



April, 2024

# Decoding Brain Signals



Speaker: Boi Mai Quach

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Agenda

- ❖ Introduction
- ❖ Hypothesis and Reasons
- ❖ Decoding Techniques
- ❖ Questions and Answers

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Introduction

HOST INSTITUTIONS

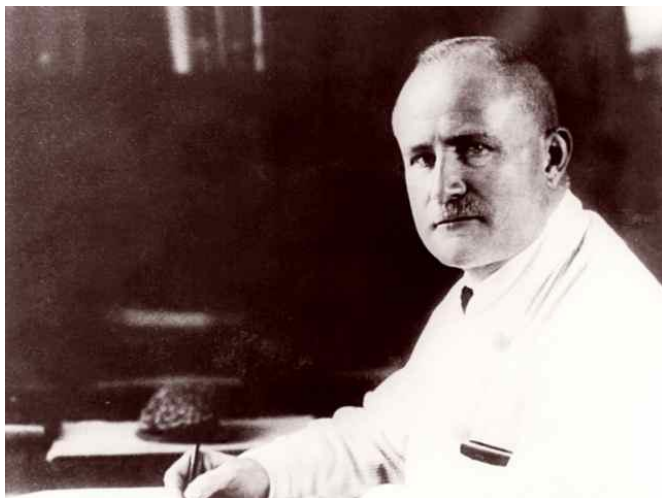


University College Dublin  
An Colaiste Oilscoile, Baile Átha Cliath

FUNDED BY:



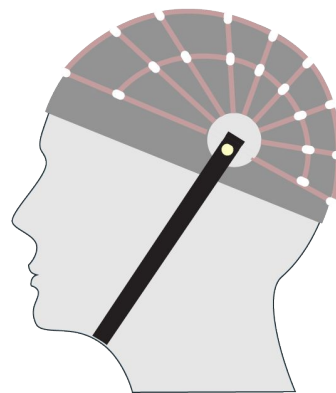
# Brain Signal Understanding - EEG



1929

Hans Berger developed Electroencephalography, the graphic representation of the difference in voltage between two different cerebral locations plotted over time.

**PO7 = (PO7 - Ground) - (Cz - Ground)**



Sources:

[https://en.wikipedia.org/wiki/Hans\\_Berger#/media/File:HansBerger\\_Univ\\_Jena.jpeg](https://en.wikipedia.org/wiki/Hans_Berger#/media/File:HansBerger_Univ_Jena.jpeg)

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# A crazy, ridiculous idea

What you are thinking, imaging in your mind can be decoded from the pattern of electrical activity on the scalp.



# What is a brain decoding model?

The purpose of brain decoding models is to align the cognitive feedback to stimulus representations. Therefore, they can generate a stimulus output using neural patterns.

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Decoding Animation



Video by Edward del Rosario/Washington University School of Medicine: Decode neural signals to determine what image the person was seeing.

HOST INSTITUTIONS

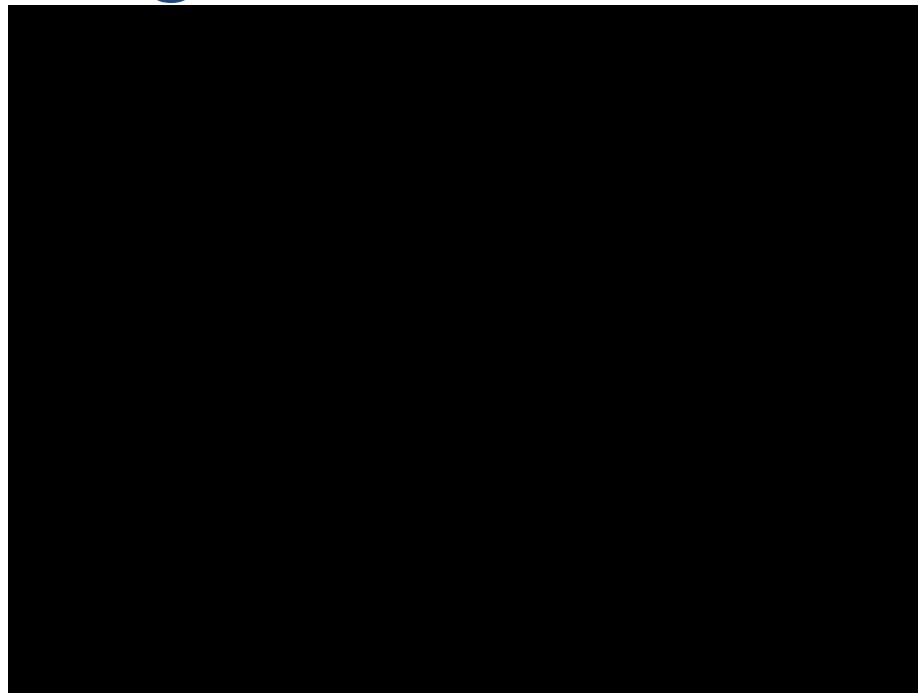


University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Decoding Images



The images that volunteer participants see (left) and those decoded from MEG activity at each instant of time (right). Each image is presented approximately every 1.5 seconds.

HOST INSTITUTIONS



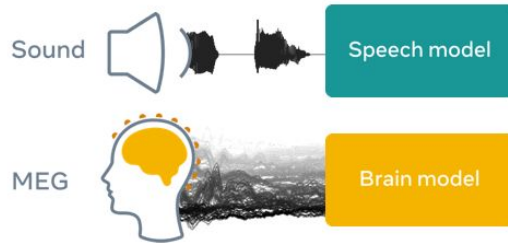
University College Dublin  
An Coláiste Ollscoile, Baile Átha Cliath

FUNDED BY:





