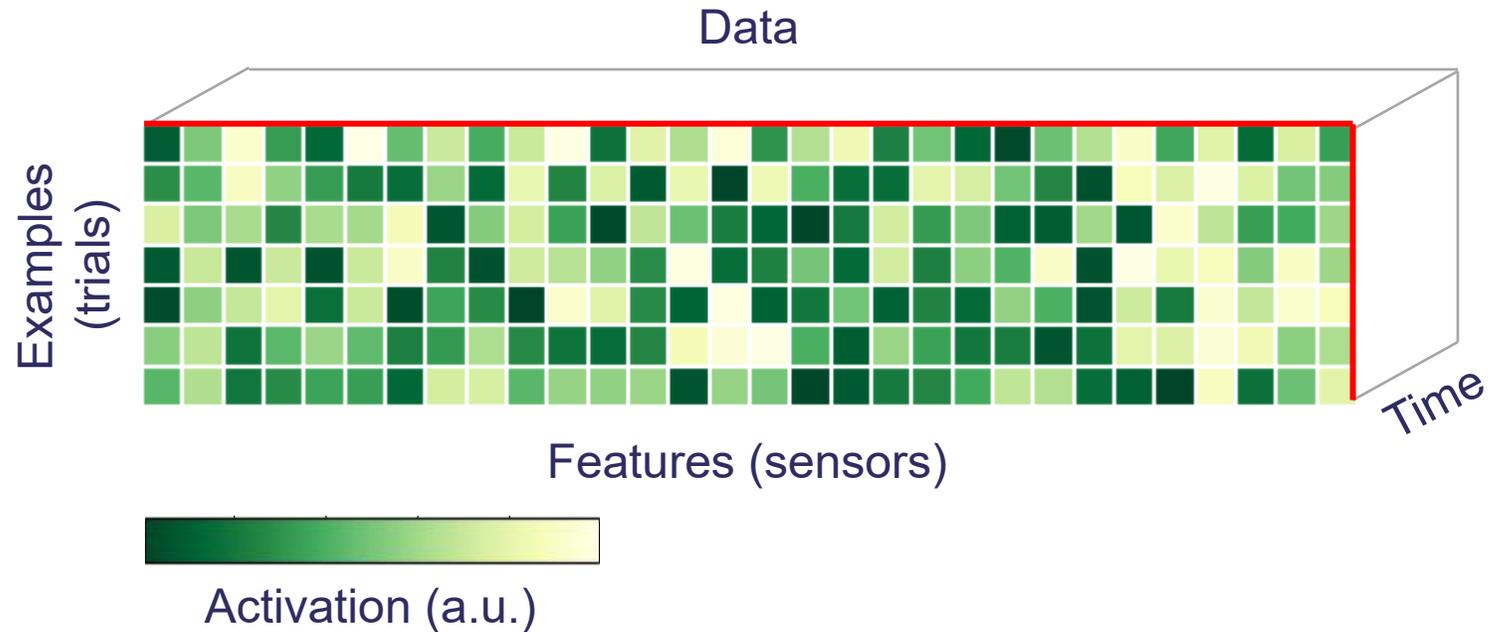


Activation (a.u.)

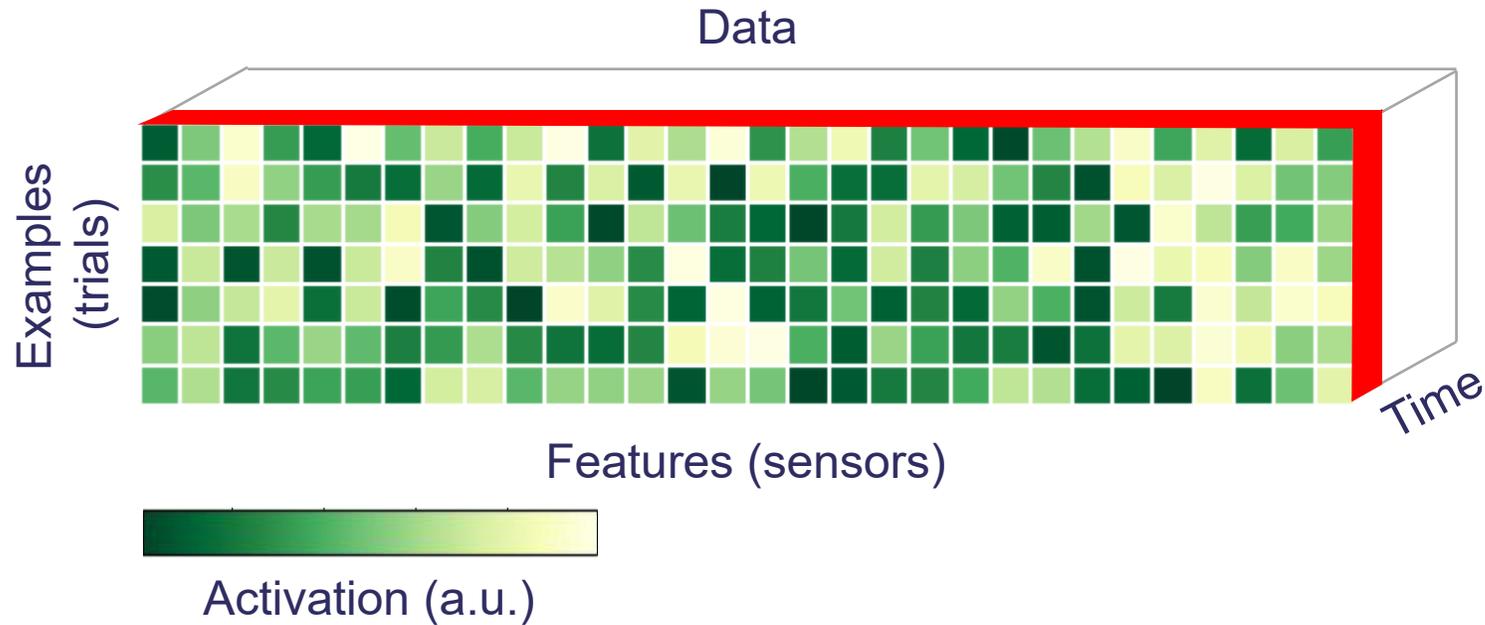
Time resolved decoding practicalities: Single trials vs pseudo-trials



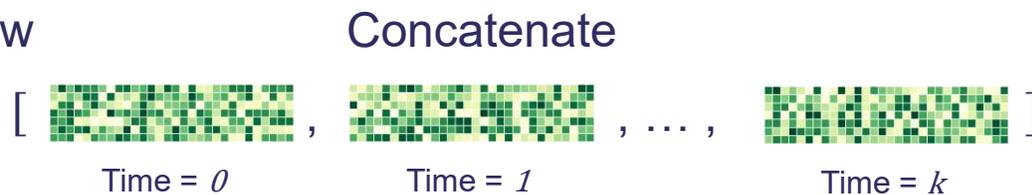
Time resolved decoding practicalities: Single time points or moving window



Time resolved decoding practicalities: Single time points or moving window

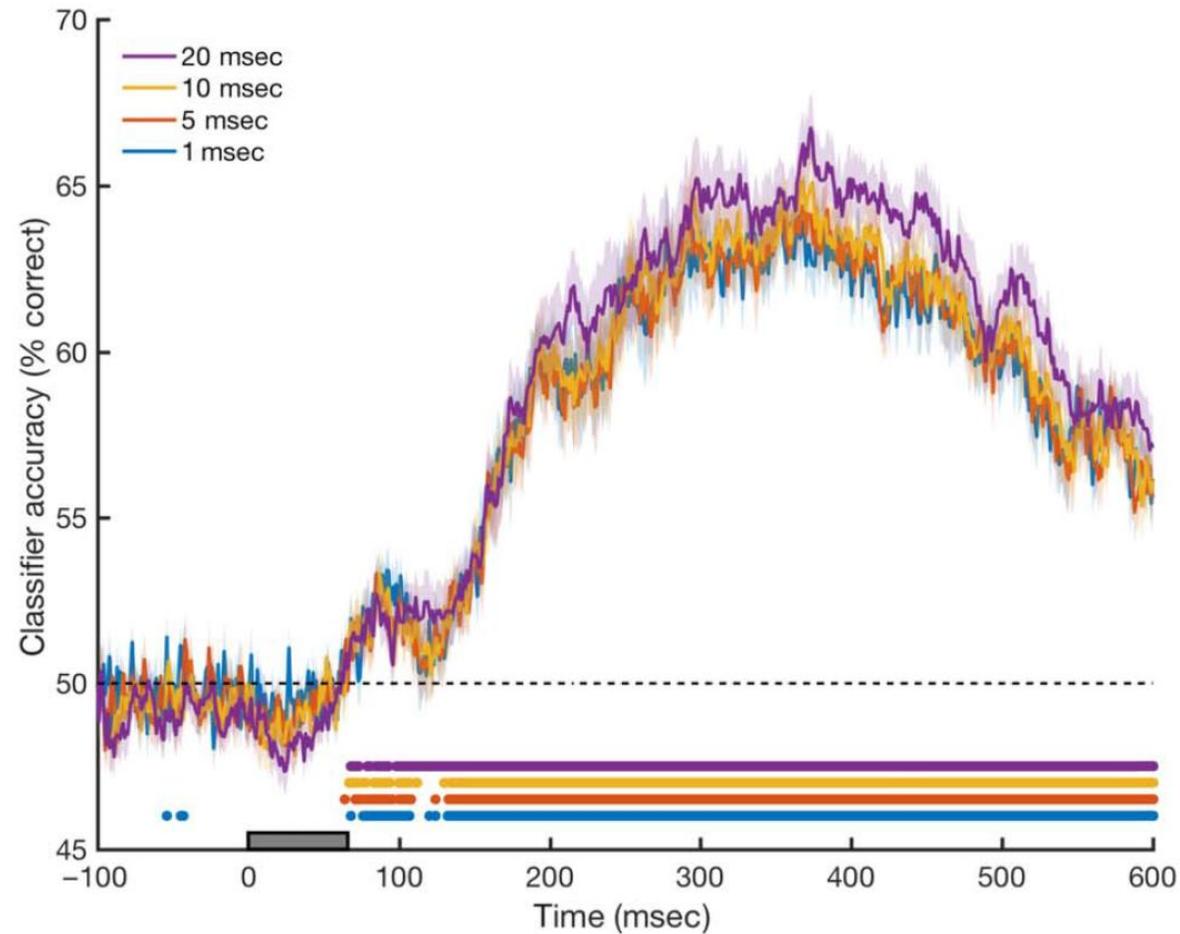


Within the moving window
of size k



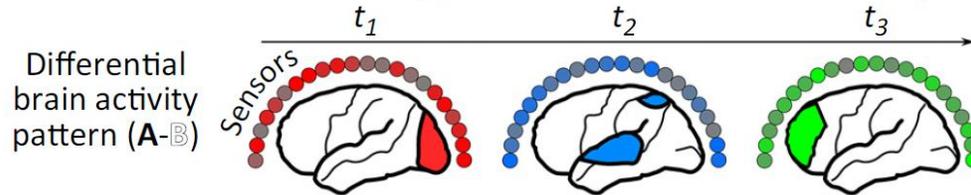
$$\frac{1}{k} \sum_{t=0}^{k-1} (\text{Heatmap}_t) \rightarrow \text{Heatmap}_{\text{avg}}$$

Time resolved decoding practicalities: Single time points or moving window

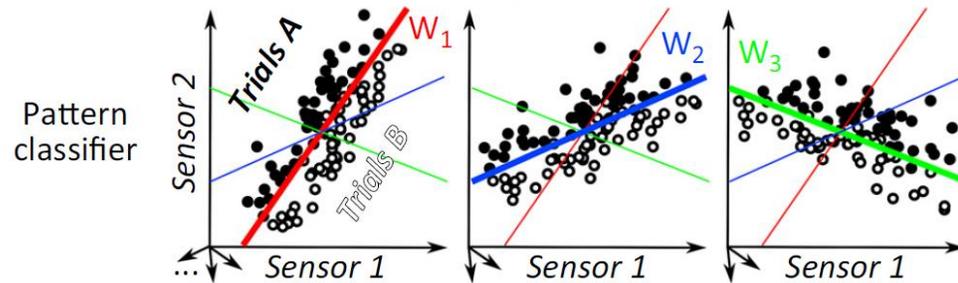


Temporal generalisation

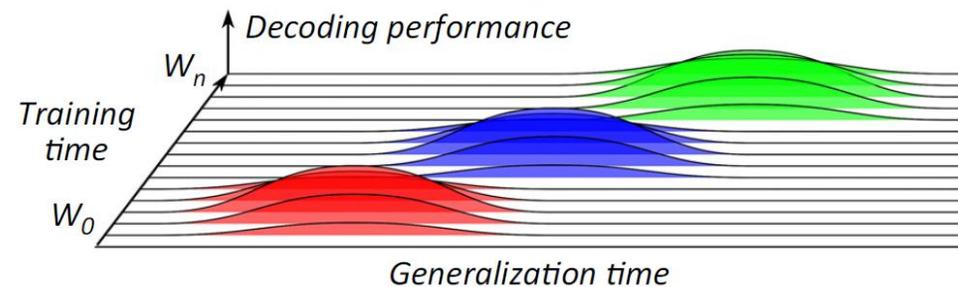
1. A differential brain activity pattern is recorded at each time point.



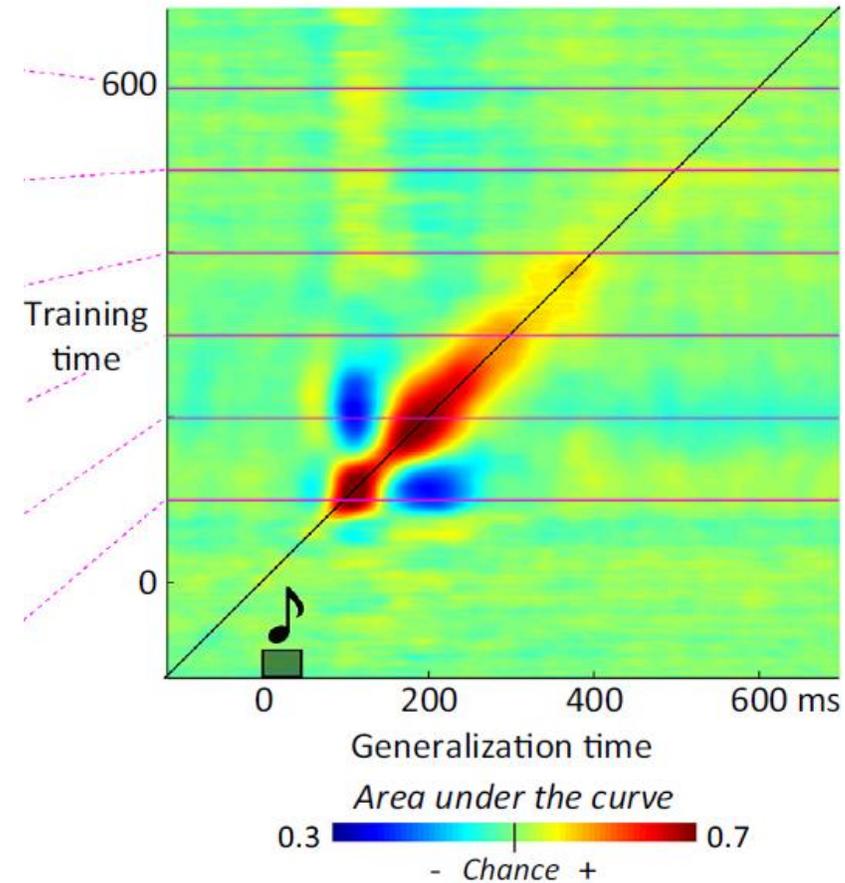
2. A classifier is trained at each time point.



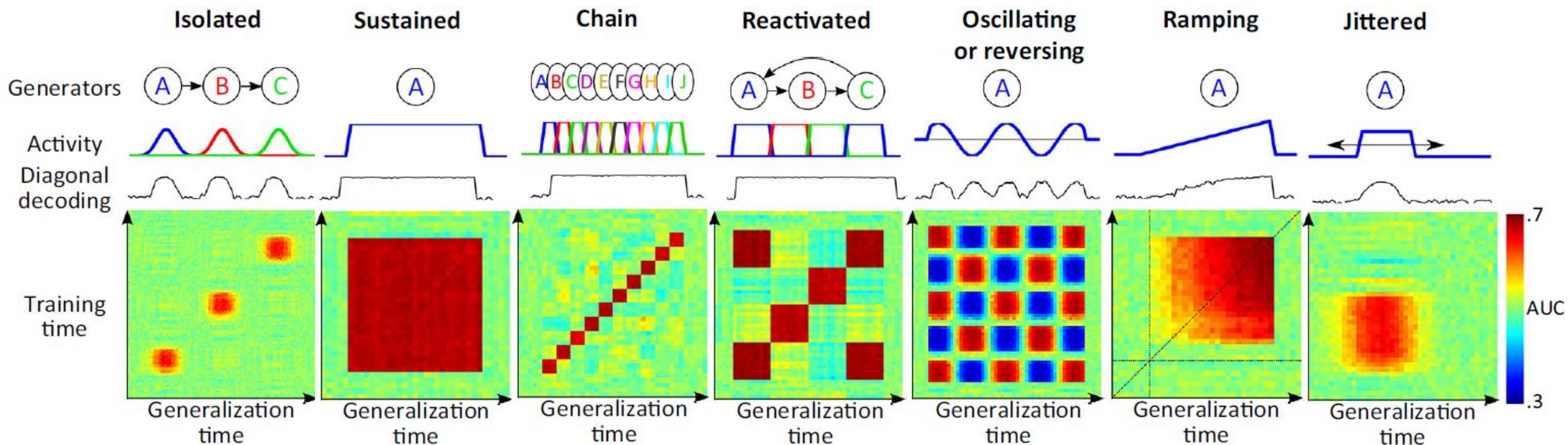
3. Each classifier is tested on its ability to generalize to all time points.



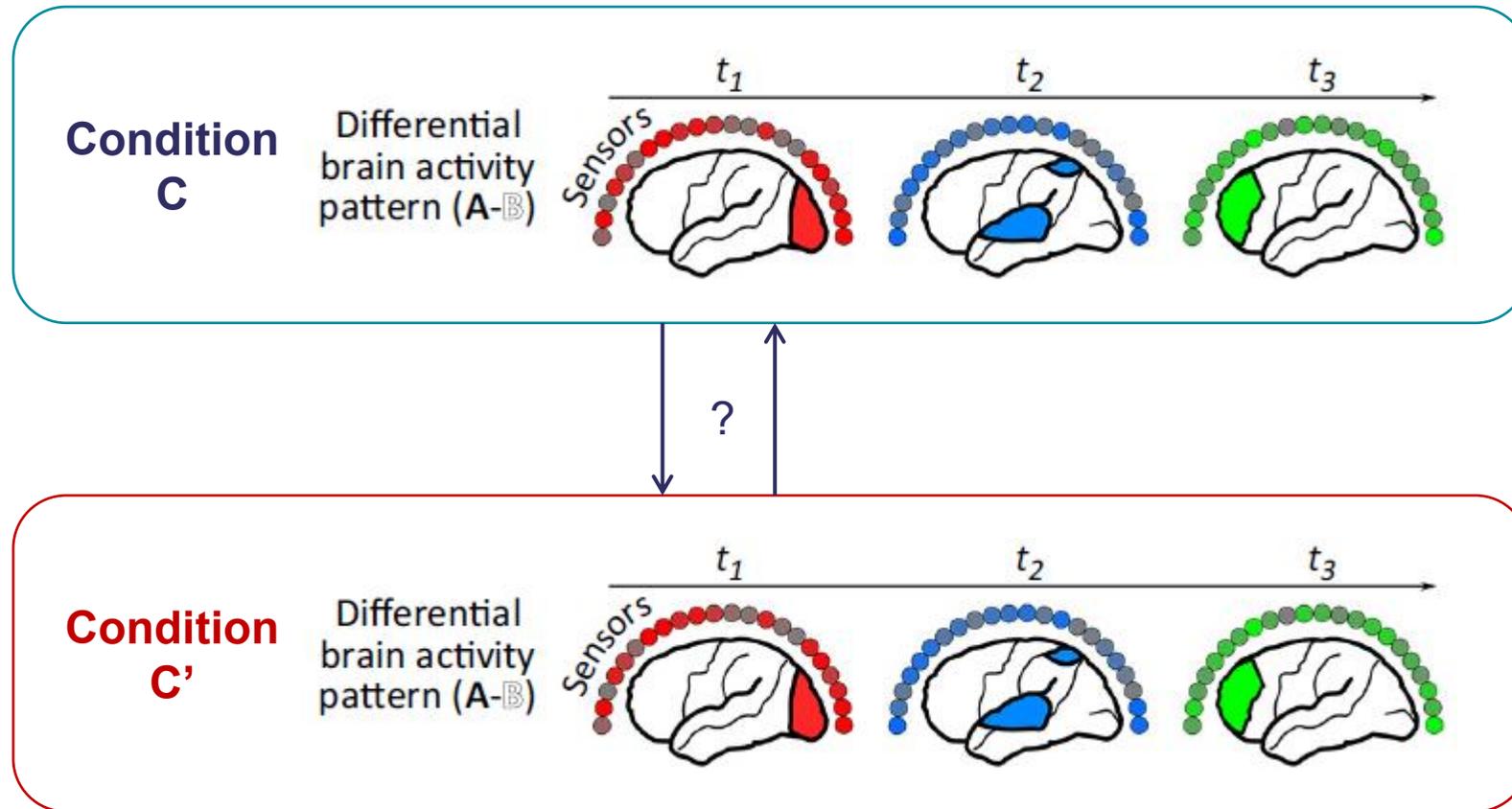
Generalization across time



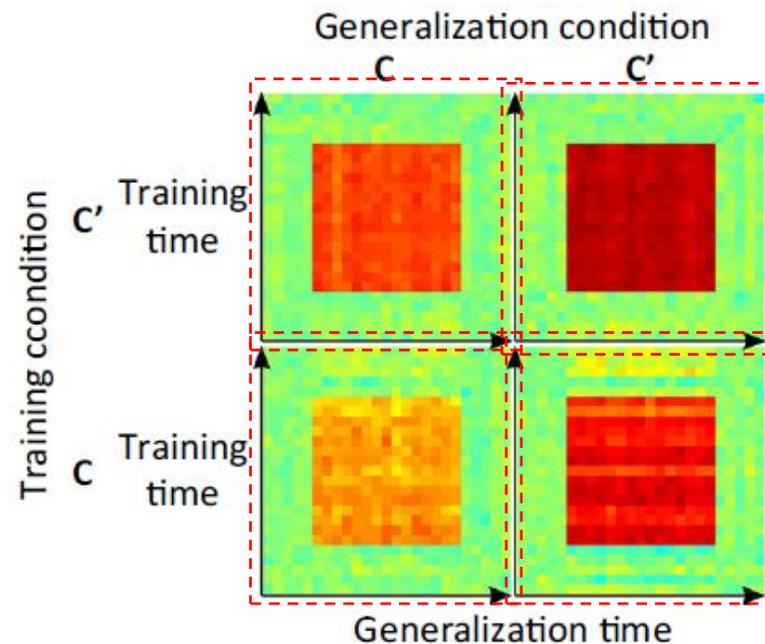
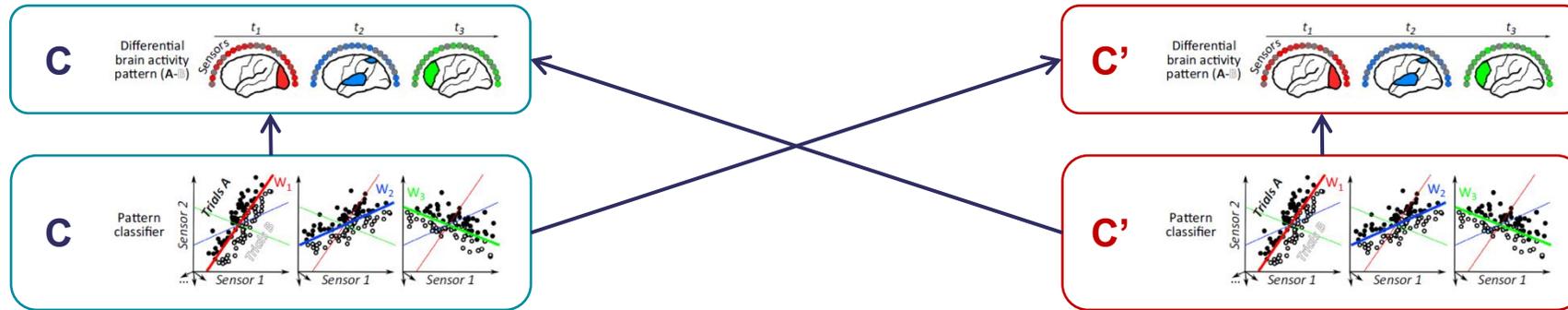
Temporal generalisation



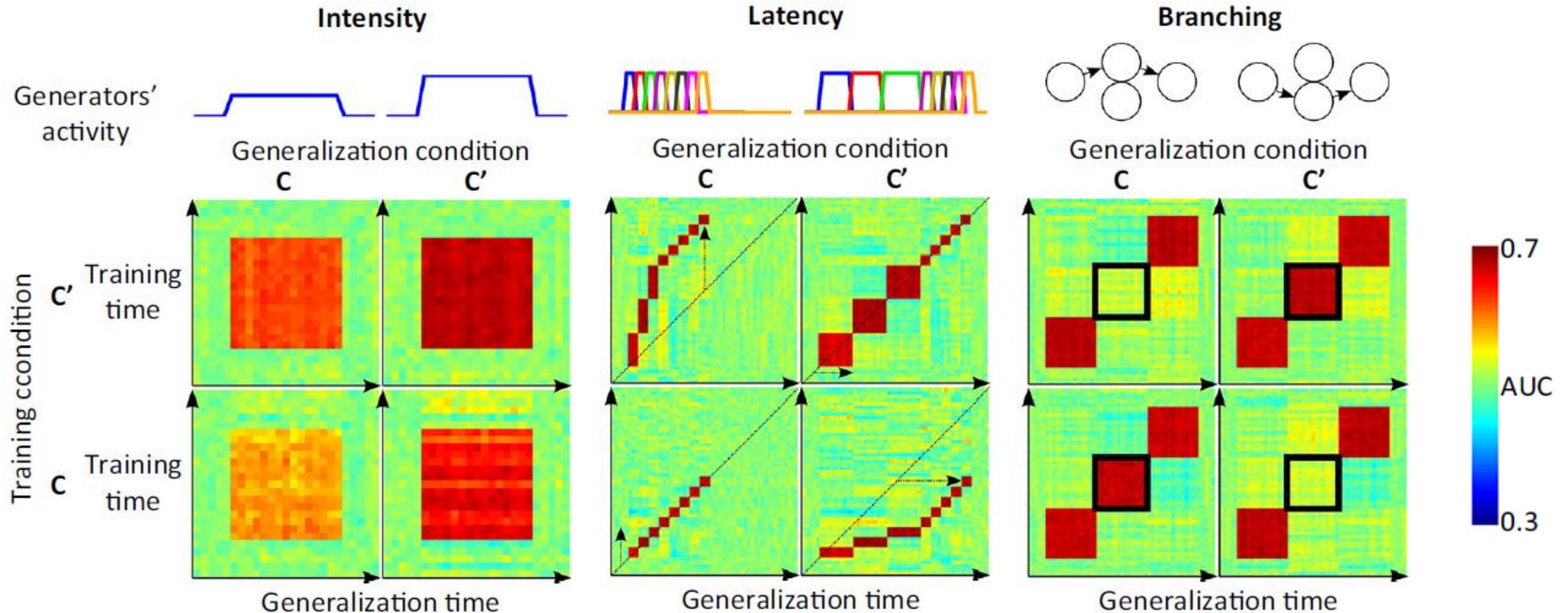
Temporal and across-condition generalisation



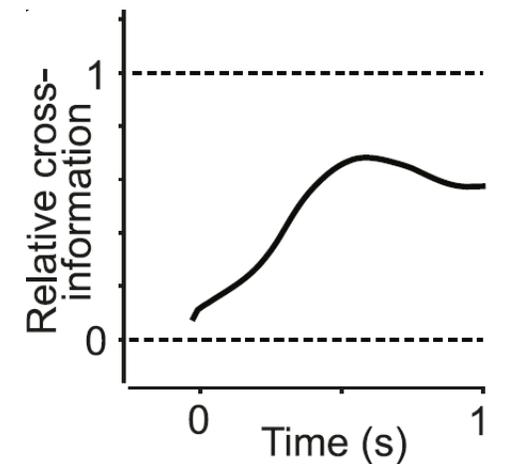
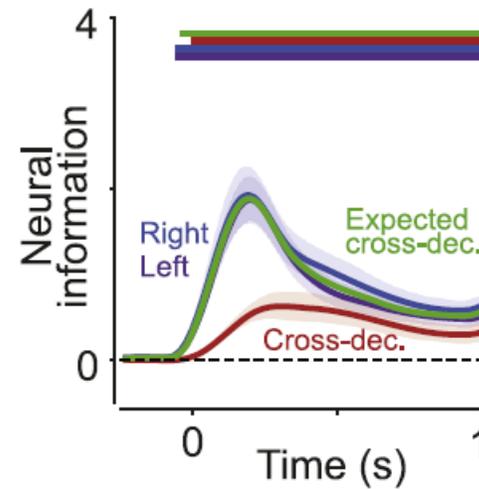
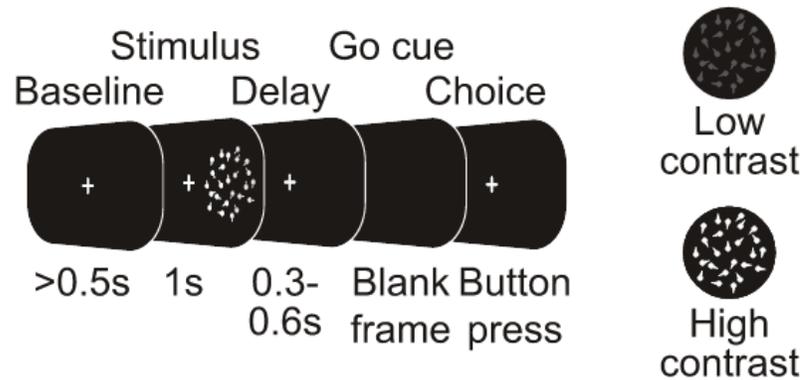
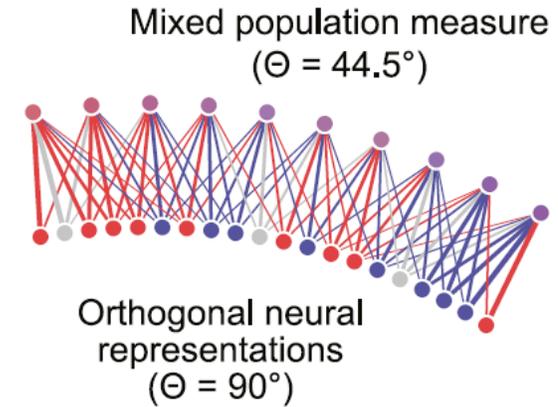
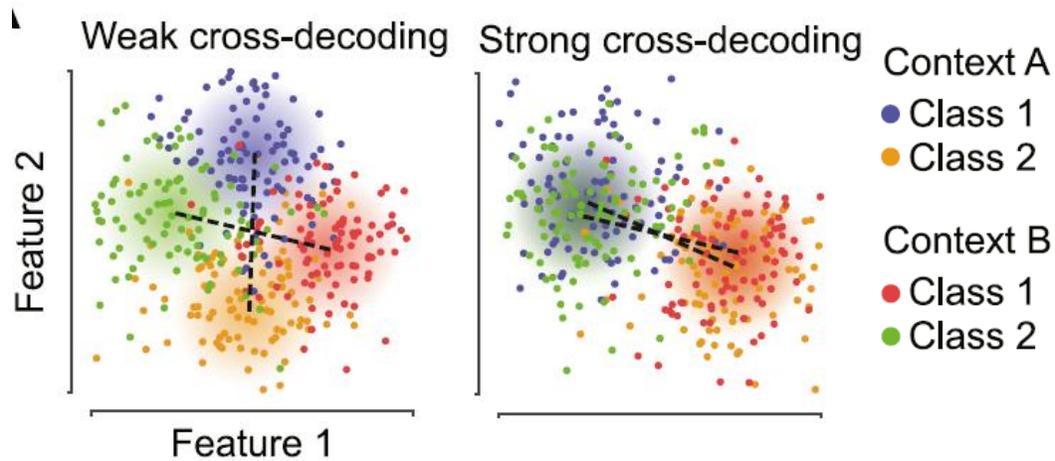
Temporal and across-condition generalisation