# Decode speech from brain activity



Source: <https://ai.meta.com/blog/ai-speech-brain-activity/>

HOST INSTITUTIONS

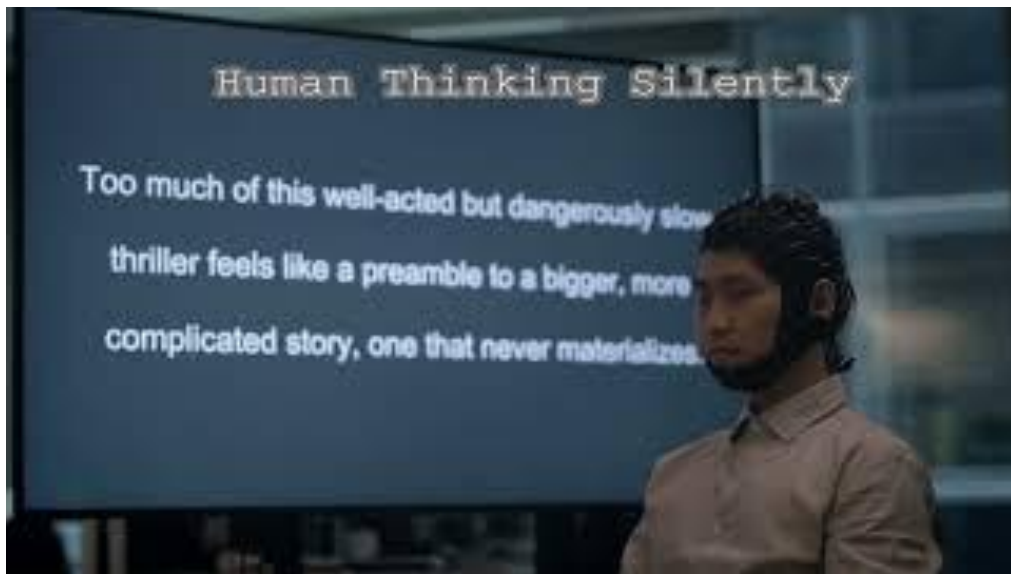


University College Dublin  
An Colaiste Oilscoile, Baile Átha Cliath

FUNDED BY:



# Decoding Sentences



Researchers from the GrapheneX-UTS Human-centric Artificial Intelligence Centre have developed a portable, non-invasive system that can decode silent thoughts and turn them into text.

HOST INSTITUTIONS

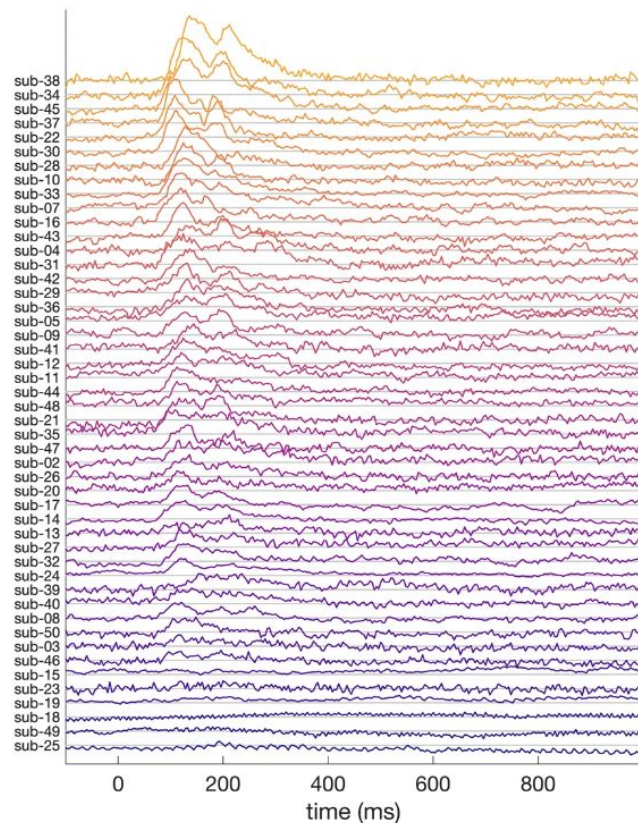


University College Dublin  
An Coláiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# EEG-based Image experiment



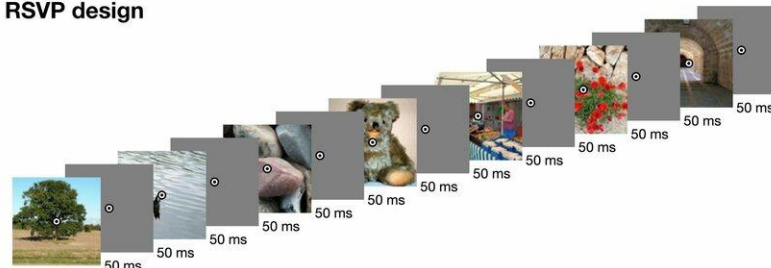
a Example images



b EEG setup



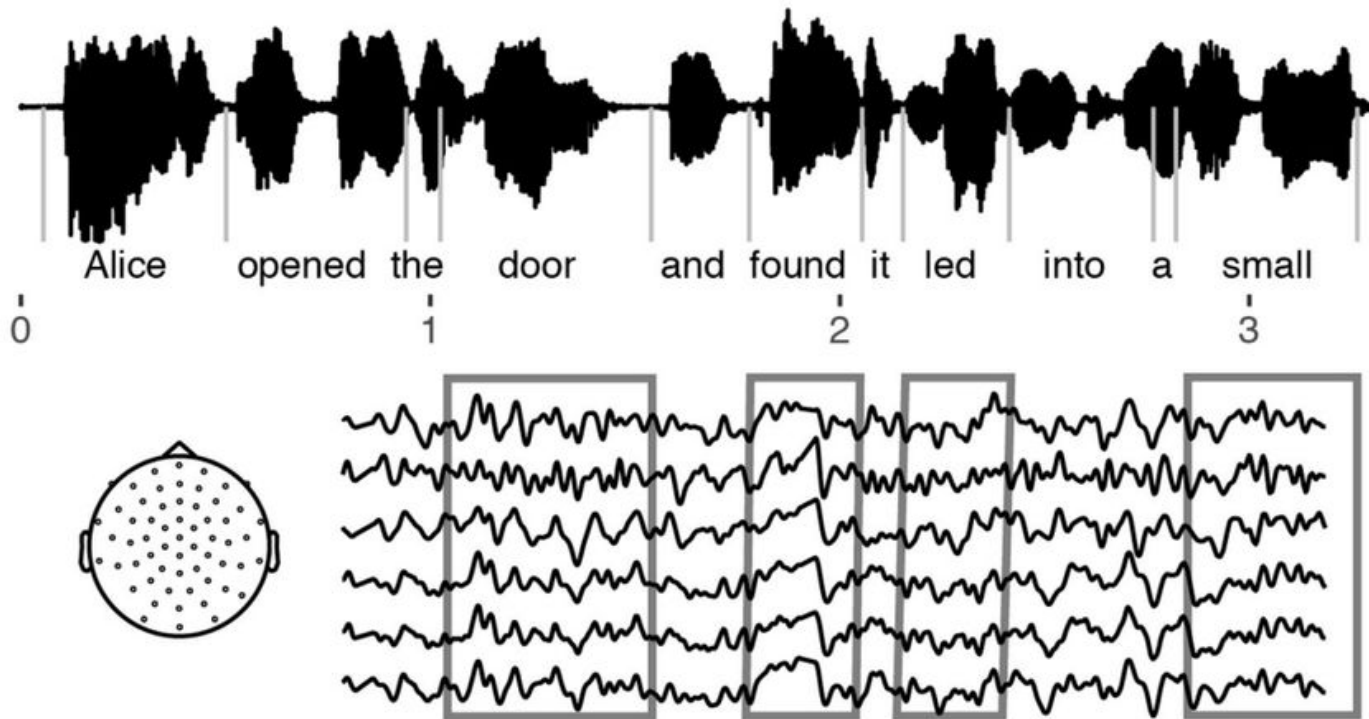
c RSVP design



Source: From PublicDomainPictures.net: Brunhilde Reinig and the paper at DOI: [10.1038/s41597-021-01102-7](https://doi.org/10.1038/s41597-021-01102-7)



# EEG-based audio experiment



Source:

<https://shizacharania.notion.site/EEG-x-Natural-Speech-Correlation-Papers-e2c98f2ed0d9401f90515084ae3d9245>

HOST INSTITUTIONS



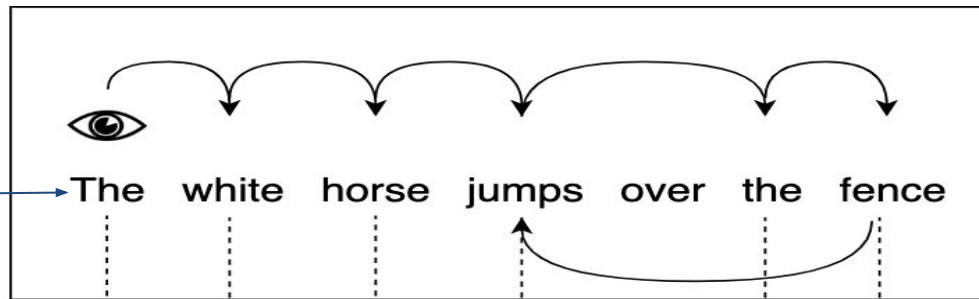
University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:

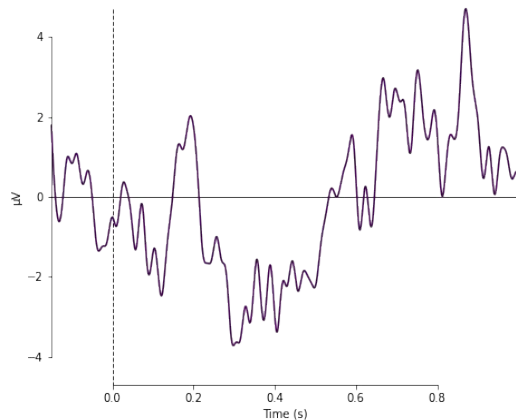
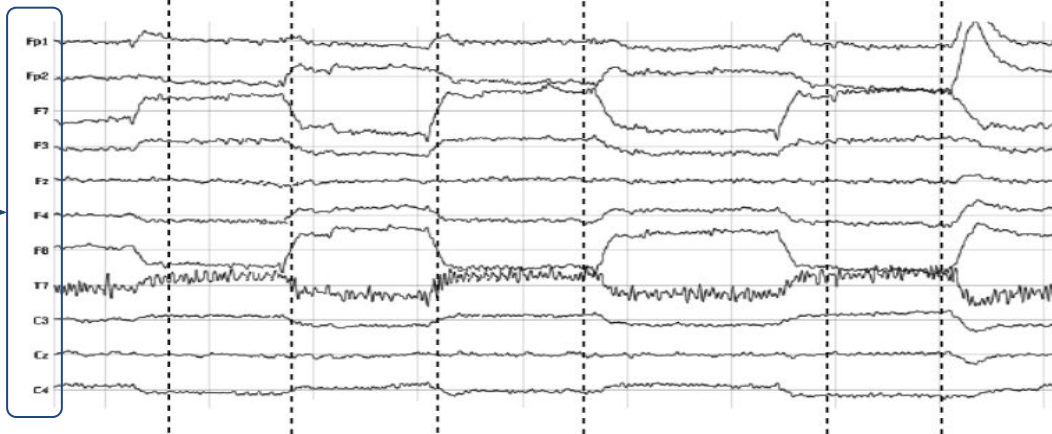


# EEG-based reading experiment

stimulus



Electrodes/  
Channels



HOST INSTITUTIONS

FUNDED BY:

# Hypothesis and Reasons

HOST INSTITUTIONS



University College Dublin  
An Colaiste Oilscoile, Baile Átha Cliath

FUNDED BY:



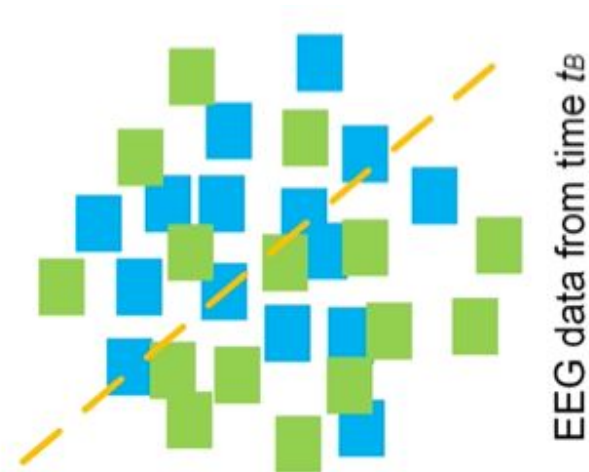


# Images - Shoe and Bottle

*shoe* vs. *bottle*



Higher classification accuracy



Lower classification accuracy

The representational differences between shoe and bottle were more strongly encoded at  $t_A$