Temporal and across-condition generalisation

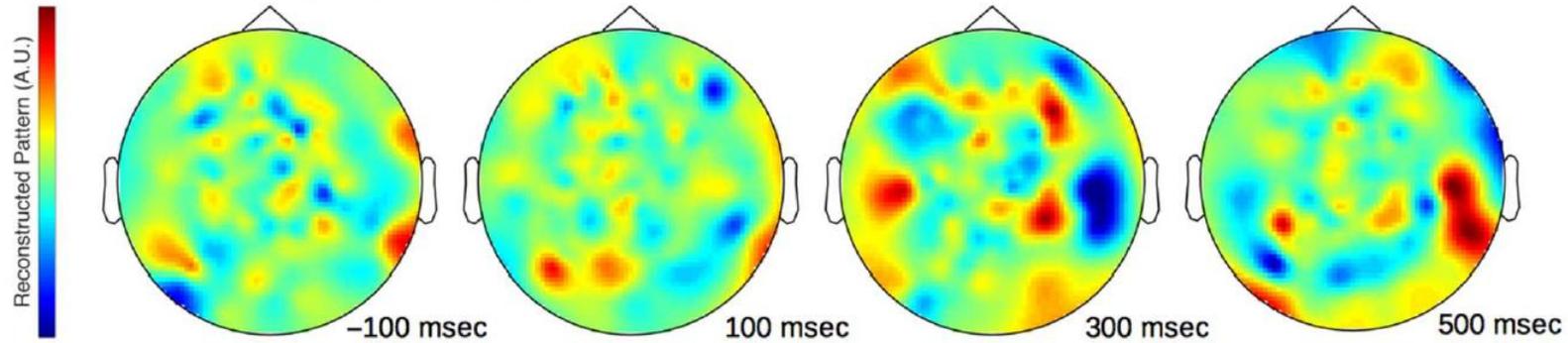


Interpreting the generalisation of neural representations

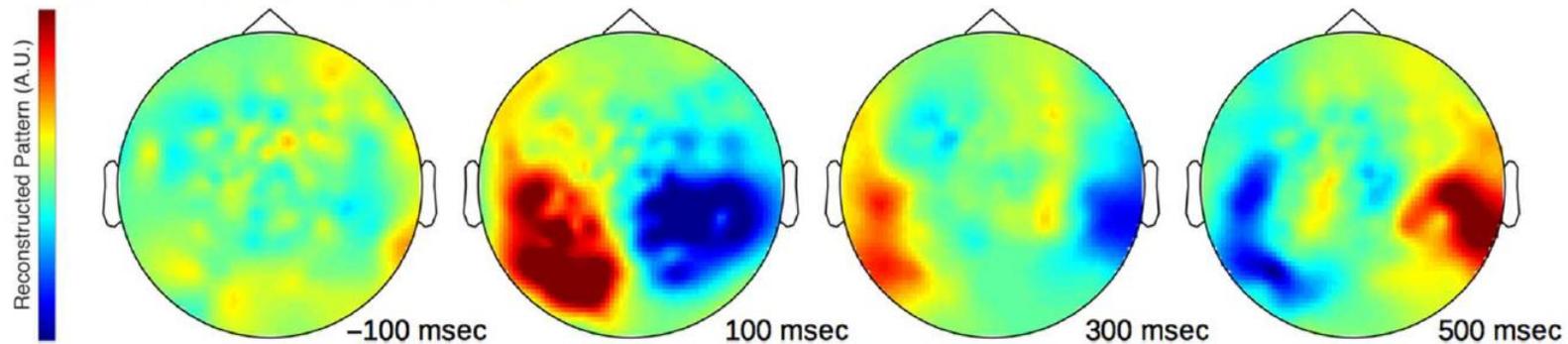


Interpreting decoding weights

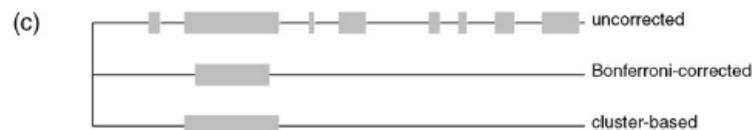
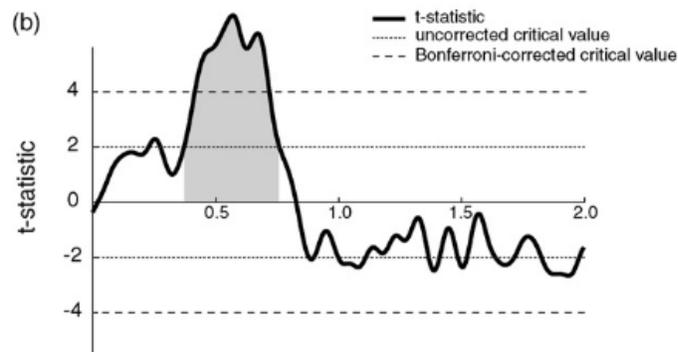
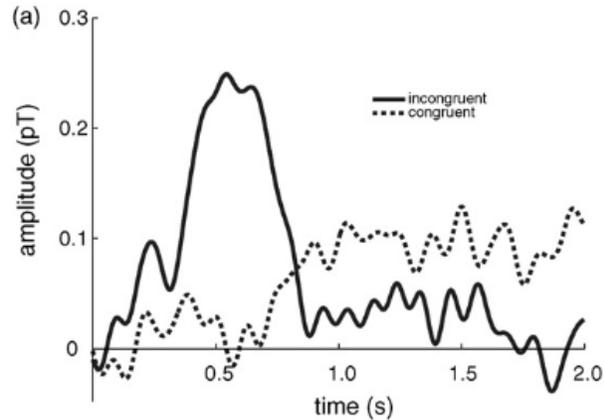
A Uncorrected activation patterns in sensor space



B Corrected activation patterns in sensor space



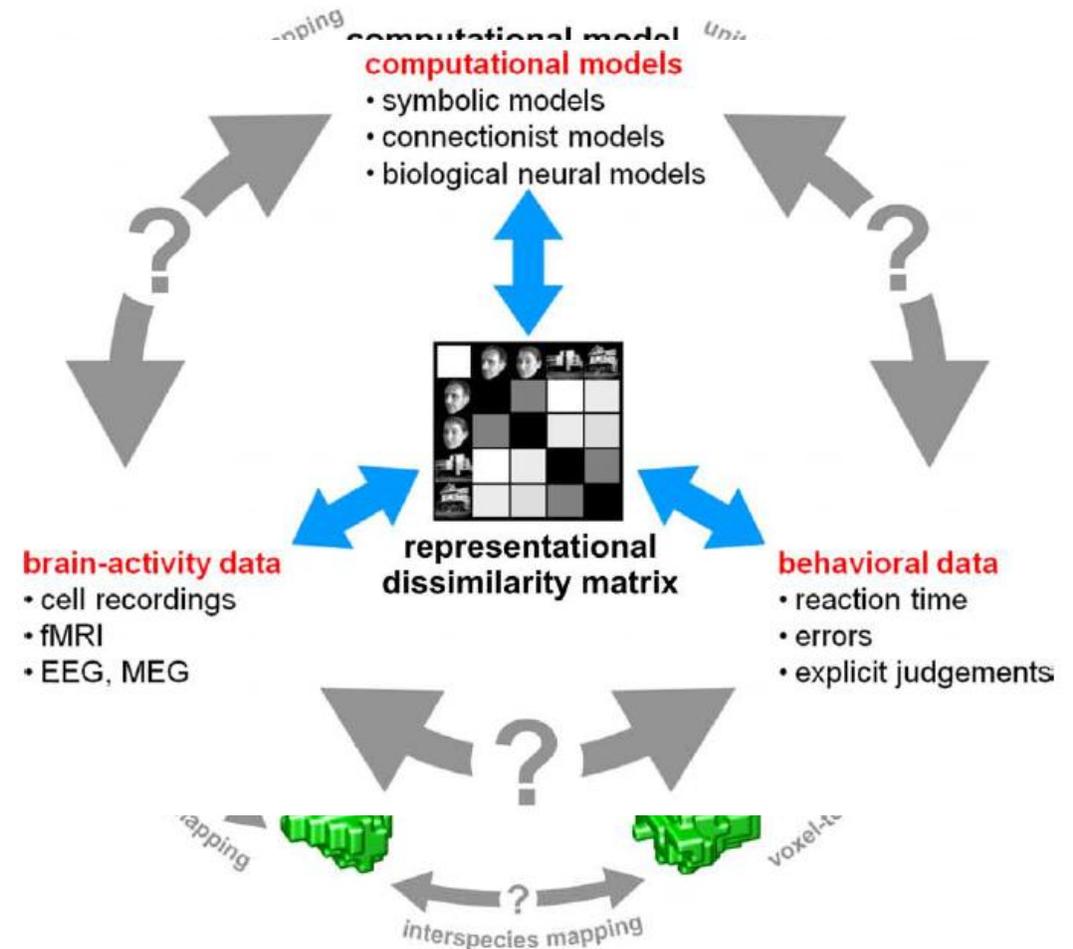
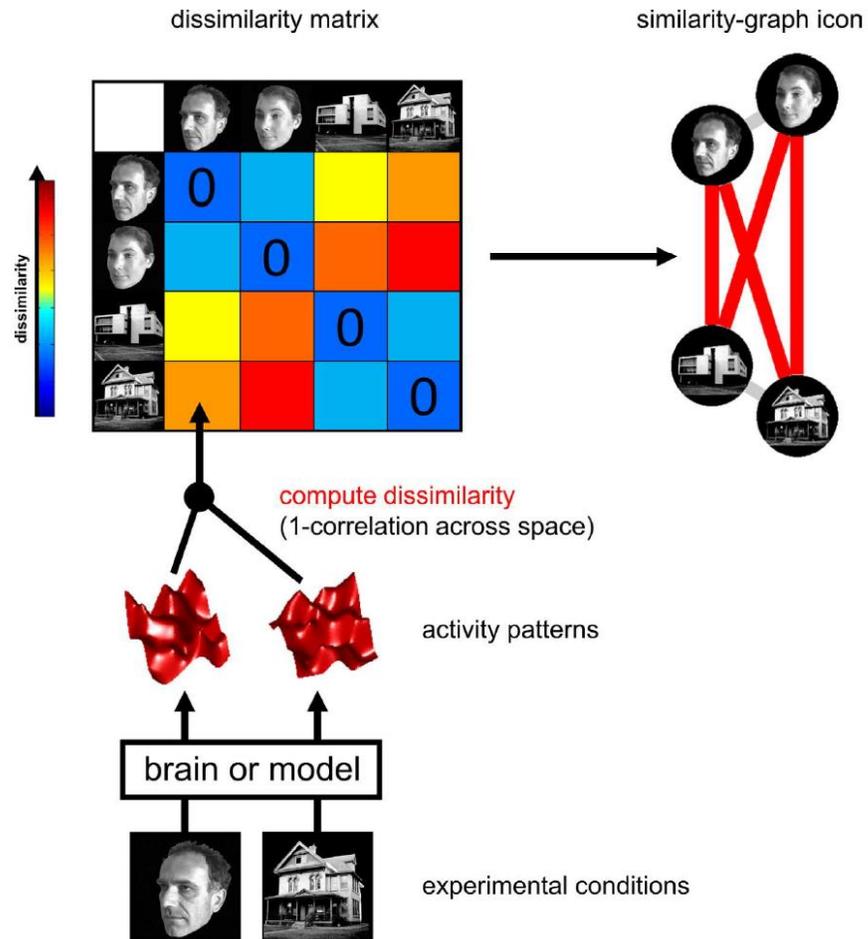
Time resolved decoding statistics: Cluster-based permutation tests



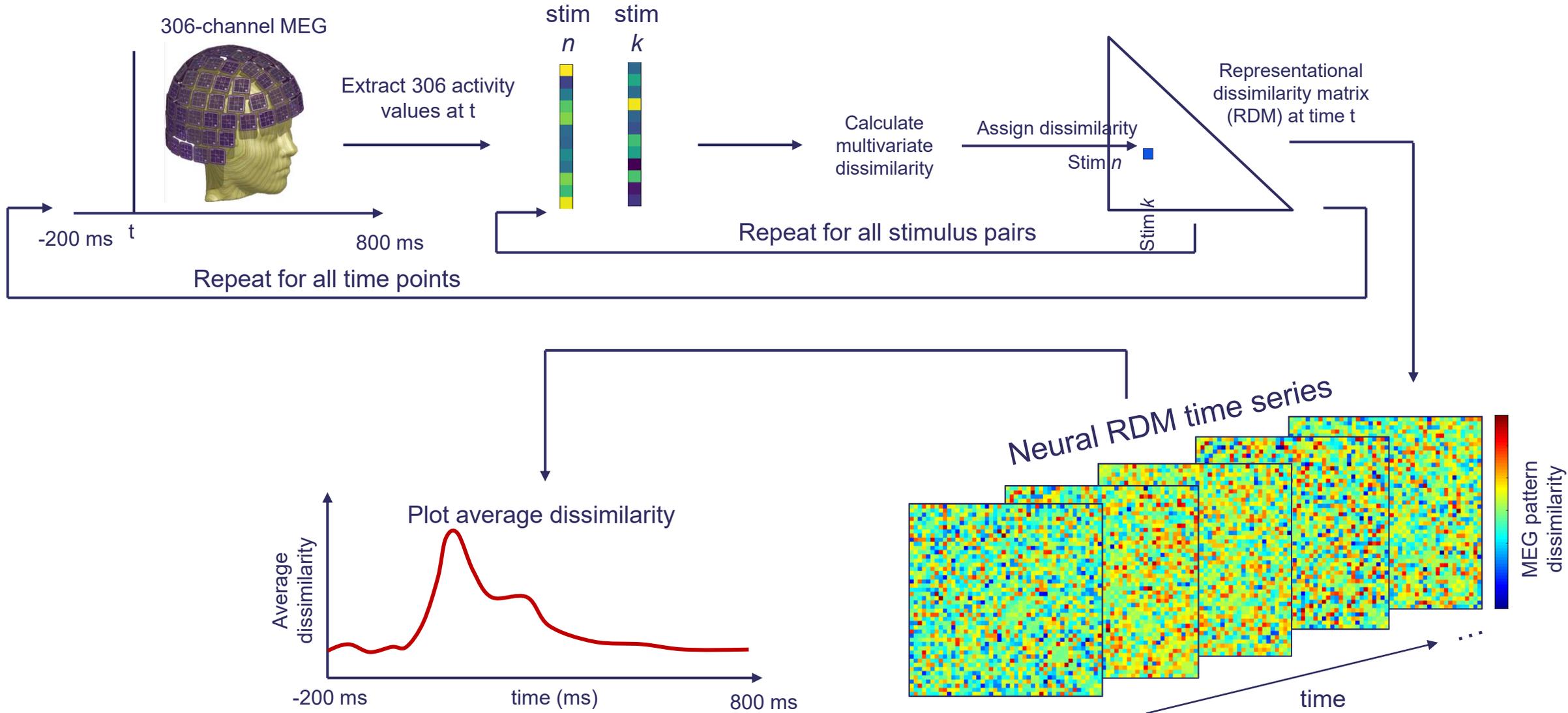
- Preferred in most cases
 - Simple, non-parametric
- Interpretation caveats
 - There are no “significant clusters”, the test is (or isn’t) significant.
 - Caution when interpreting location (space or time) of effect