# ML Classification

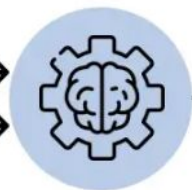
Labeled Data



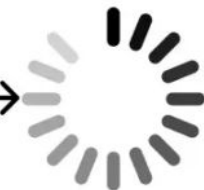
Lables



Model  
Training



Prediction



Test Data

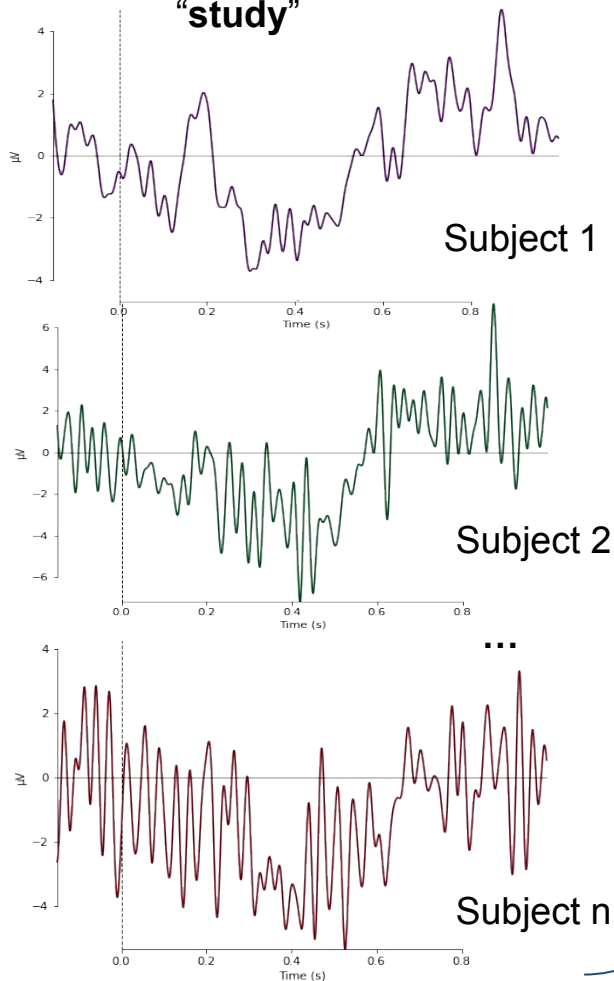


Dog

Cat



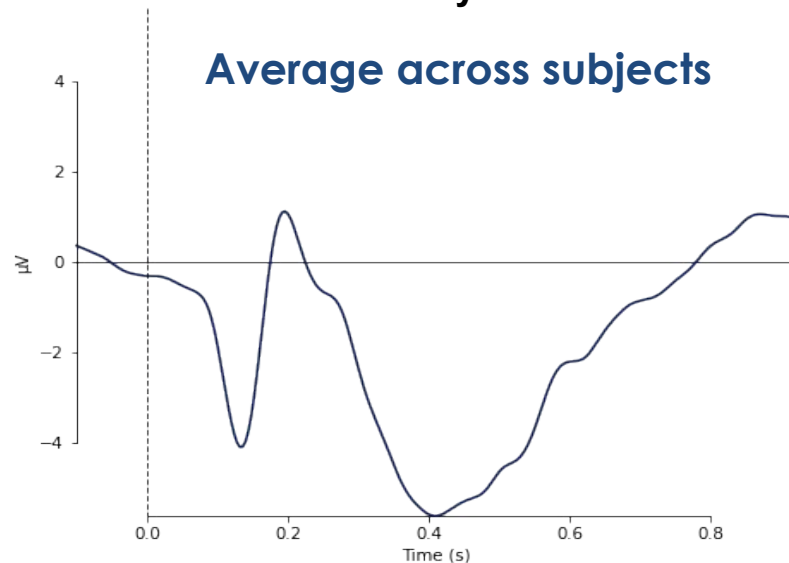
**“study”**



## Event-related Potential (ERP)

**“study”**

**Average across subjects**

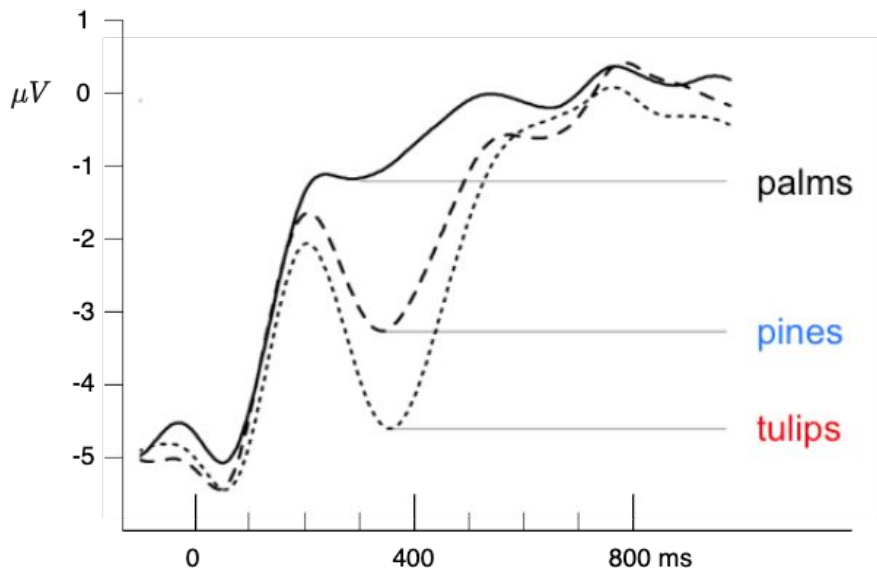


# ERPs to next-word prediction

“They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of palms/ pines/ tulips.”

palms / pines / tulips

[tree] / [tree] / [flower]



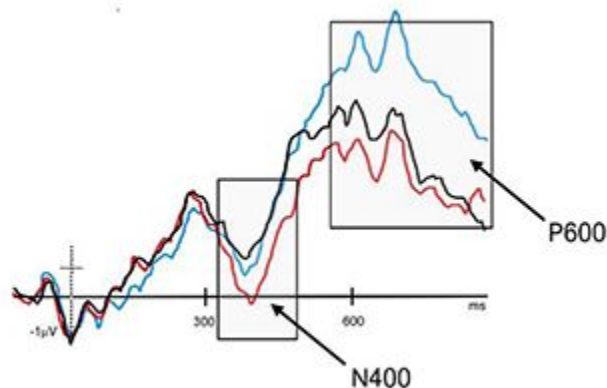
- Expected word.

- Unexpected within-category violation

- Unexpected between-category violation

**Source:** Federmeier & Kutas (1999). A rose by any other name:  
Long-term memory structure and sentence processing. *Journal of  
memory and Language*

# ERPs to next-word prediction



The door had been **locks**.  
The famous chef was **outlining**.  
A better salary was **negotiated**.

- Syntactic violation
- Semantic violation
- No violation

**Conclusion:** More surprising words result in more negative N400s

**Source:** Example of N400 (semantic violation) and P600 (syntactic violation). Positivity plotted upwards. Adapted from “Syntactic anomaly elicits a lexico-semantic (N400) ERP effect in second language but not the first”, by K. Weber and A. Lavric, 2008, *Psychophysiology*.