Representational similarity analysis on EEG/MEG

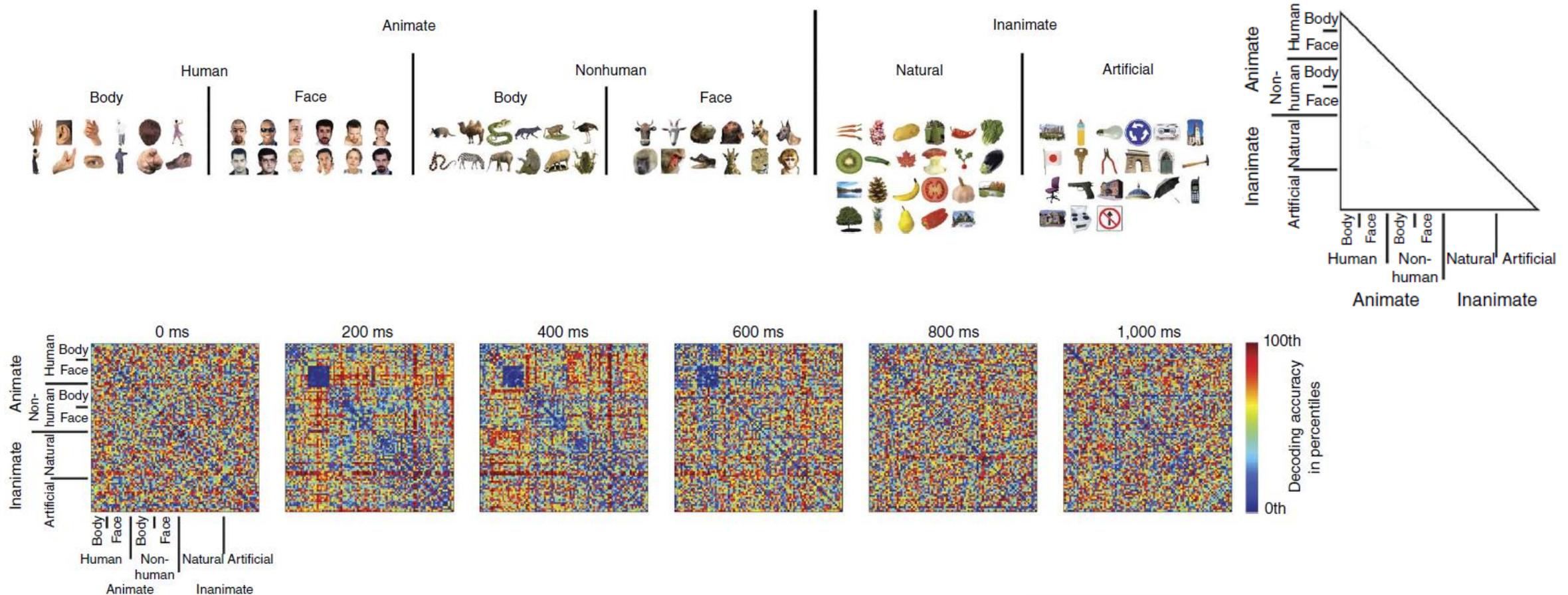
RSA recap



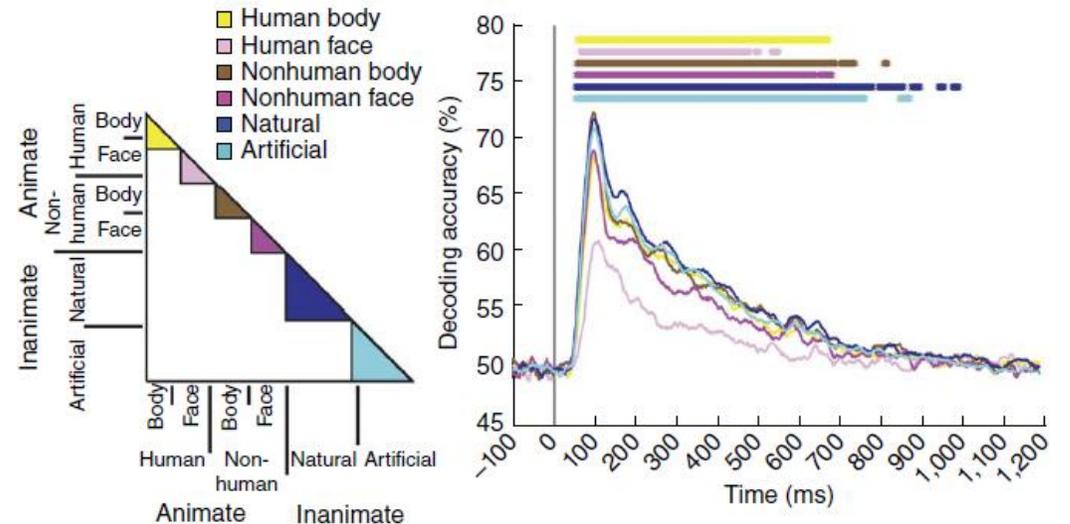
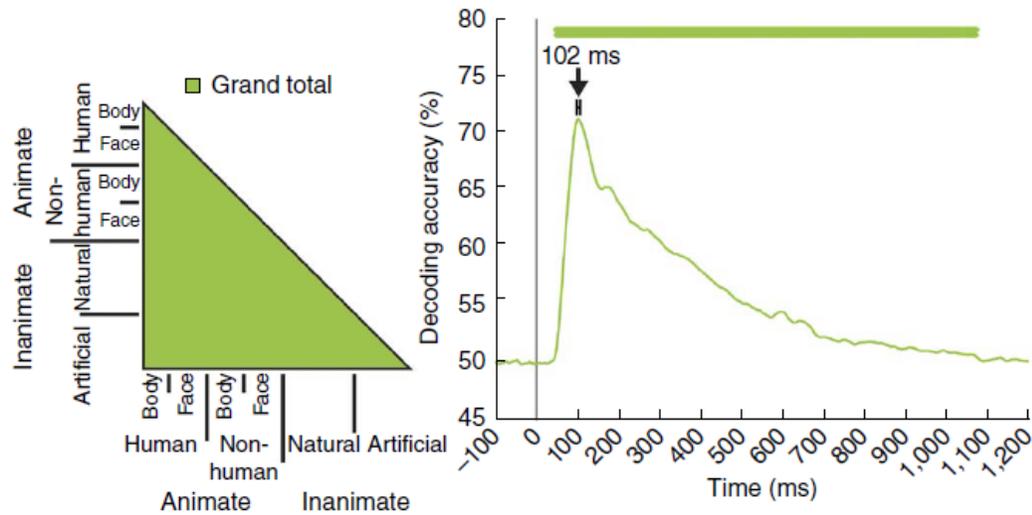
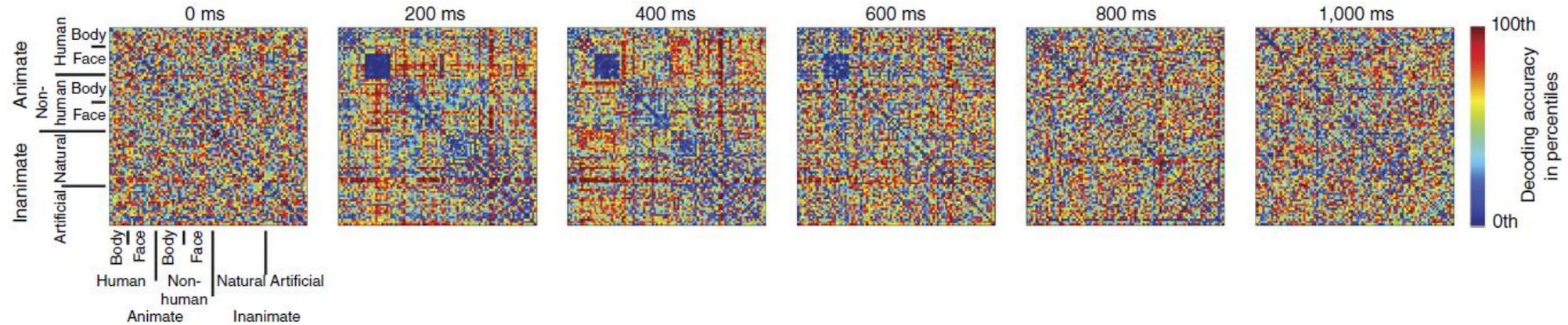
Time resolved RSA



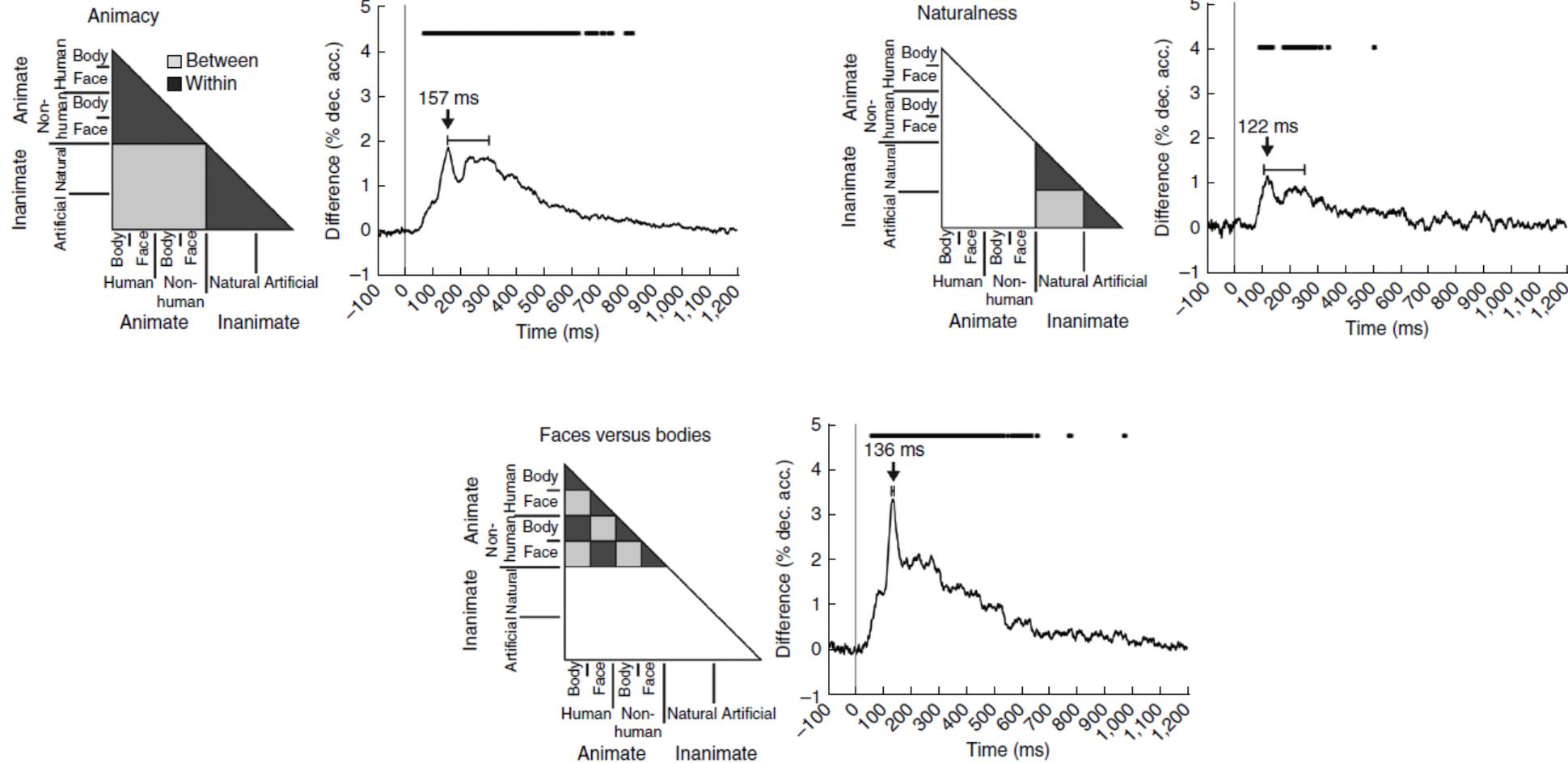
Time resolved RSA - example study Cichy et al. (2014)



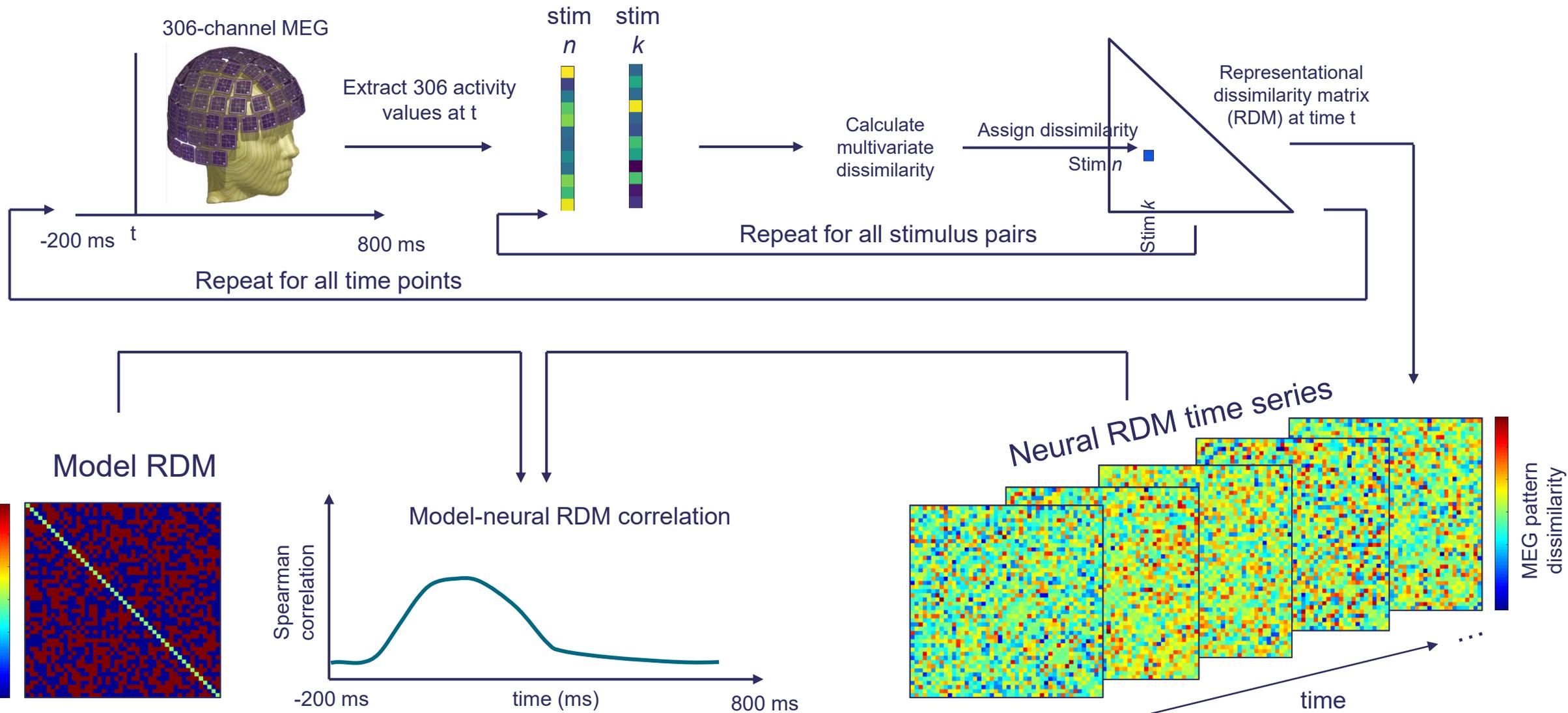
Time resolved RSA - dissimilarity time courses



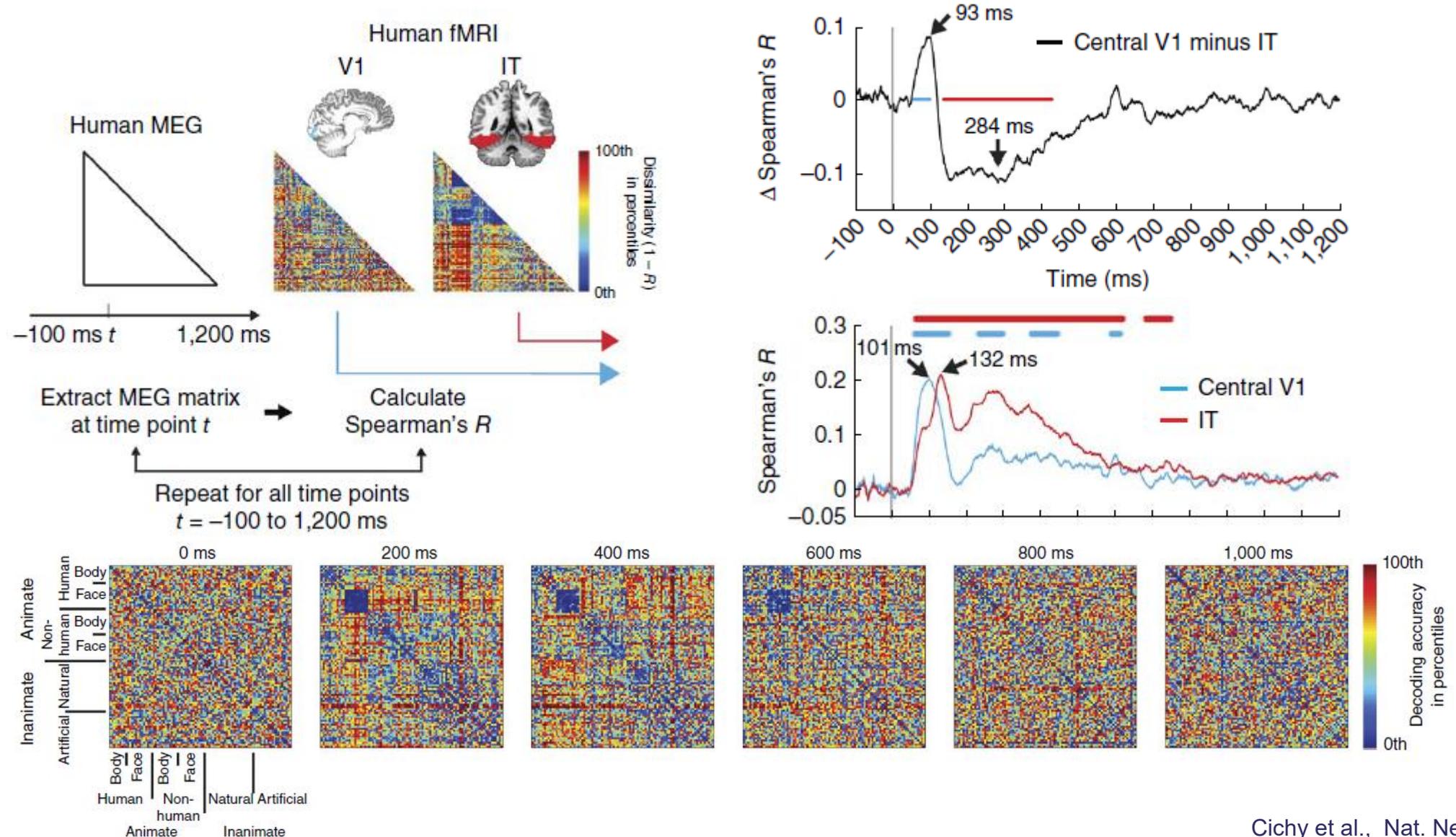
Time resolved RSA – decoding categories



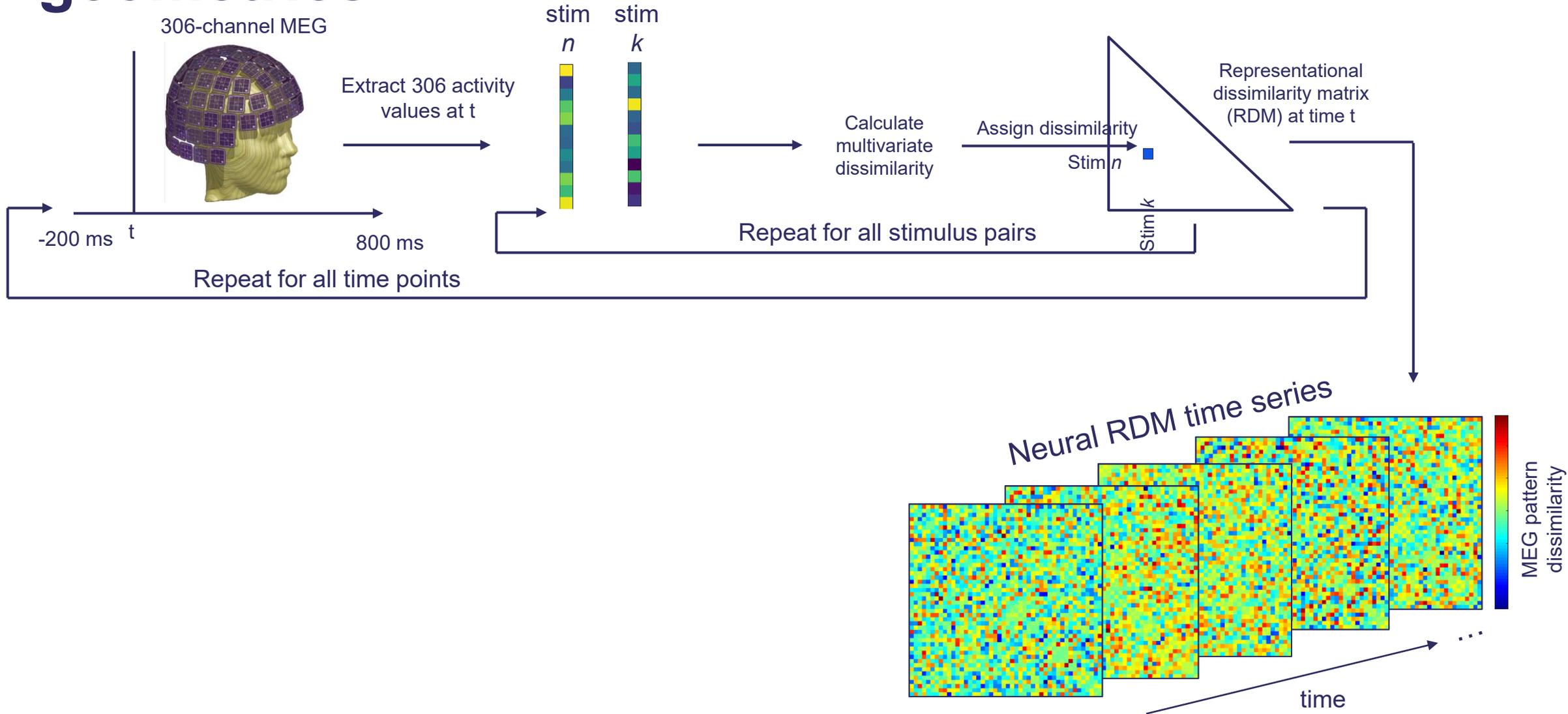
Time resolved RSA – compare with model



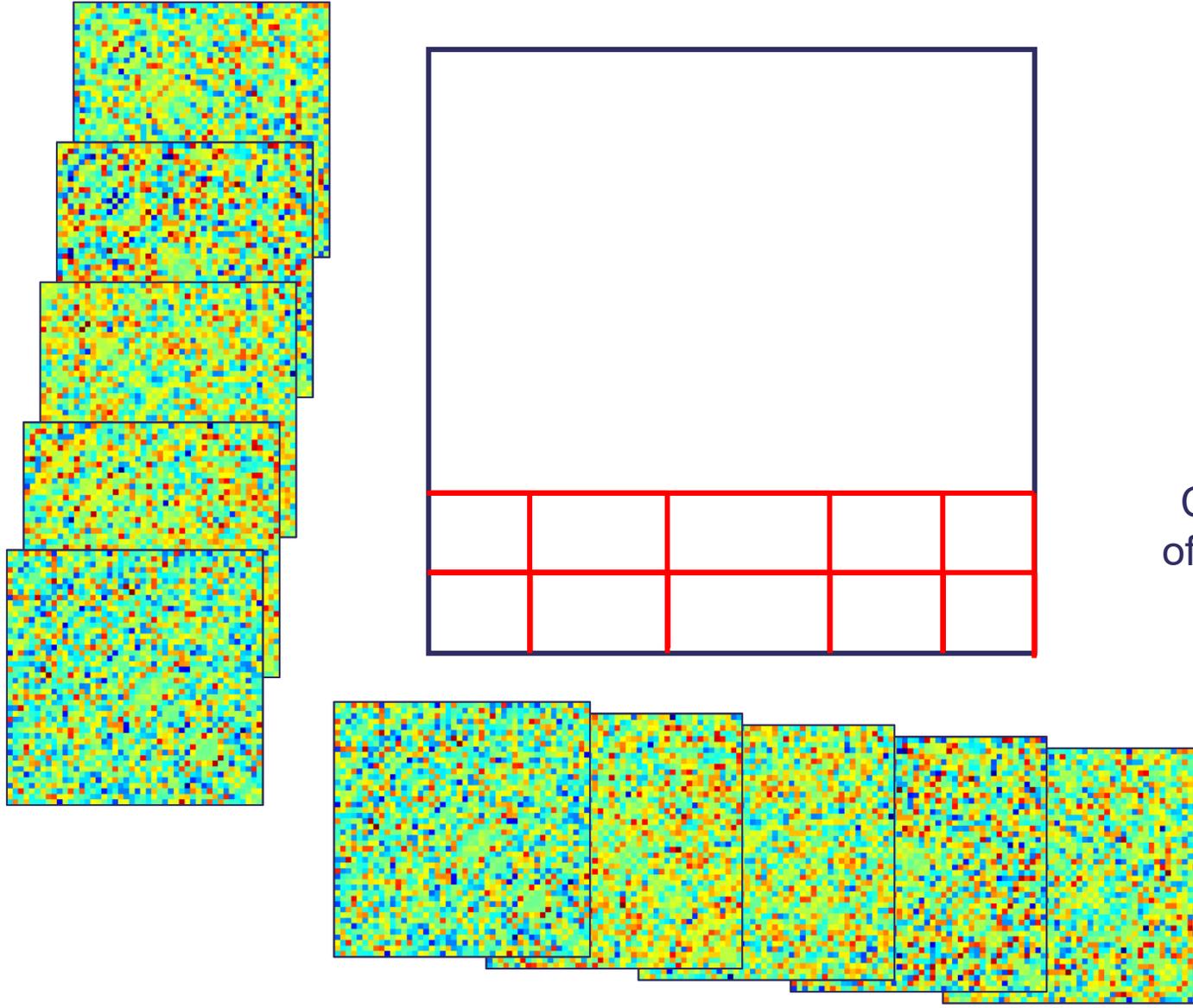
Time resolved RSA – compare with model



Temporal generalisation of representational geometries

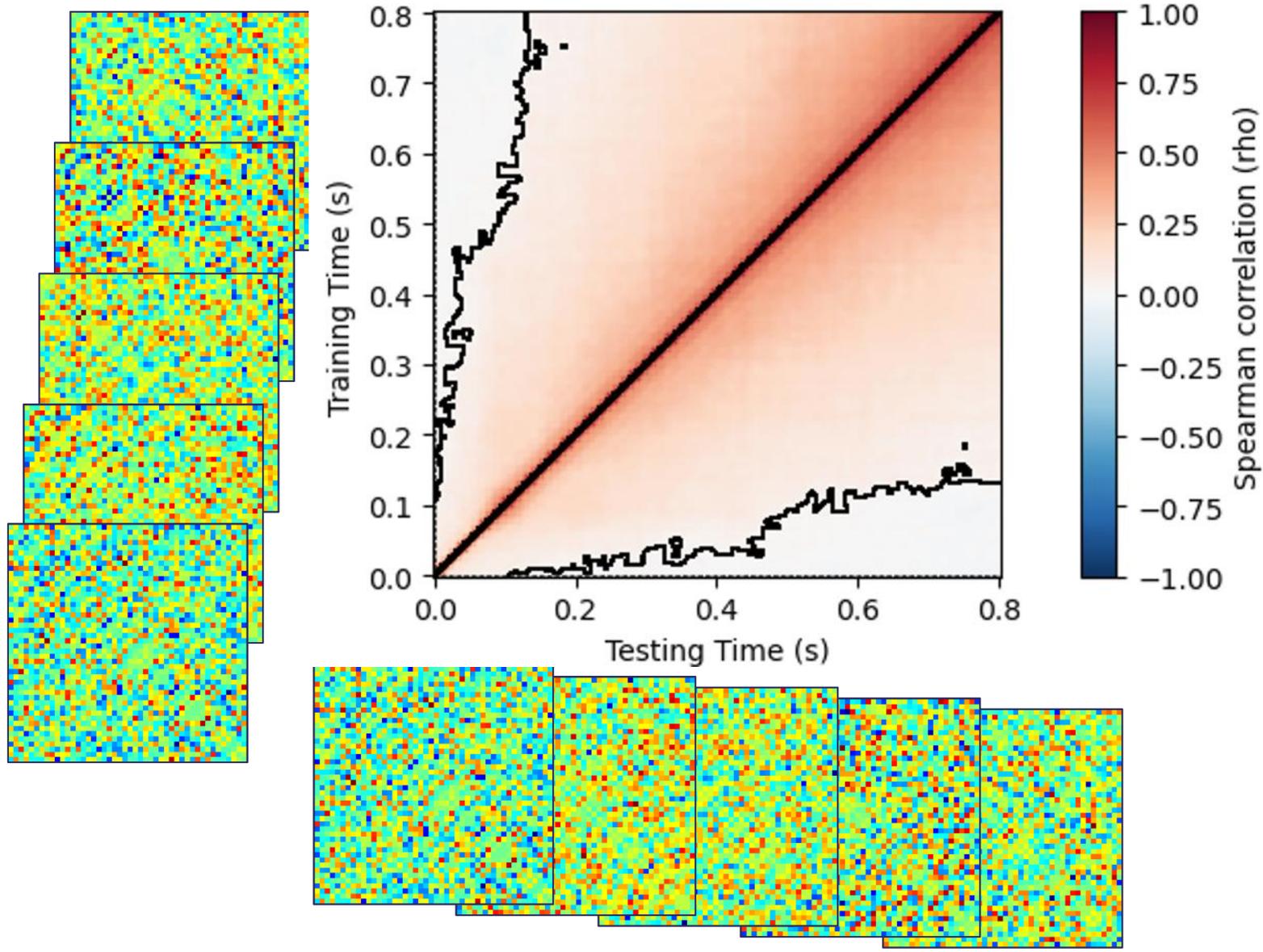


Temporal generalisation of representational geometries

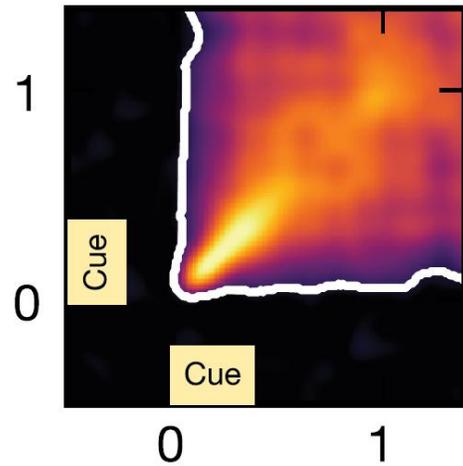


Compute pairwise correlation
of RDMs between all time point
pairs

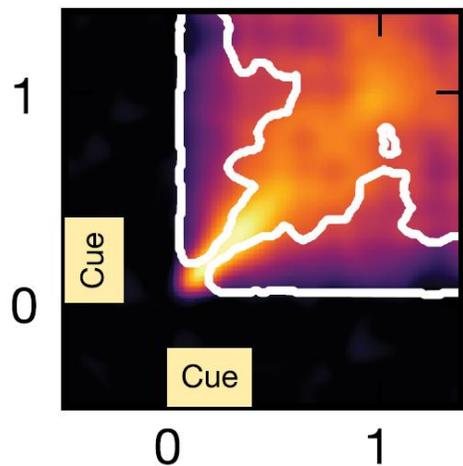
Temporal generalisation of representational geometries



Temporal generalisation of representational geometries

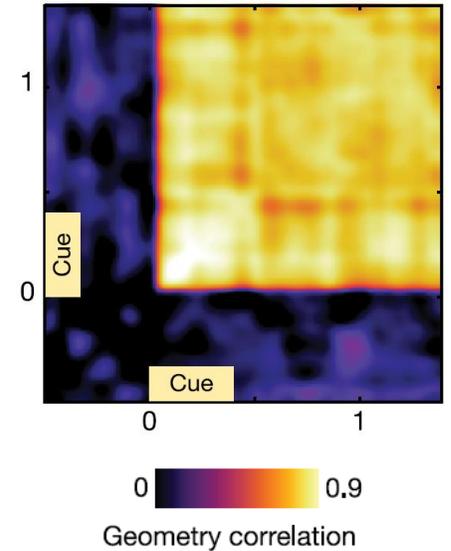
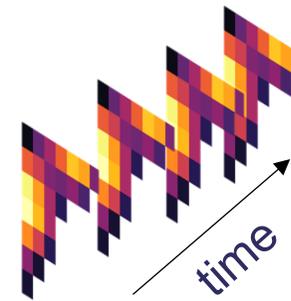
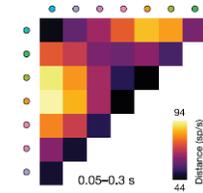