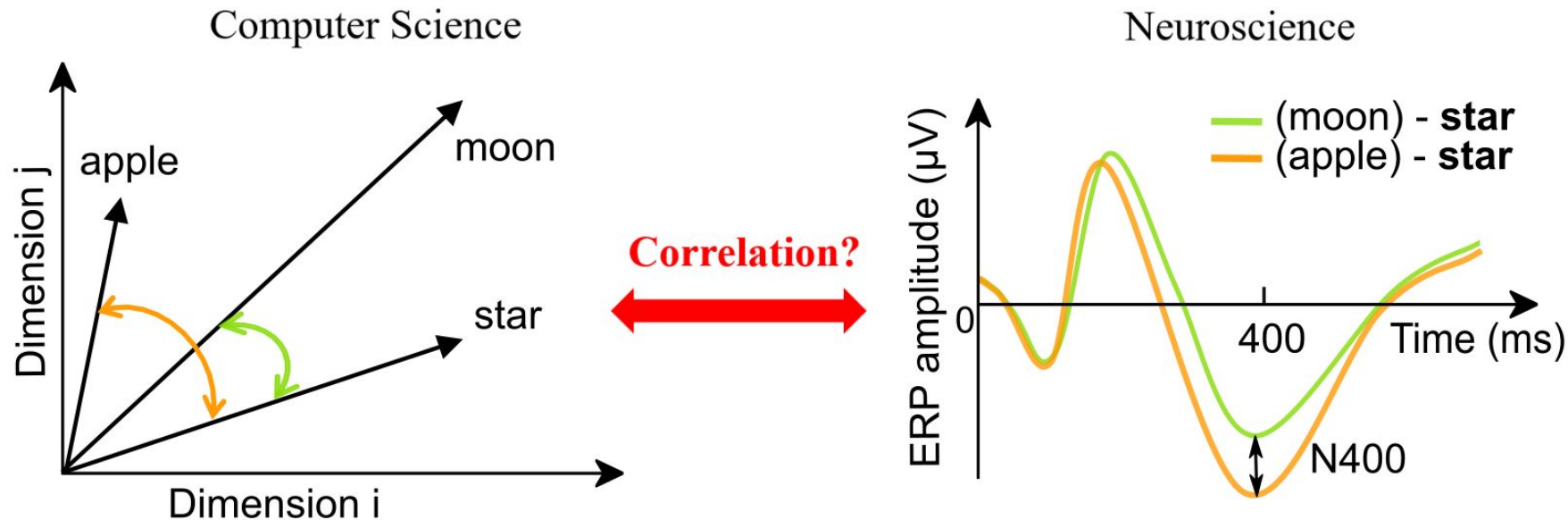
Brain

Once upon a ...

Algorithm

Once upon a ...

# Neural correlates of word representation vectors



# Two Different Goals of Brain Decoding

Decoding for prediction	Decoding for understanding
Don't care what underlying activity underlies the decoding (or even whether it comes from the brain)	Nature of signals underlying the decoding is fundamentally important
High accuracy is essential	Can be informative even if accuracy is barely above chance
Stability over time is usually important	Training and testing are usually done from the same session, so longer-term stability is not an issue
Single-trial decoding is usually necessary	Not usually important to decode from single-trial data

# Decoding Techniques

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Classification-based Decoding

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:





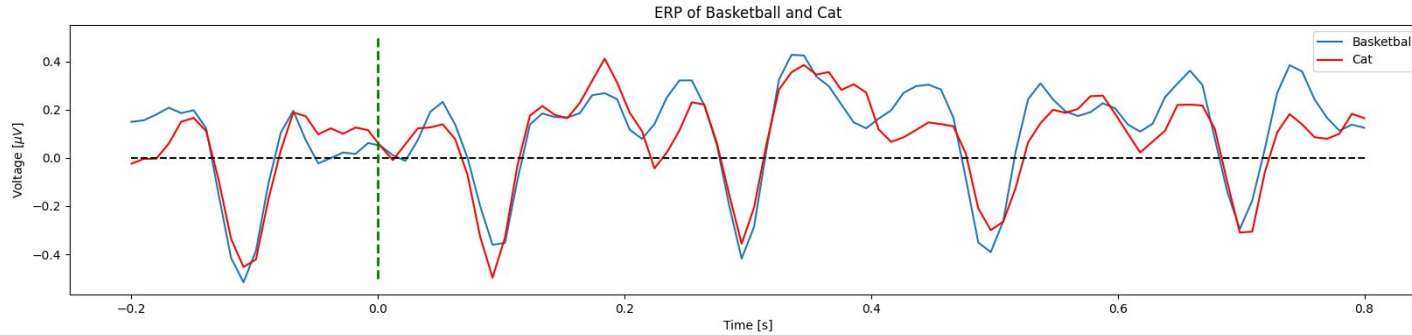
# Binary Classification - Basketball and Cat



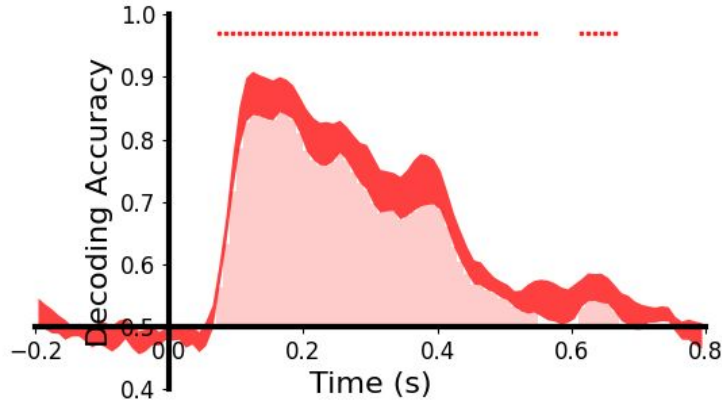
Can we decode which image contains cat or basketball?

- 10 subjects (participants)
- Total of 160 trials for each subject: 80 basketball and 80 cat images.
- Presented in random order
- 17 electrodes were recorded
- Sample frequency = 100 Hz
- Duration: -200 ms to 800 ms

# Binary Classification - Basketball and Cat



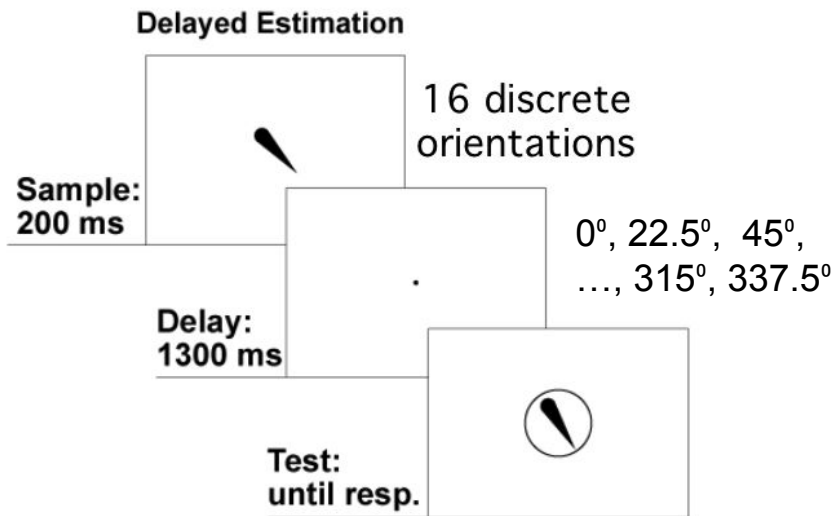
Barely any ERP difference  
between basketball and cat  
images