Significant generalisation



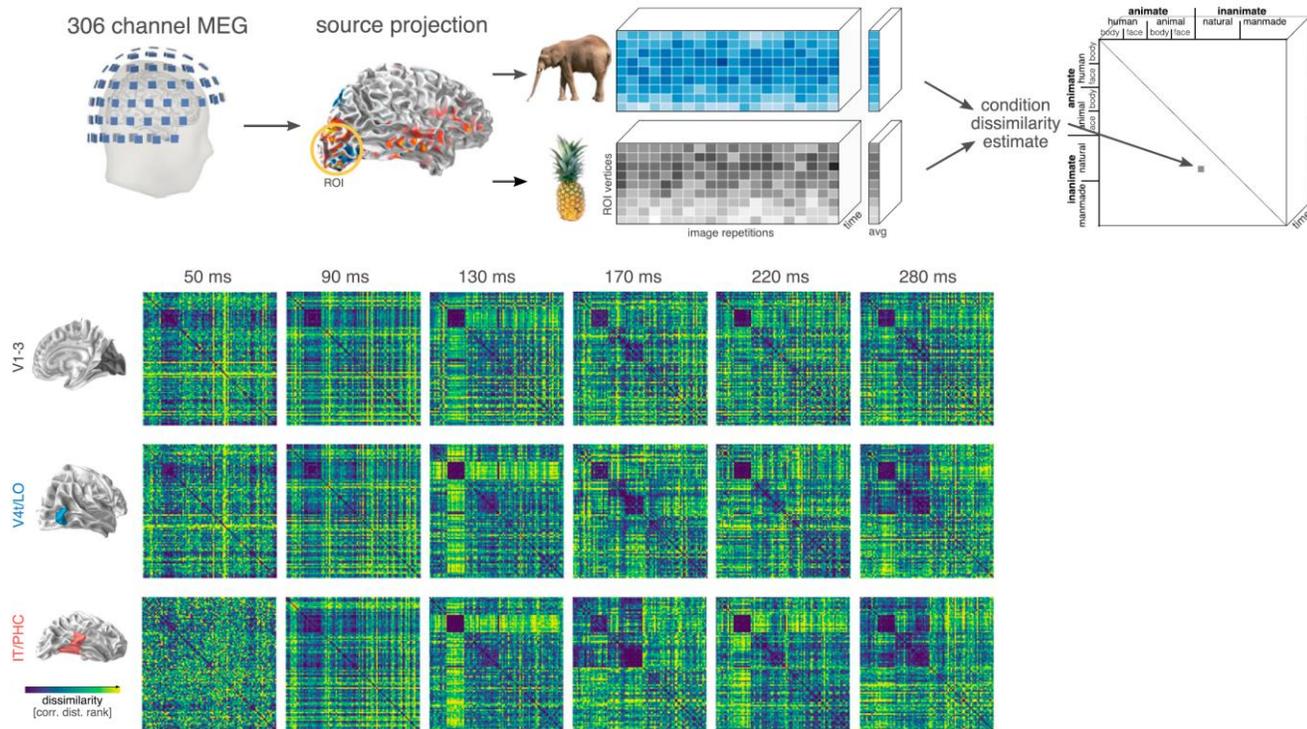
Significant dynamics

0 0.63
Discriminability

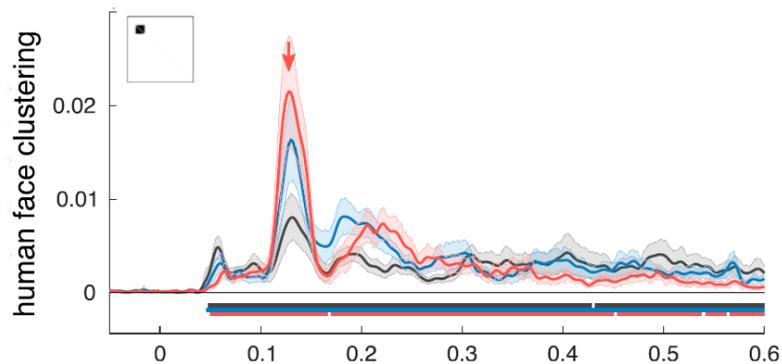
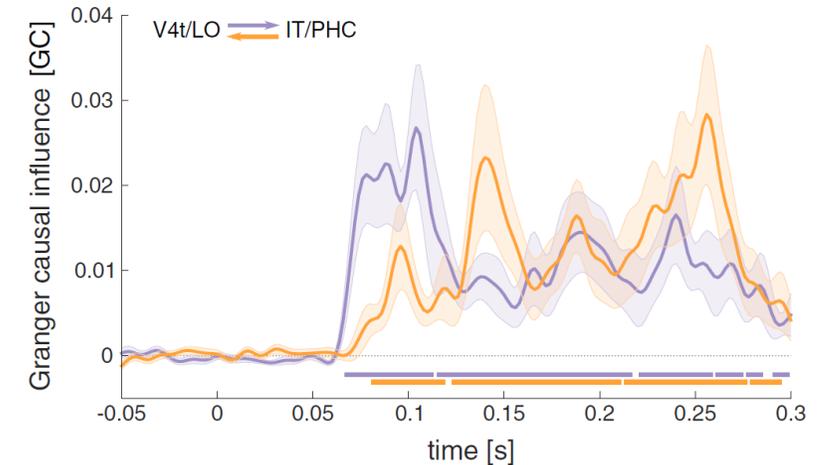
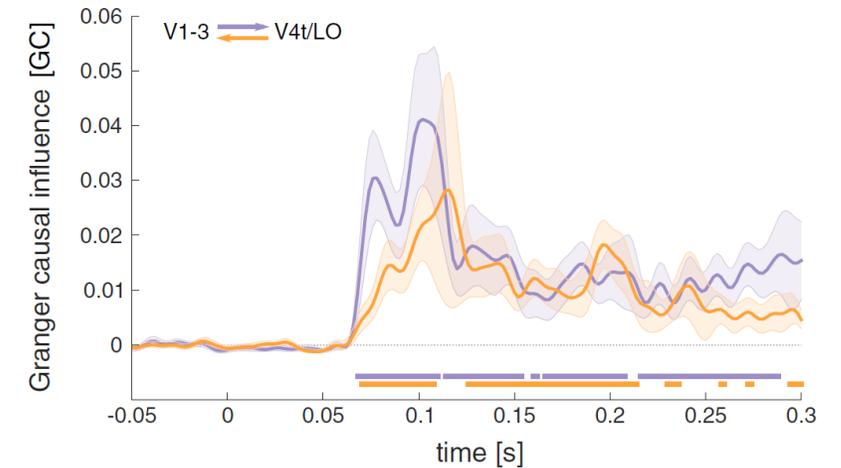


Stable representational geometry despite dynamic neural representations

Decoding Information Over Time And Space



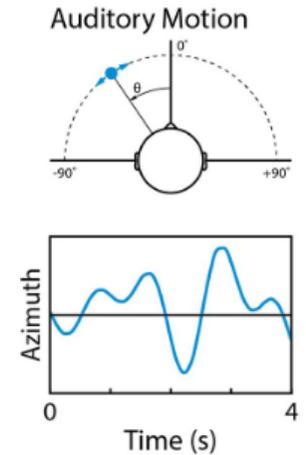
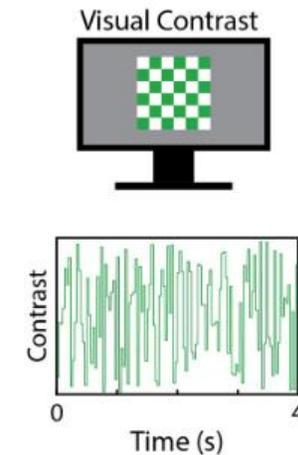
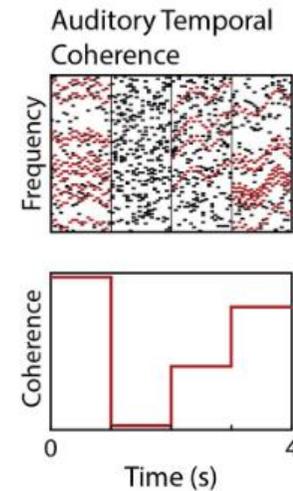
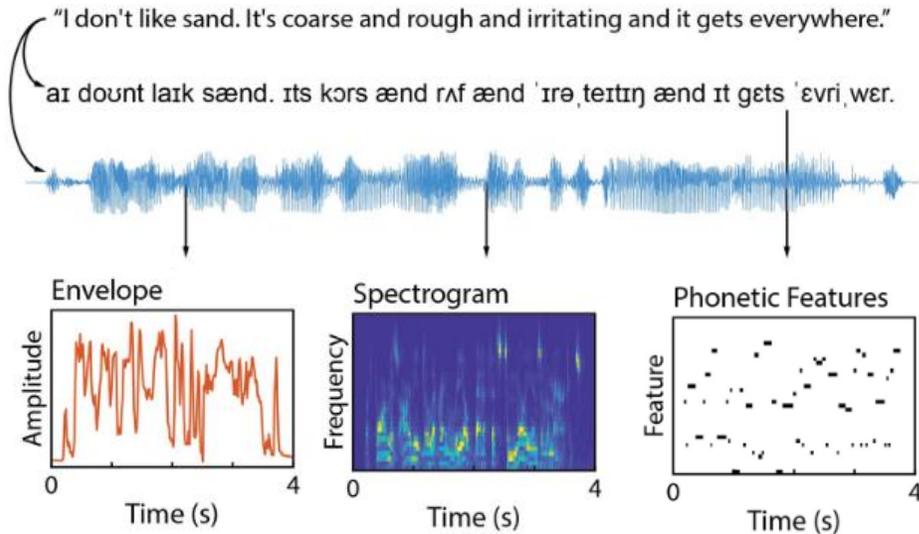
RSA Granger Analysis of Information Flow



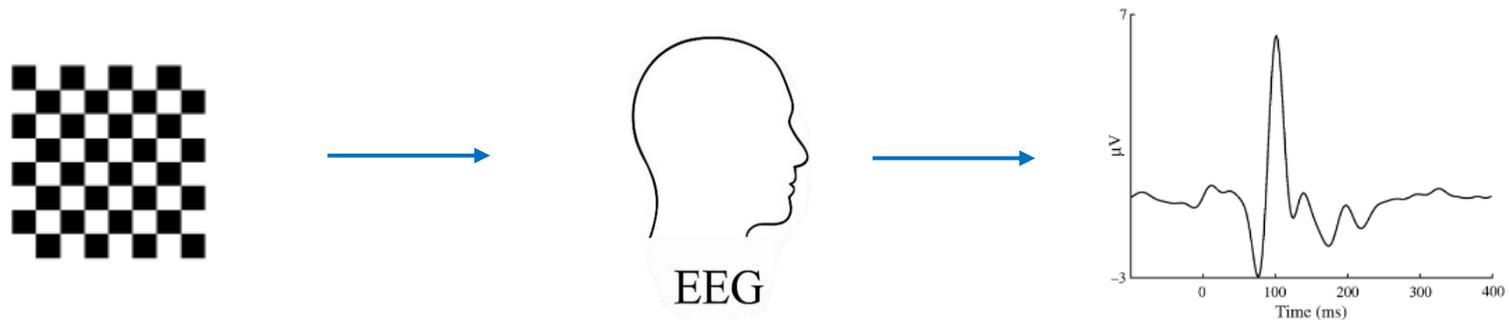
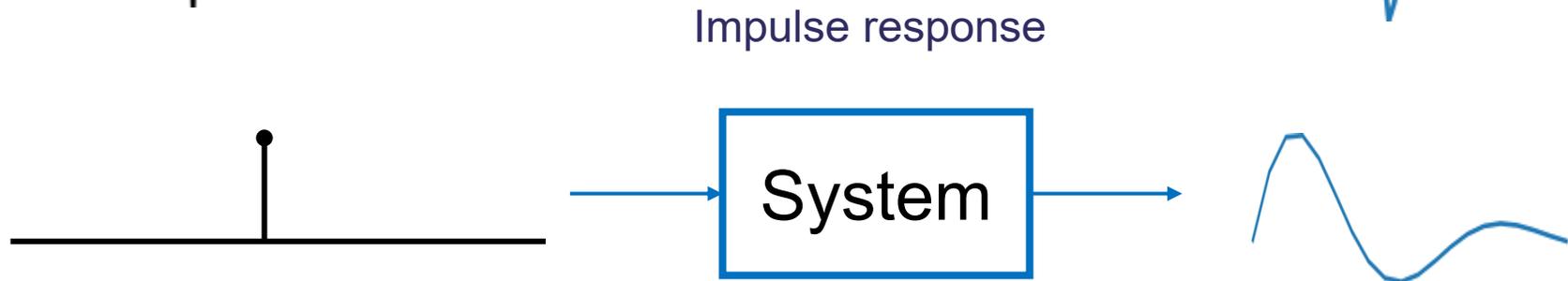
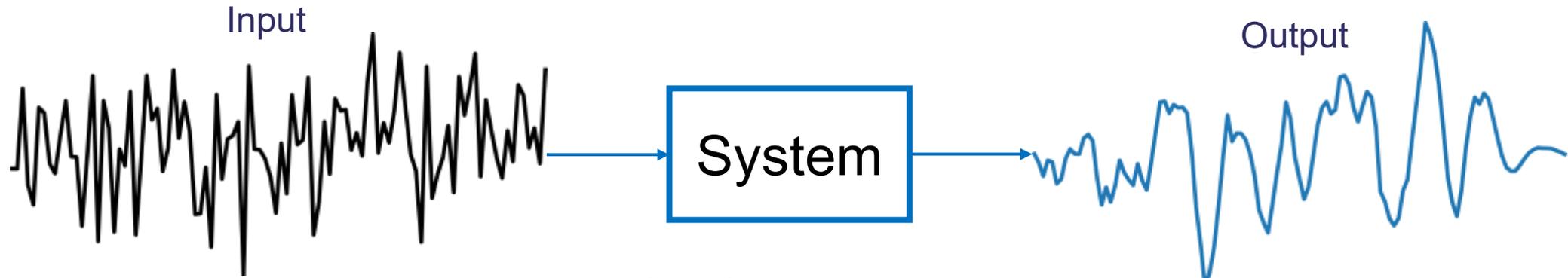
Temporal Response Function (TRF) analyses

Motivation – moving towards more naturalistic stimuli

- Classic ERP paradigm
 - Brief isolated stimuli
 - Often unnatural (e.g. single words repeated many times)
- Continuous, time-varying stimuli



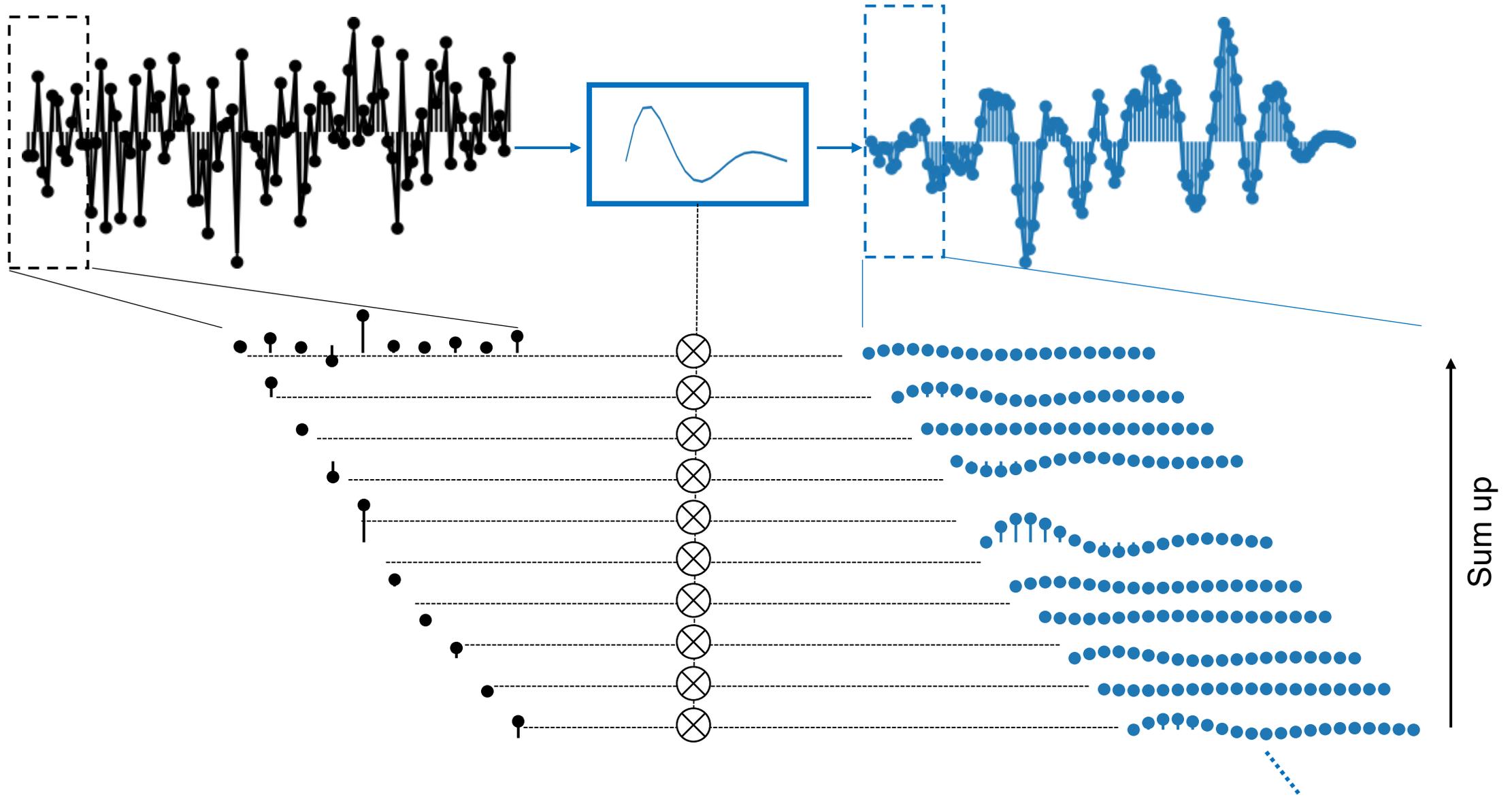
Background – signals and systems view



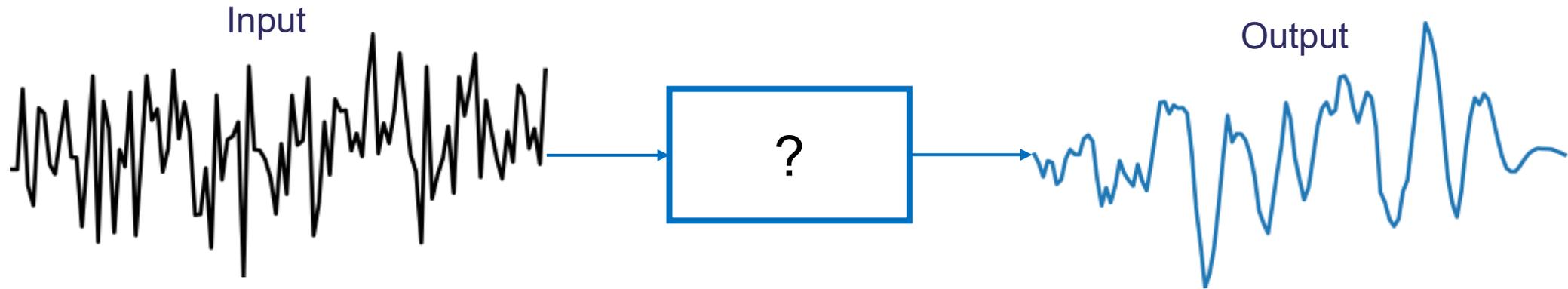
Background – Linear Time Invariant systems

- The brain is highly non-linear and time dependent
- We need to simplify. We assume:
 - Linearity: output is the sum of inputs
 - Time invariance: system response is the same every time
- Linear Time Invariant (LTI) systems
- Impulse response
- Series of impulse responses

LTI systems - Intuition



How to find the system response?

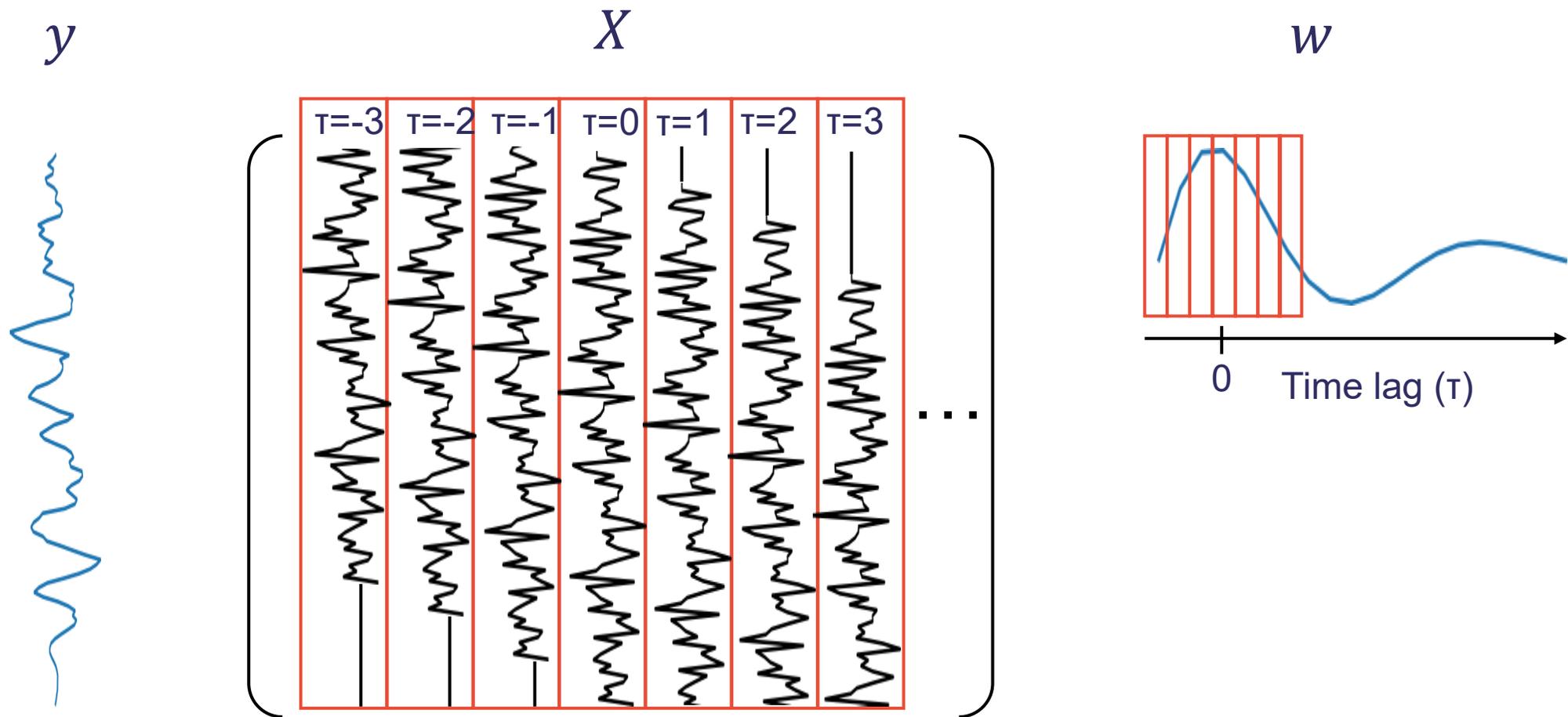


- System identification techniques
- Regression approach: use time-lagged copies of the input to predict the output

$$y = Xw + \varepsilon$$

Where y is the output, X is the matrix of time-lagged copies of the input, w is the system response and ε is noise

System identification – intuition



Temporal Response Function analysis

- Ordinary Least Squares (OLS) regression:

$$w = (X^T X)^{-1} X^T y$$

Where X is the time-lagged stimulus matrix, and y is the neural response

- OLS is suboptimal because:

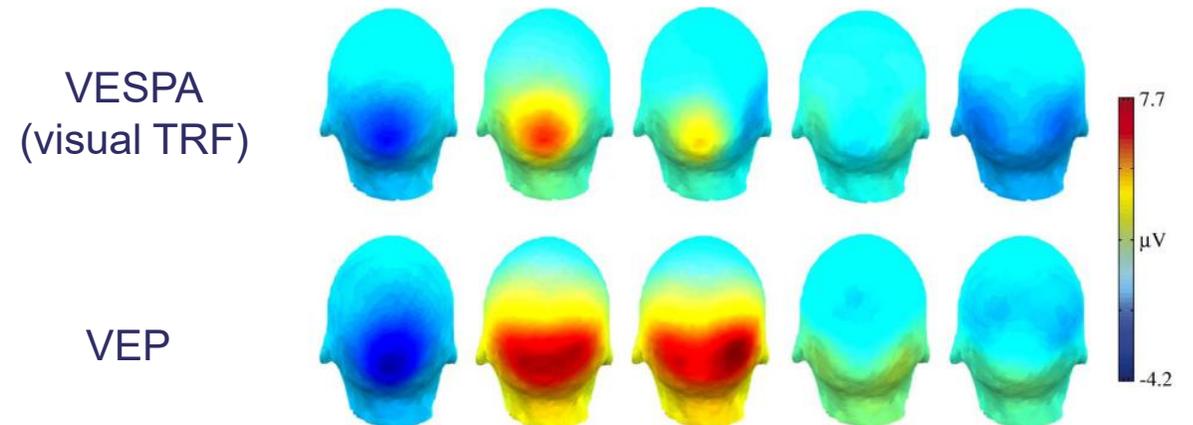
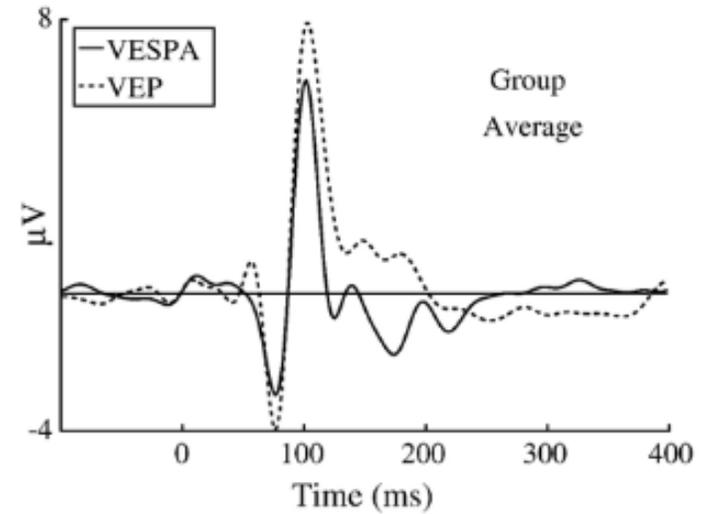
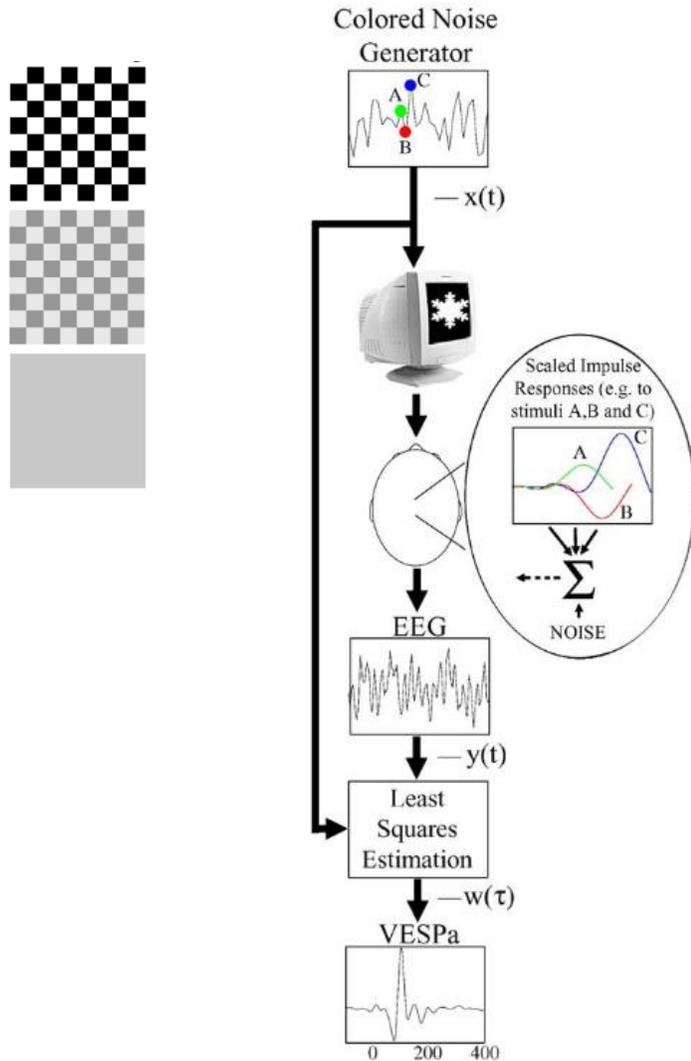
- Multicollinearity problem due to lagged copies of the signal

- Therefore it is better to use regularised (Ridge) regression:

$$w = (X^T X + \lambda I)^{-1} X^T y$$

Where I is the identity matrix and λ is a scalar regularisation parameter

TRFs applied to visual evoked responses

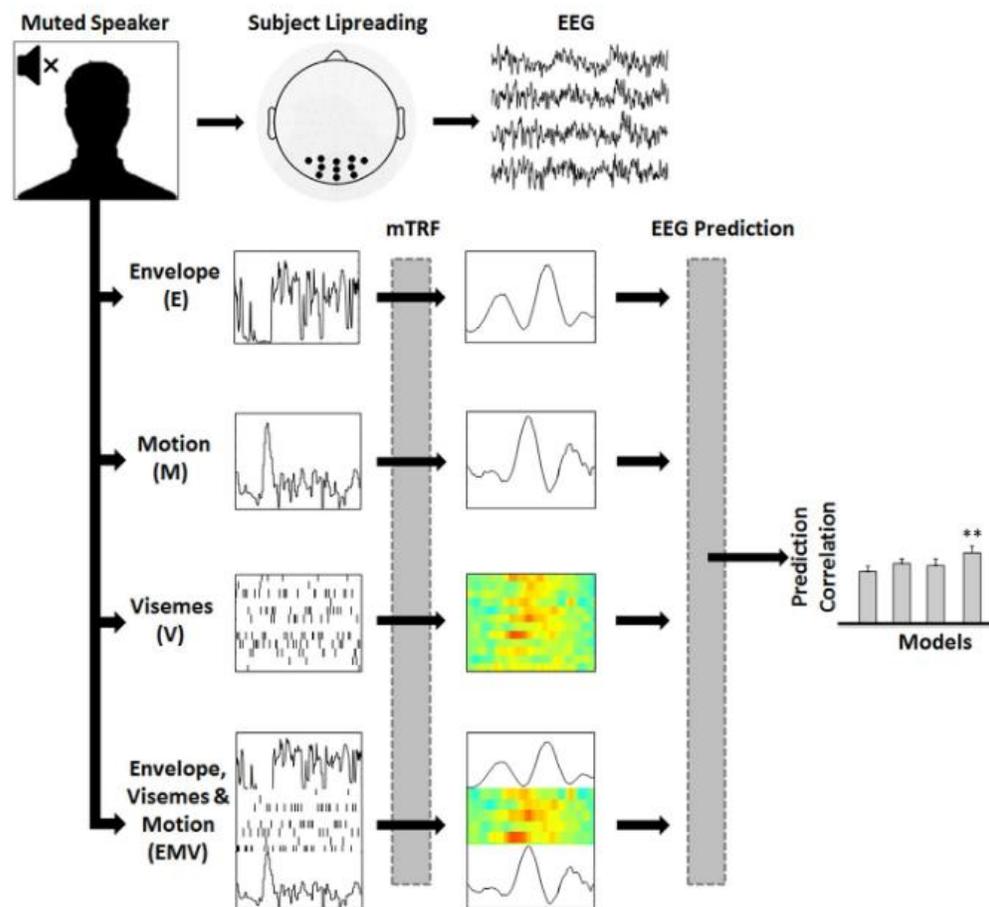
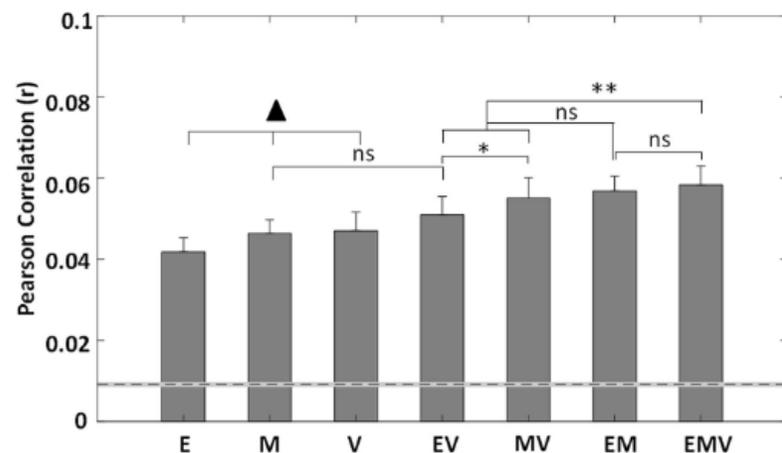


TRF practicalities – Demo notebook

- Overfitting
 - Use cross-validation
- Hyper-parameter (regularisation) optimisation
 - Nested cross-validation (for finding the best regularization parameter)
- Using the mTRFpy toolbox

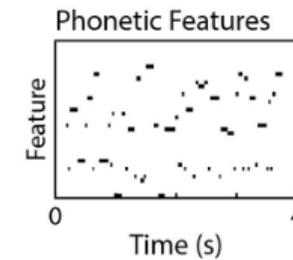
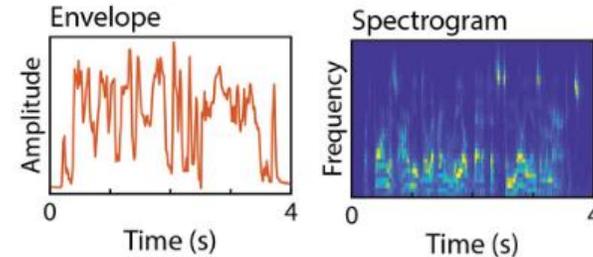
Multivariate TRFs

- Using more than one stimulus feature at once
 - E.g. separate frequency bands of a spectrogram
- Still mass-univariate



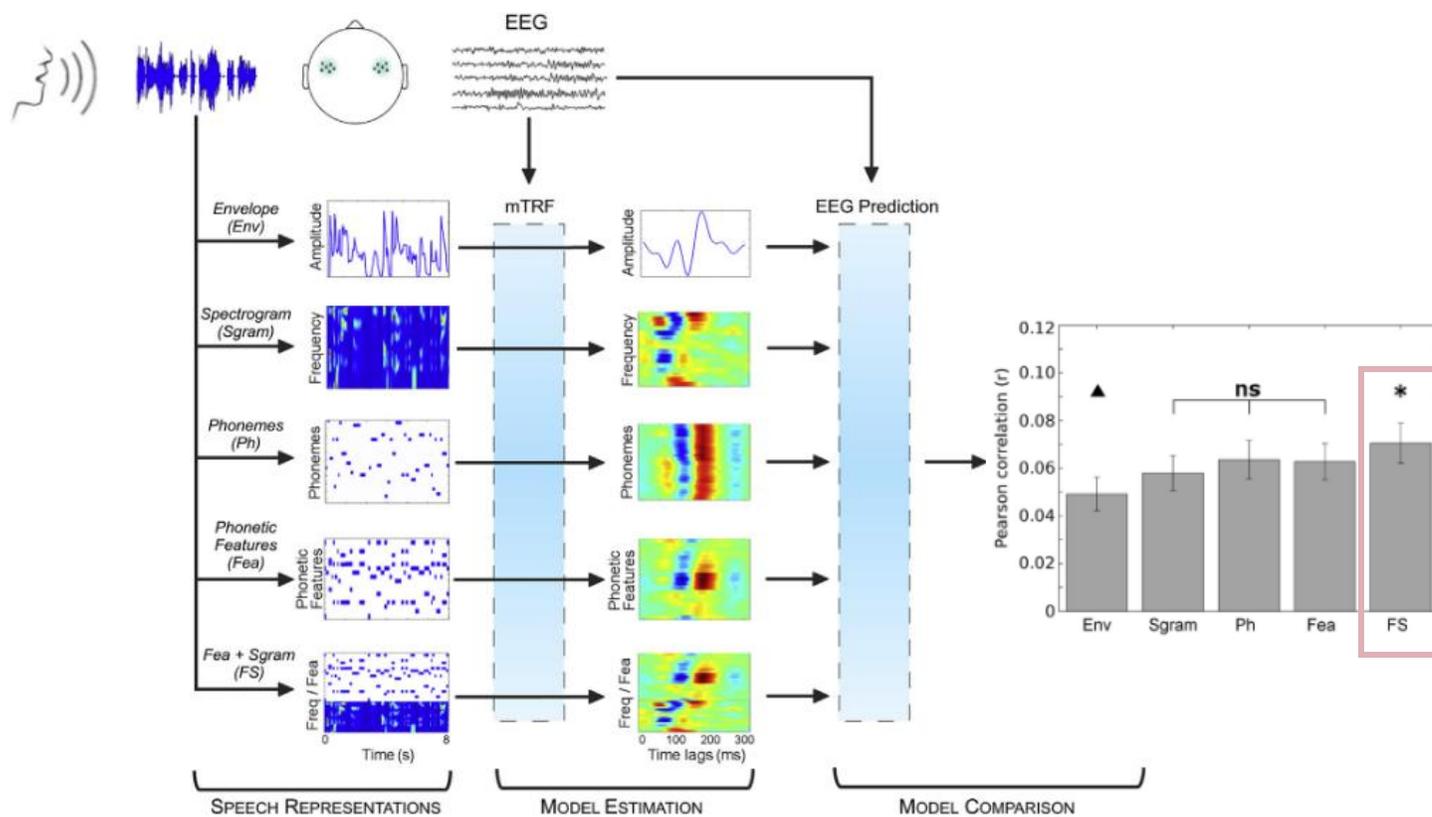
Stimulus features

- Continuous:
 - Speech envelope, spectrogram
 - Auditory motion, visual contrast
- Discreet:
 - Phonetic features, visemes
 - Onsets (segment, phoneme, word, phrase etc.)
 - Lexical information (phonetic surprisal, entropy)
 - Auditory temporal coherence

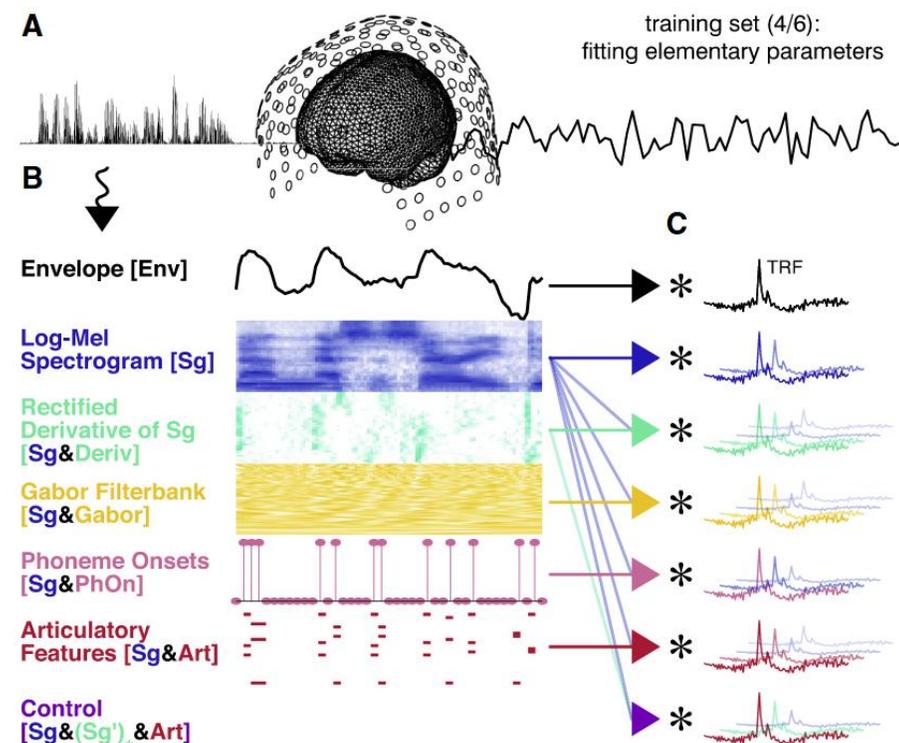


Do linguistic features exist in the brain?

YES!

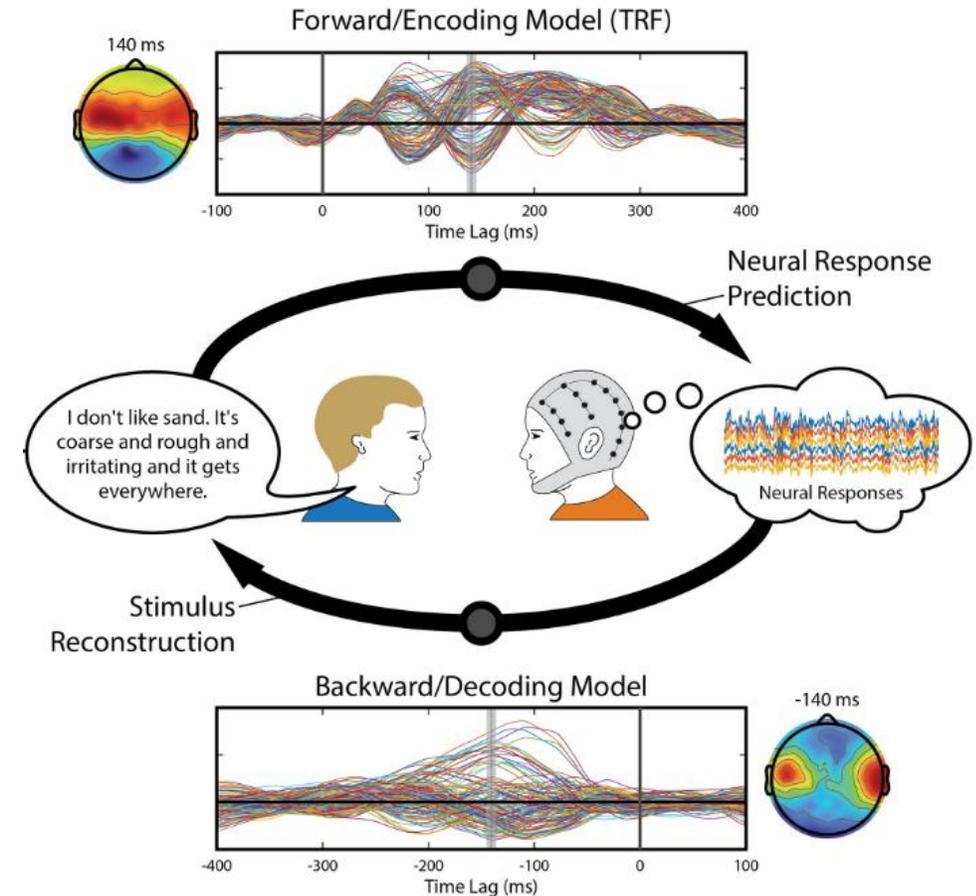


Hmm, maybe not...



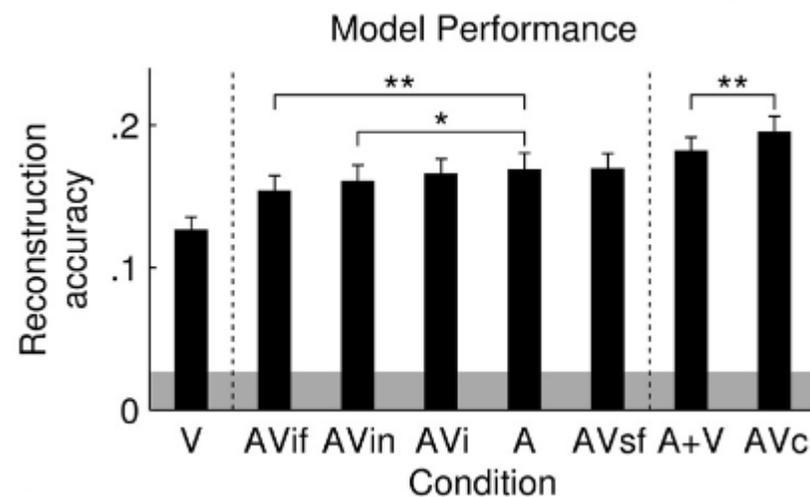
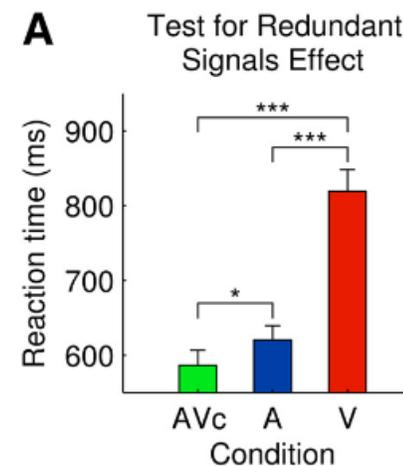
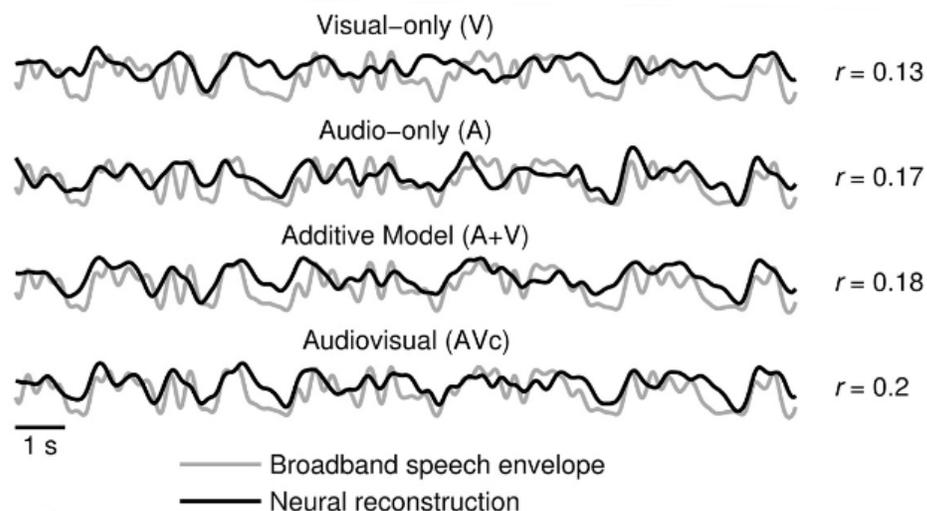
Backwards TRFs - Decoding

- Reversing the system now from response to stimulus
- Reconstructing the stimulus from all the neural responses
- Advantages to forward TRFs
 - Multivariate all responses taken into consideration at once
 - No response pre-selection required
 - Reconstruction accuracy usually higher than forward
- Recommended only to use continuous stimulus features
- Backwards TRFs need to be transformed



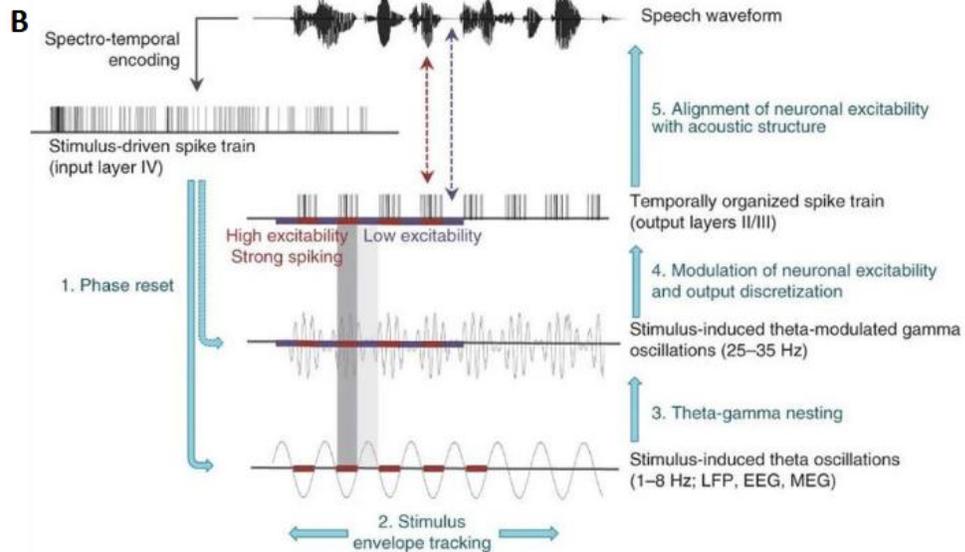
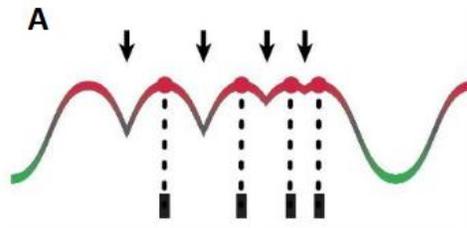
TRF decoding example

Condition	Stimuli	
	Audio	Video
A	Male speaker	Black screen with gray fixation crosshair
V	None	Male speaker
AVc	Male speaker	Congruent male speaker
AVi	Male speaker	Incongruent male speaker

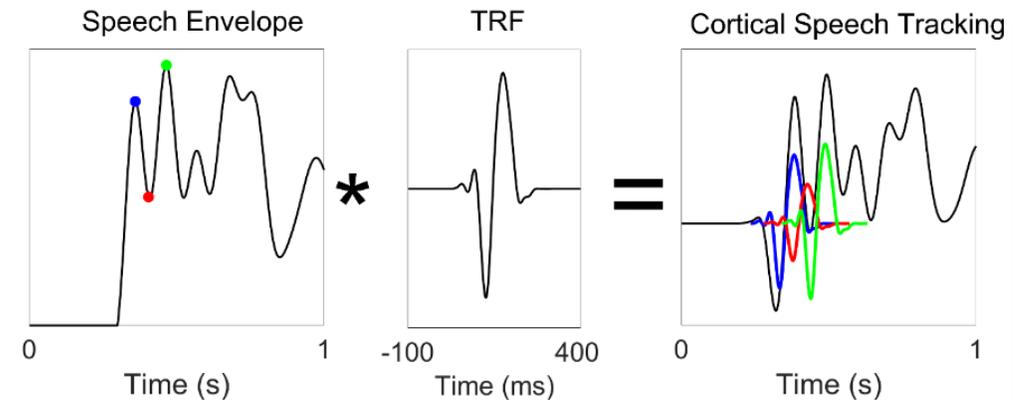


Implications on theories of speech tracking in the brain

Intrinsic oscillations



Evoked responses



Resources

- Toolboxes
 - [mTRF toolbox](#) (MATLAB)
 - [mTRFpy toolbox](#) (python version)
 - [Eelbrain toolbox](#) (using boosting instead of Ridge regression)
- [CNSP workshop](#)



MRC Cognition
and Brain
Sciences Unit



UNIVERSITY OF
CAMBRIDGE

Thank you

MRC Cognition and Brain Sciences Unit

 @MRCCBU

mrc-cbu.cam.ac.uk