Decoding accuracy is very  
high relative to Standard  
Error of Mean (SEM)



# Multiclass Decoding - Working Memory



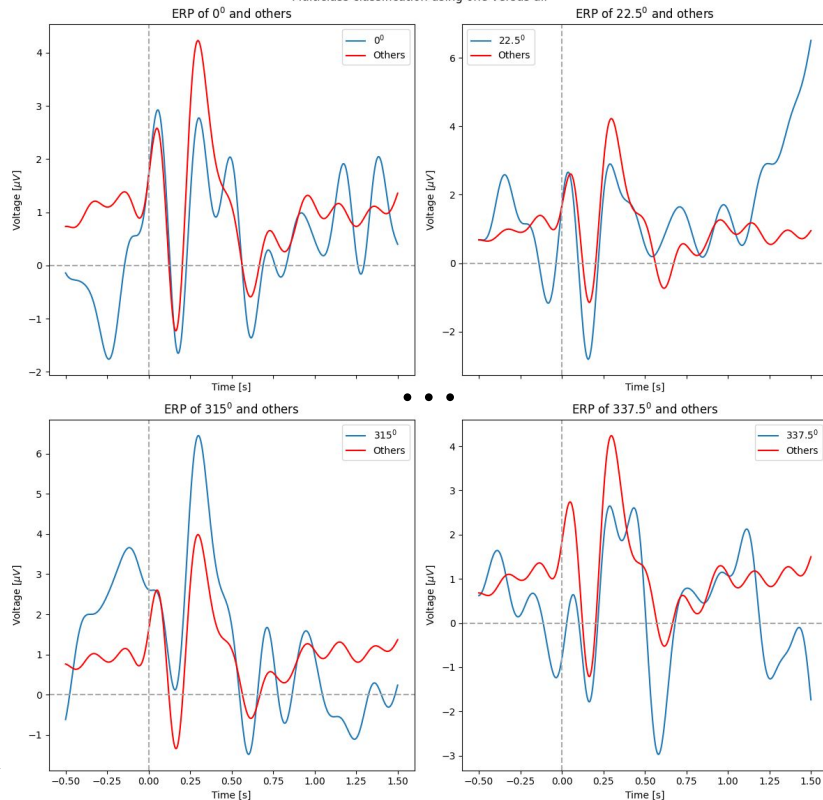
Could we decode exactly which one of these 16 orientations was present?

- 5 subjects (participants)
- Total of 640 trials.
- Presented in random order
- 27 electrodes were recorded
- Sample frequency = 500
- Duration: -500 ms to 1500 ms

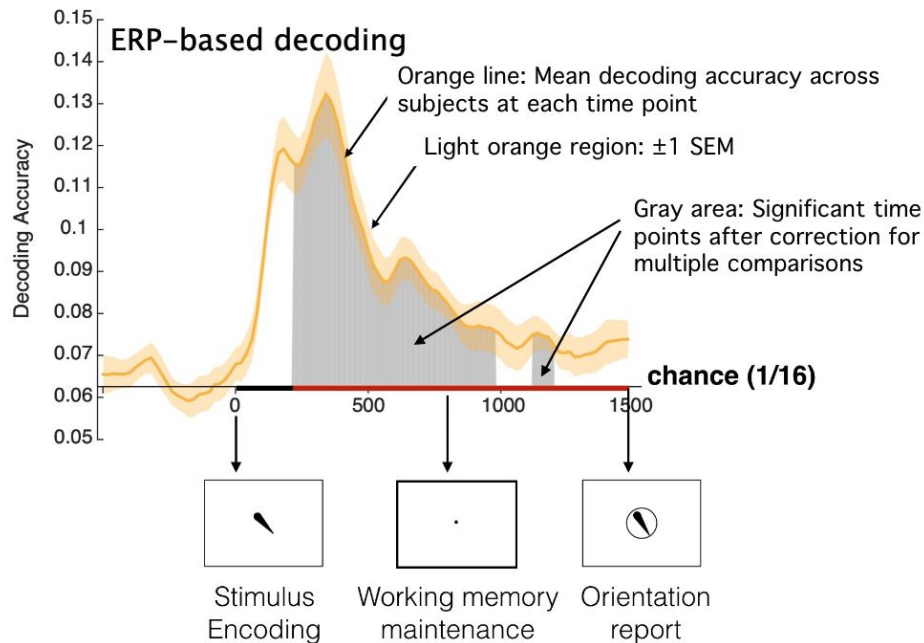
Bae and Luck, JNeuro, 2018

# Orientation representation

Multiclass classification using one versus all

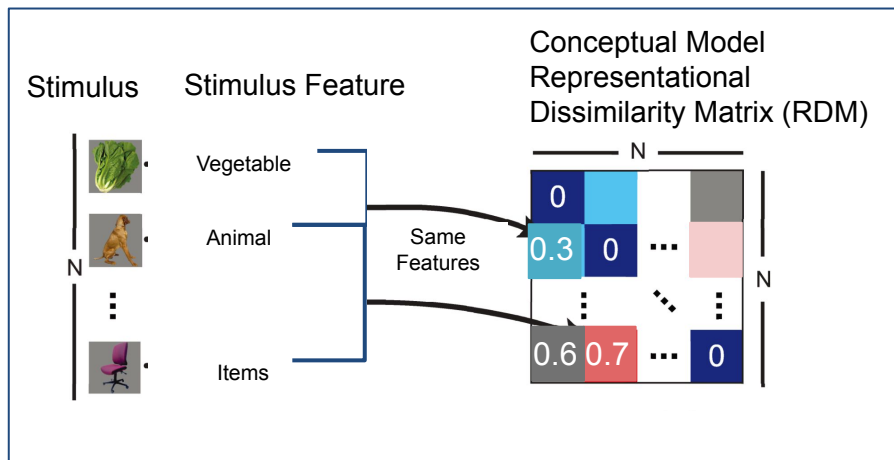
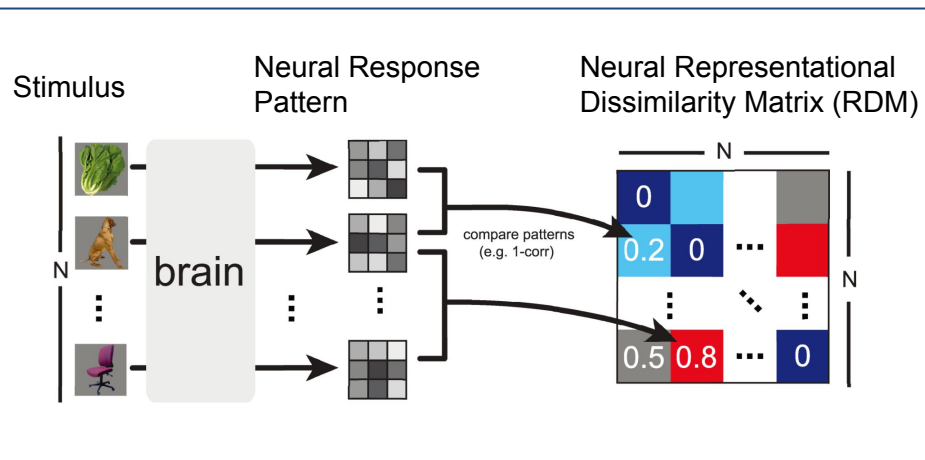


## Decoding Results



Bae & Luck (2018, J Neuroscience)

# RSA-based Decoding

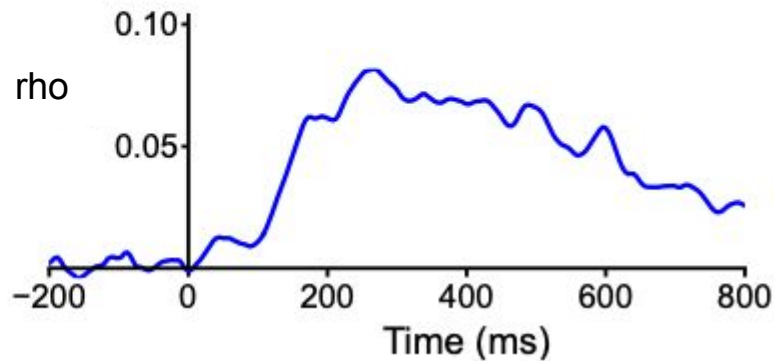
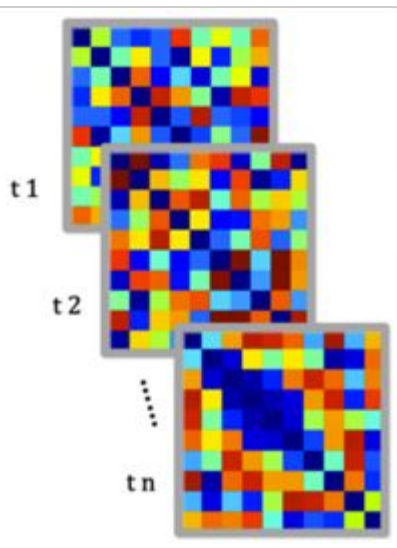


# Compare between Hypothesis-based RDM and neural RDM

Hypothesis-based  
RDM



Time-by-time EEG  
RDMs



Source: NeuroRA

HOST INSTITUTIONS

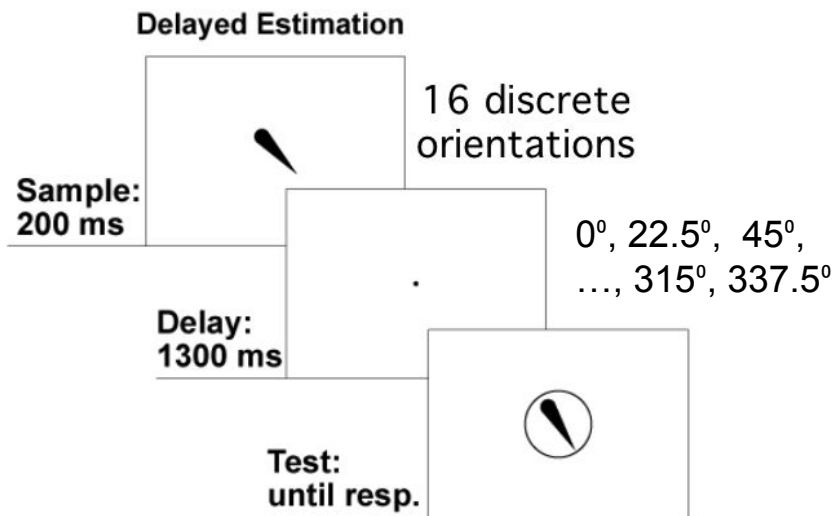


University College Dublin  
An Coláiste Ollscoile, Baile Átha Cliath

FUNDED BY:



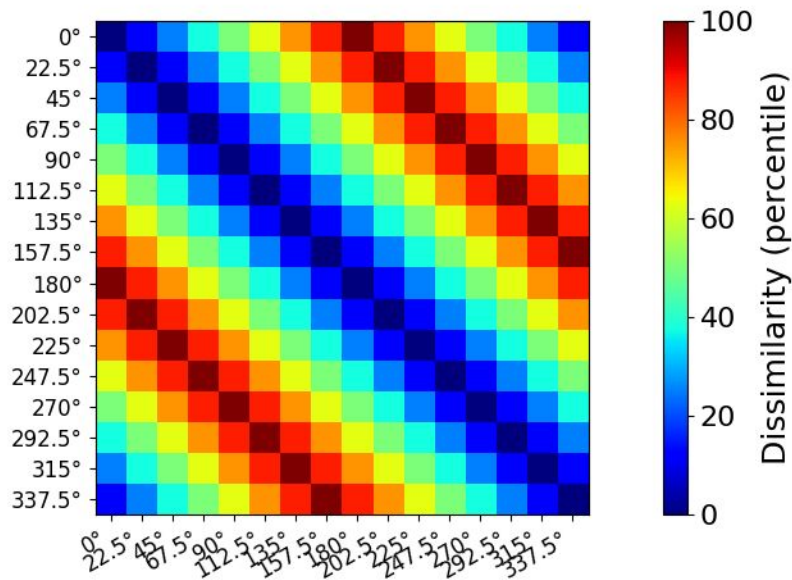
# Working Memory



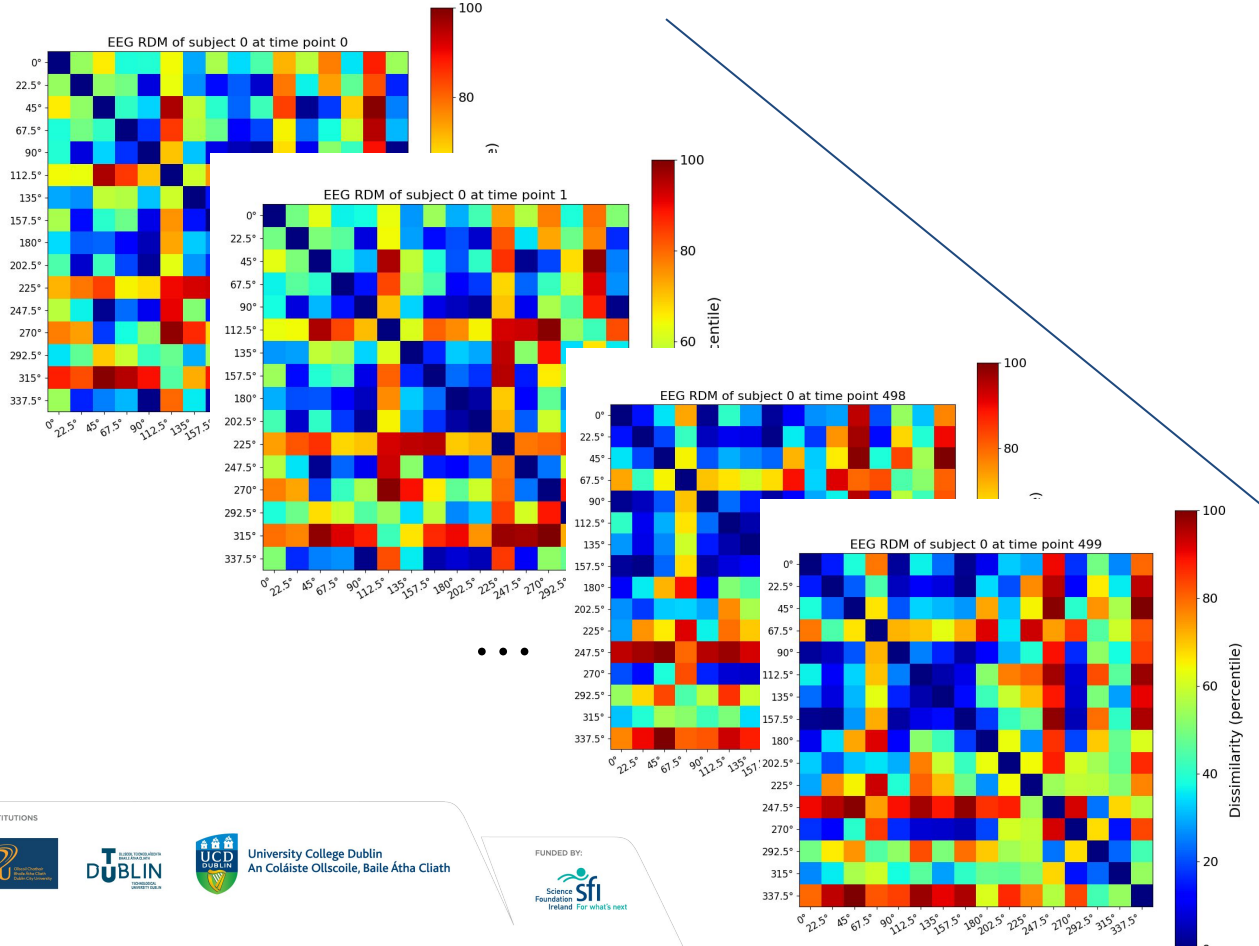
Bae and Luck, JNeuro, 2018

How to use RSA to decode 16 orientations from EEG?

## Hypothesis-based orientation RDM



# EEG Representational Dissimilarity Matrices



Time points

HOST INSTITUTIONS



University College Dublin  
An Coláiste Oilescóla, Baile Átha Cliath

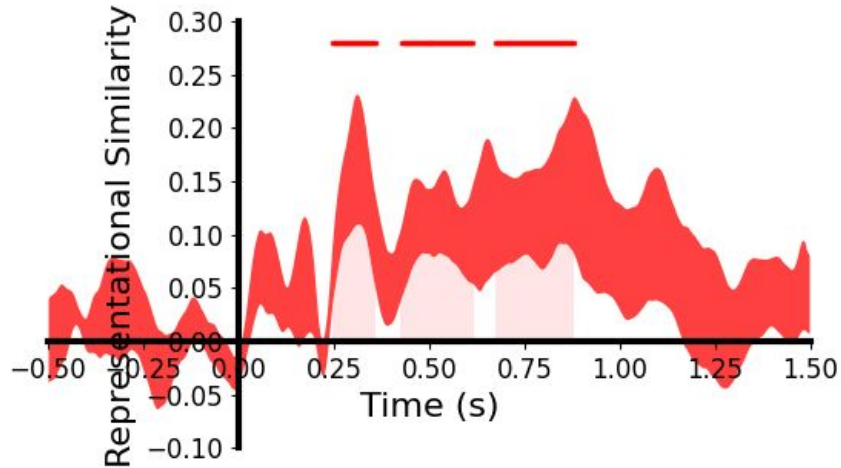
FUNDED BY:



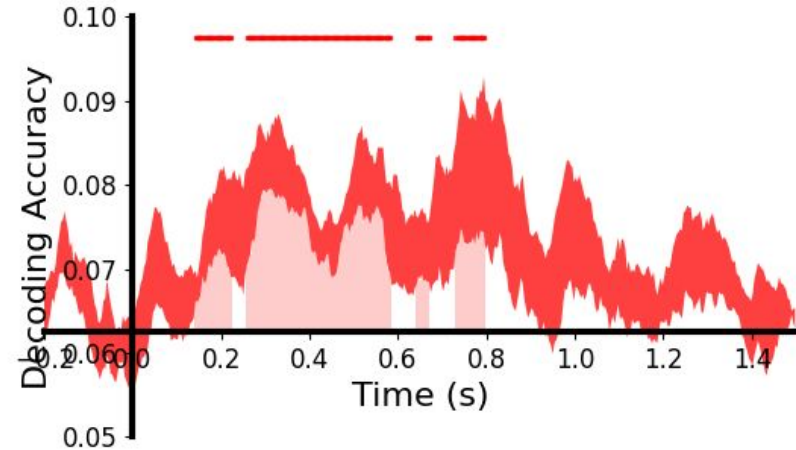


# RSA-based decoding result

## RSA-based decoding



## Classification-based decoding



# Thank you!

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:



# Discussion

HOST INSTITUTIONS



University College Dublin  
An Colaiste Ollscoile, Baile Átha Cliath

FUNDED BY:

