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Decoding Brain Signals

ML Labs

April, 2024

Speaker: Boi Mai Quach

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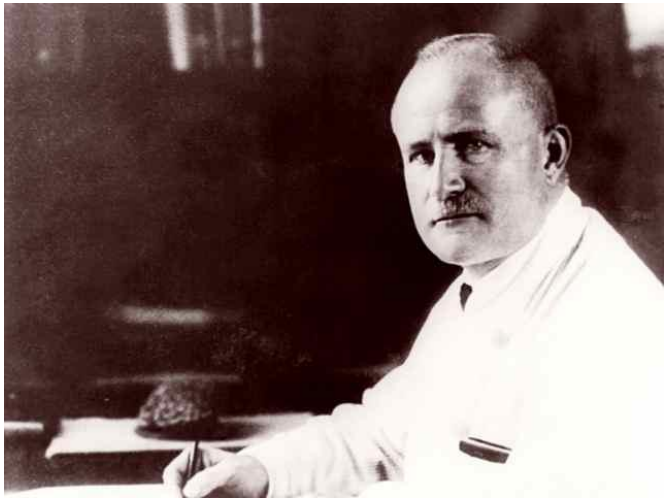
Agenda

- Introduction
- Problems
- Solutions
- Questions and Answers

Introduction

Brain Signal Understanding - EEG

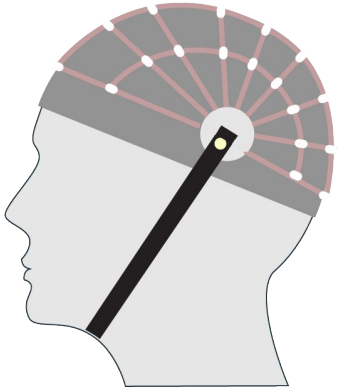


Sources:
https://en.wikipedia.org/wiki/Hans_Berger#/media/File:HansBerger_Univ_Jena.jpeg

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)



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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.

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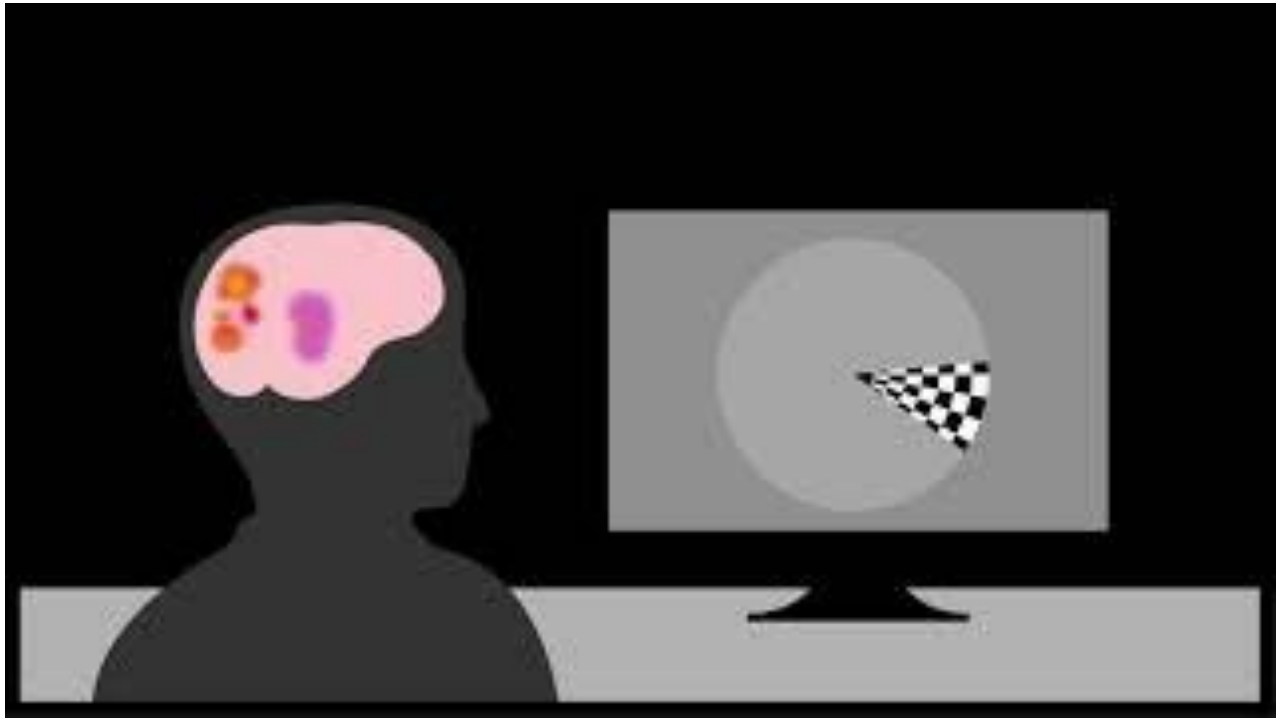
Decoding Animation



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

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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.

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Speech Synthesized from Brain Activity

Video by Chang lab / UCSF Dept. of Neurosurgery; Simulated Vocal Tract Animation Credit by Speech Graphics
Chang lab/UCSF Dept. of Neurosurgery

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Decoding Sentences

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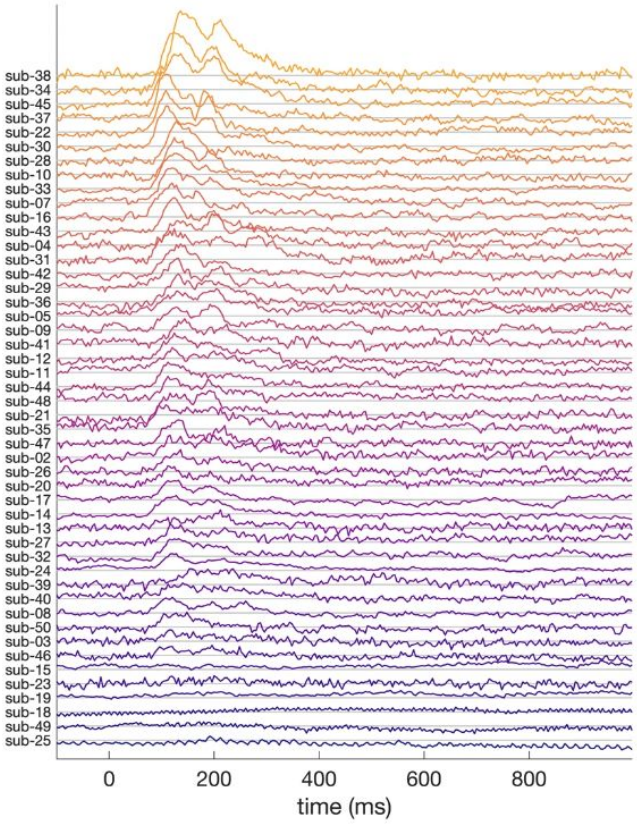
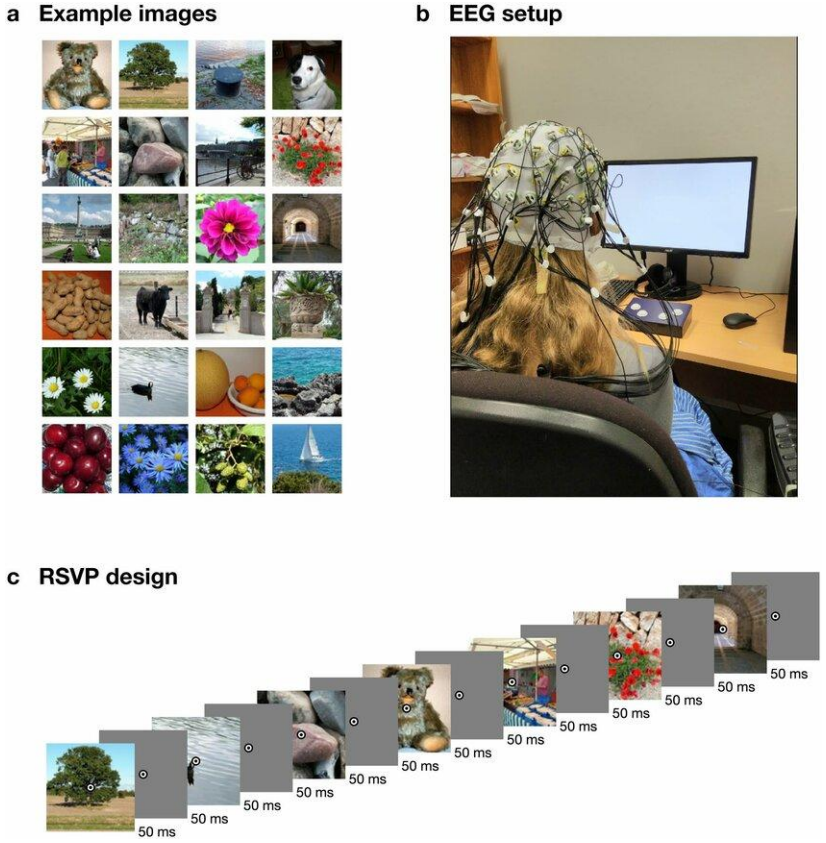
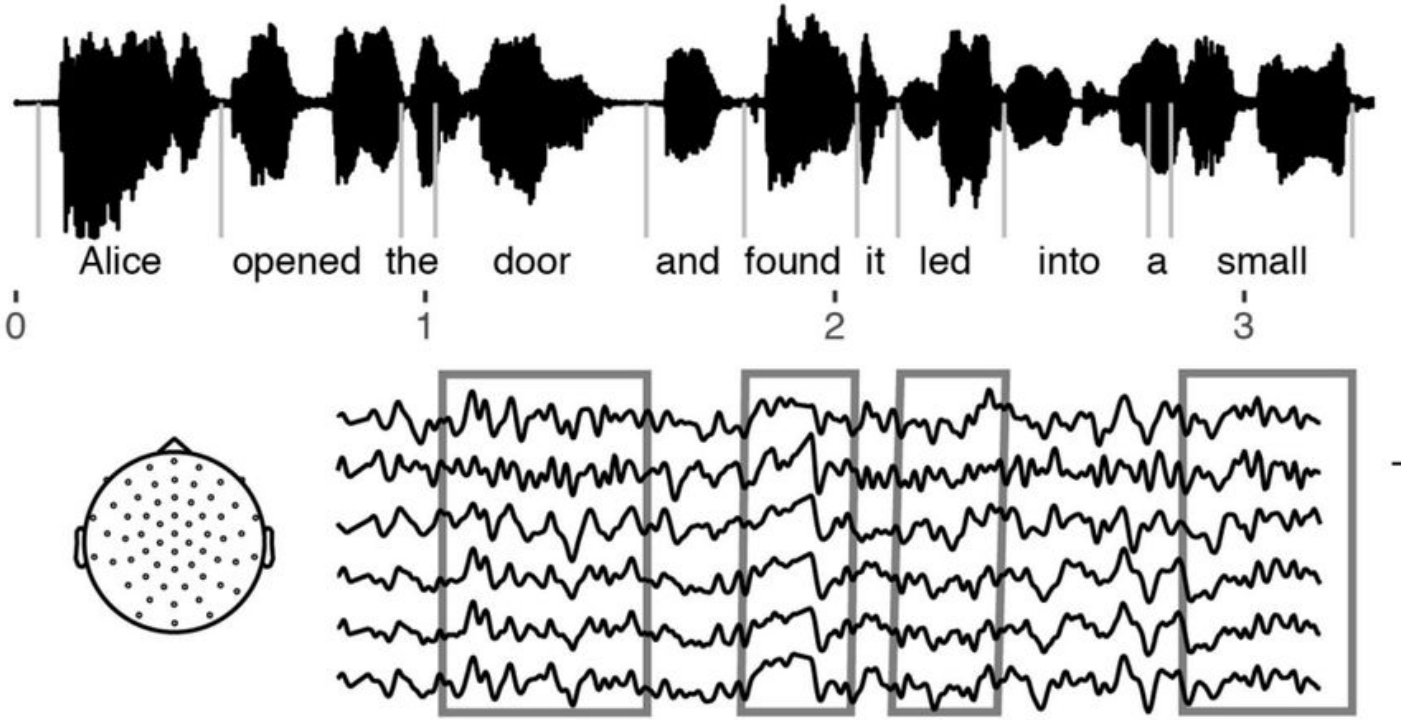
EEG-based Image experiment





Source: From PublicDomainPictures.net: Brunhilde Reinig and the paper at DOI:10.1038/s41597-021-01102-7

EEG-based audio experiment



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

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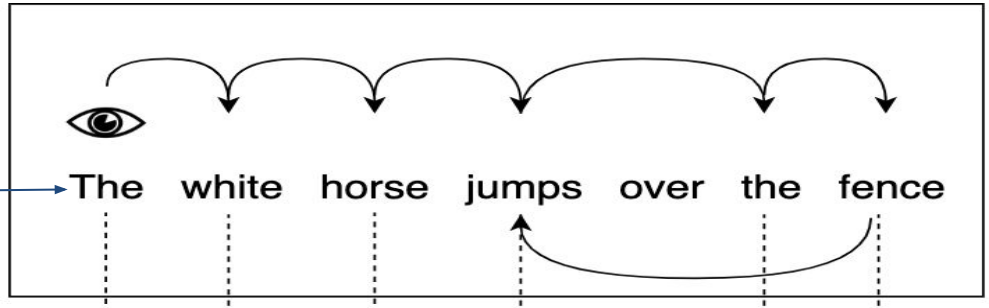
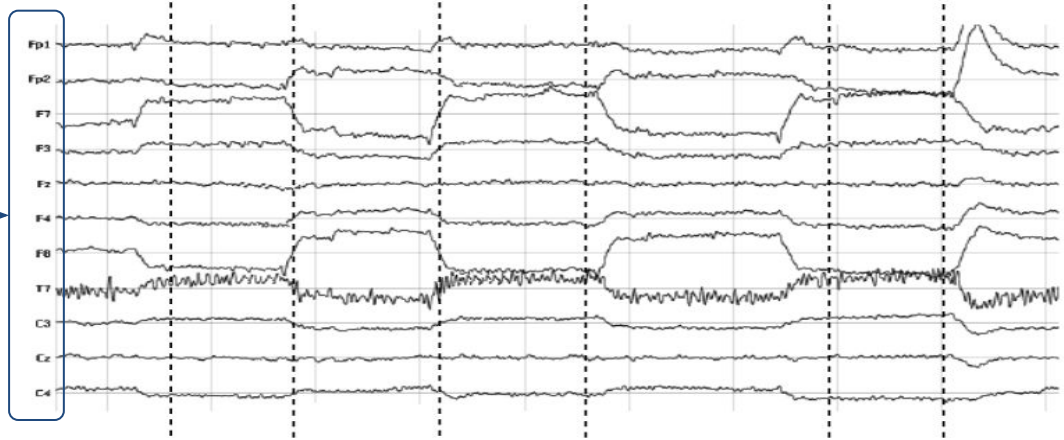
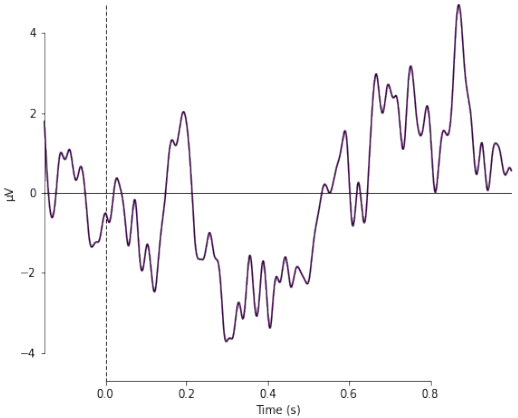
EEG-based reading experiment

stimulus →



Electrodes/ Channels →

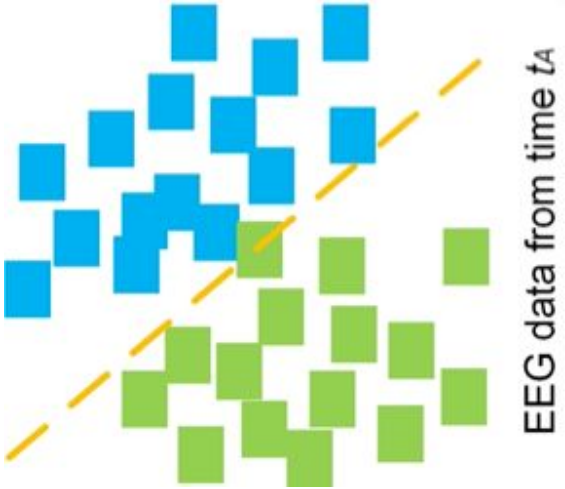




Problems/Hypothesis

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

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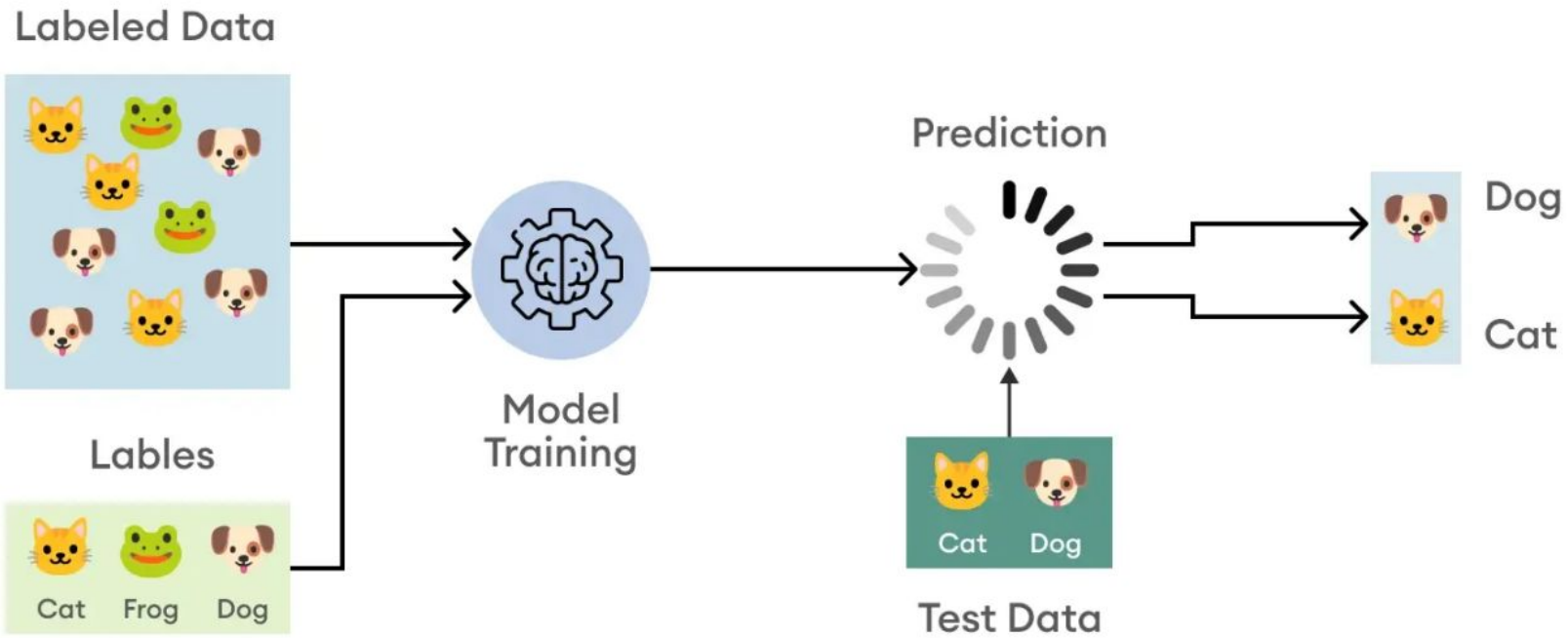
ML Classification



Source: https://www.linkedin.com/pulse/types-ml-classification-algorithms-hari-narayanan-p2lqc/

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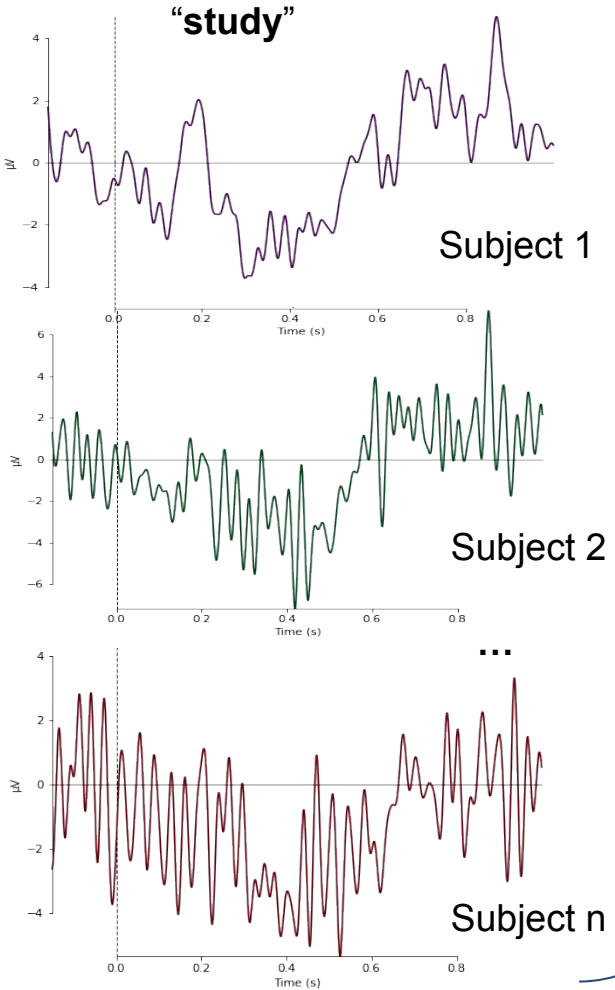
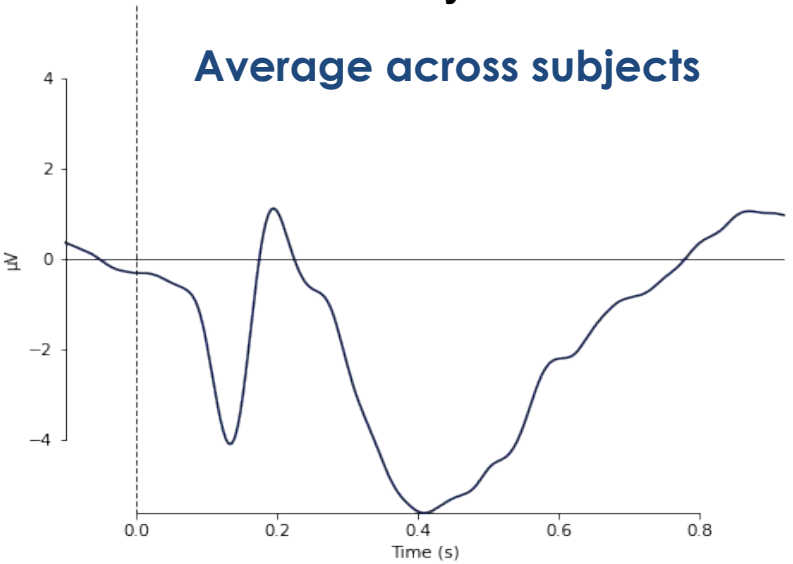
EEG - Text and Audio



Event-related Potential (ERP)

"study"

Average across subjects

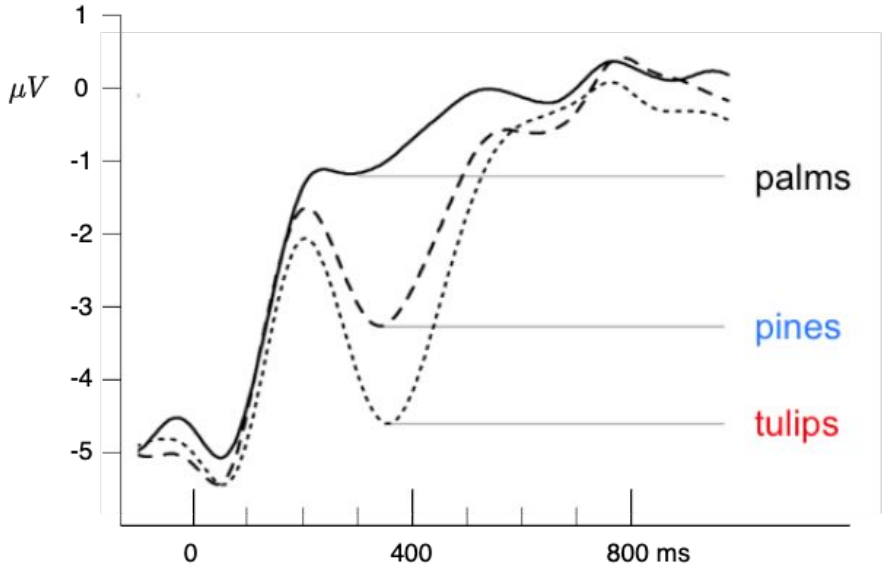


ERPs to next-word prediction

"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

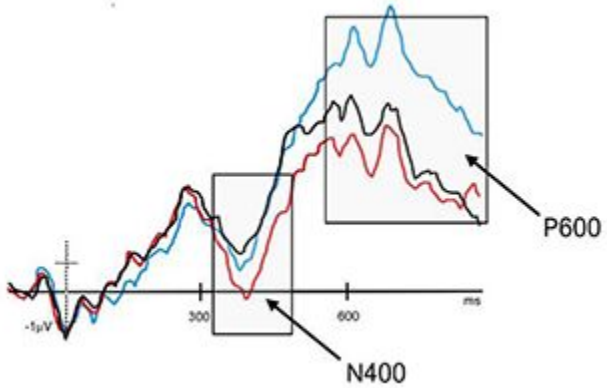
[tree] / [tree] / [flower]



- palms - Expected word.
- pines - Unexpected within-category violation
- tulips - 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

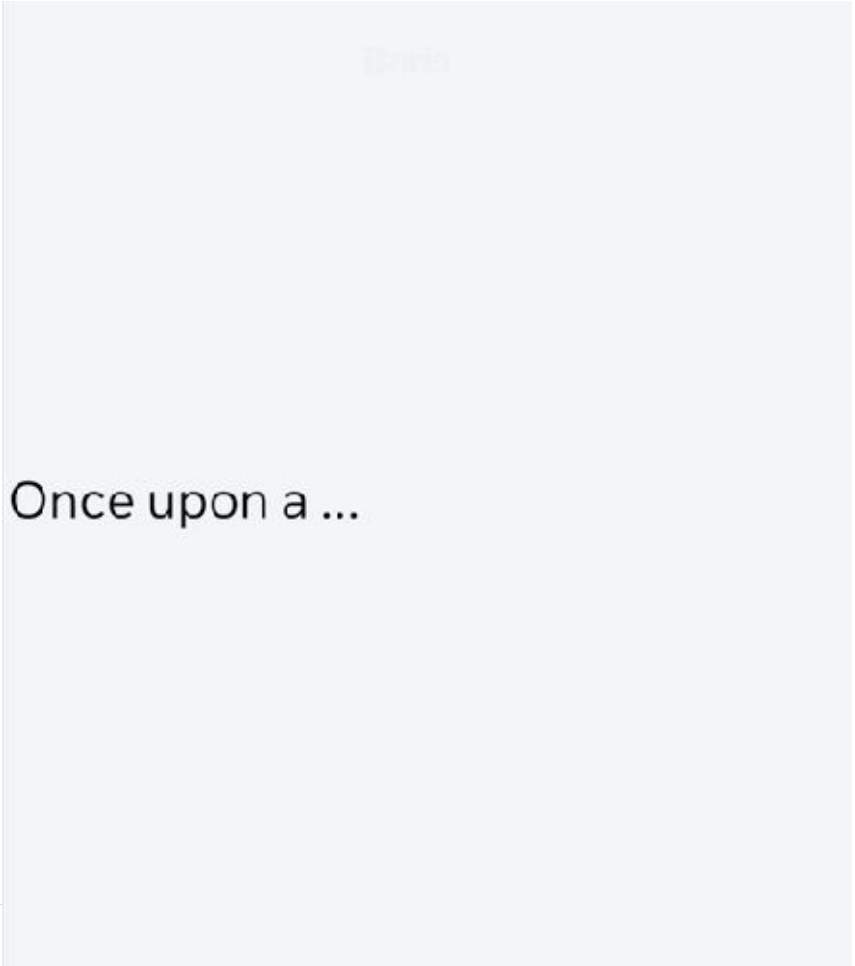


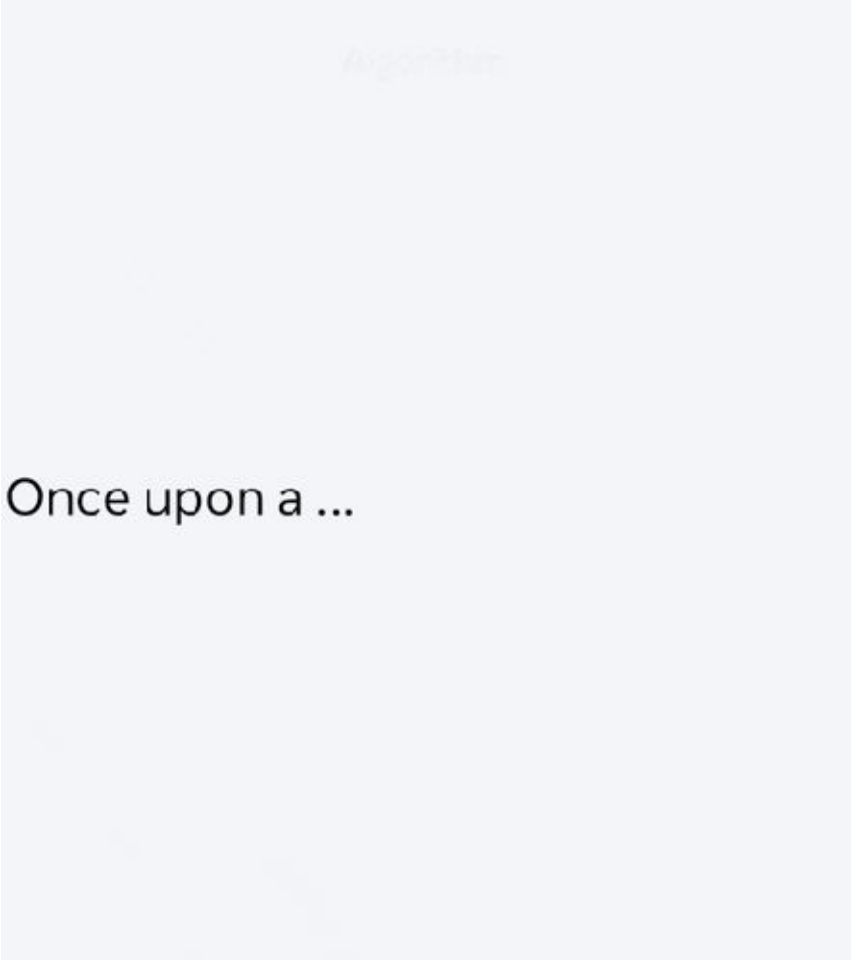
The door had been **locks**.
The famous chef was **outlining**.
A better salary was **negotiated**.

Syntactic violation
Semantic violation
No violation

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

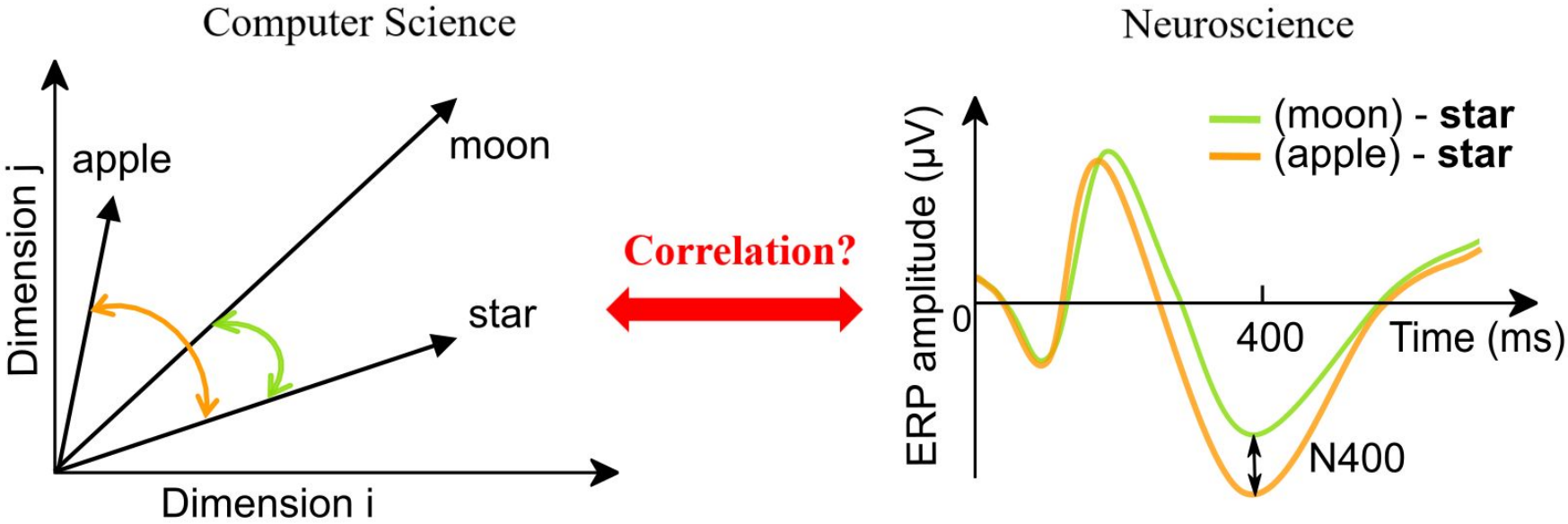
Source: Example of N400 (semantic violation) and P600 (syntactic violation). Positivity plotted upwards. Adapted from "Syntactic anomaly elicits a lexico-semantic (N400) ERP effect in second language but not the first", by K. Weber and A. Lavric, 2008, *Psychophysiology*.





***Source**: https://ai.facebook.com/blog/studying-the-brain-to-build-ai-that-processes-language-as-people-do/*

Neural correlates of word representation vectors



***Source**: Zhang, L., Wang, L., Yang, J., Qian, P., Wang, X., Qiu, X., Zhang, Z. and Tian, X., 2019. Can computers understand word meanings like the human brain does? Comparable semantic representation in neural and computer systems. *Ms, NYU Shanghai.*

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

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Solutions

Classification-based Decoding

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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
- Duration: -200 ms to 800 ms

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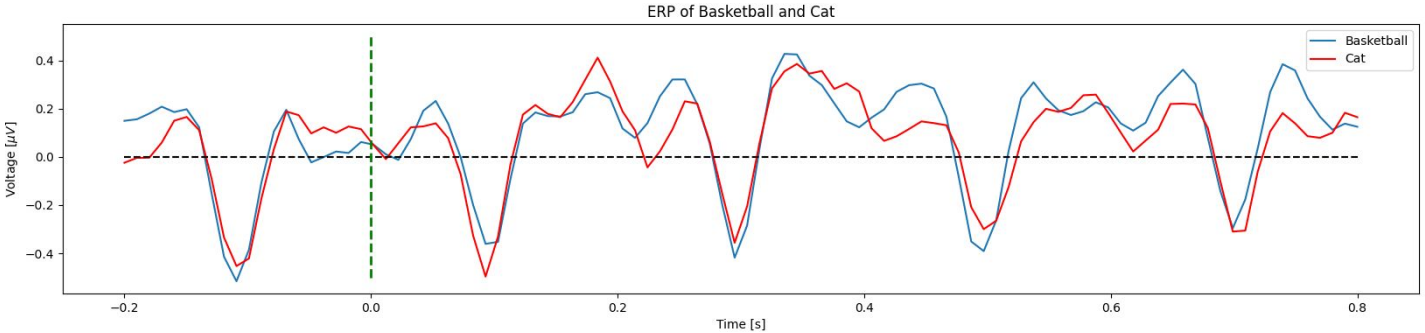
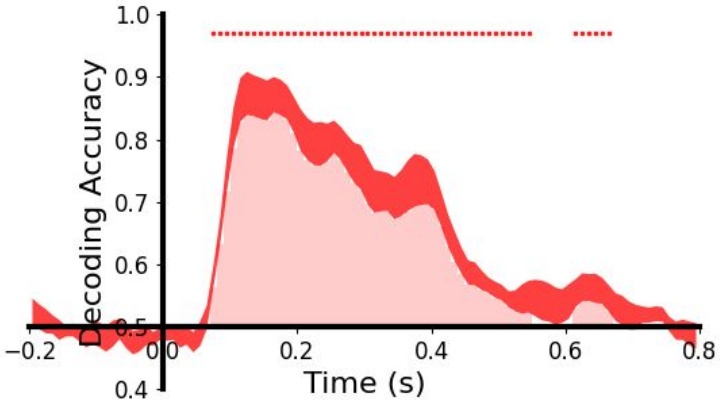
Binary Classification - Basketball and Cat

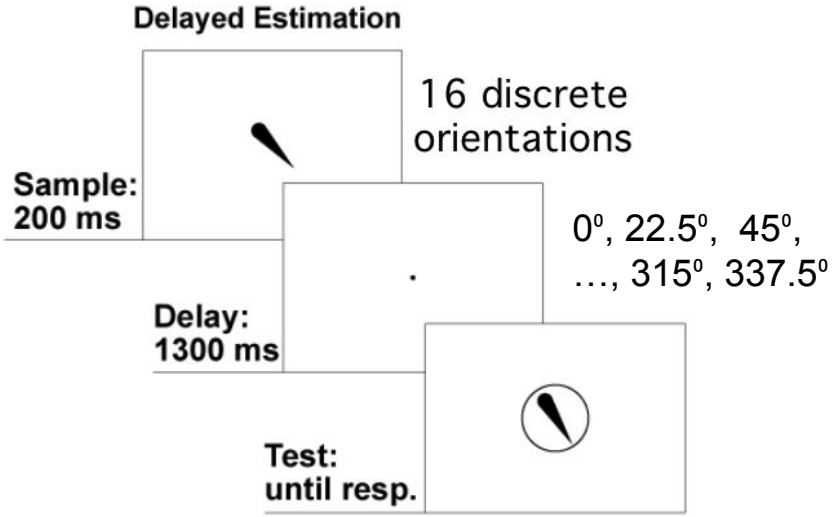


Barely any ERP difference between basketball and cat images



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

Multiclass Decoding - Working Memory



Bae and Luck, JNeuro, 2018

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

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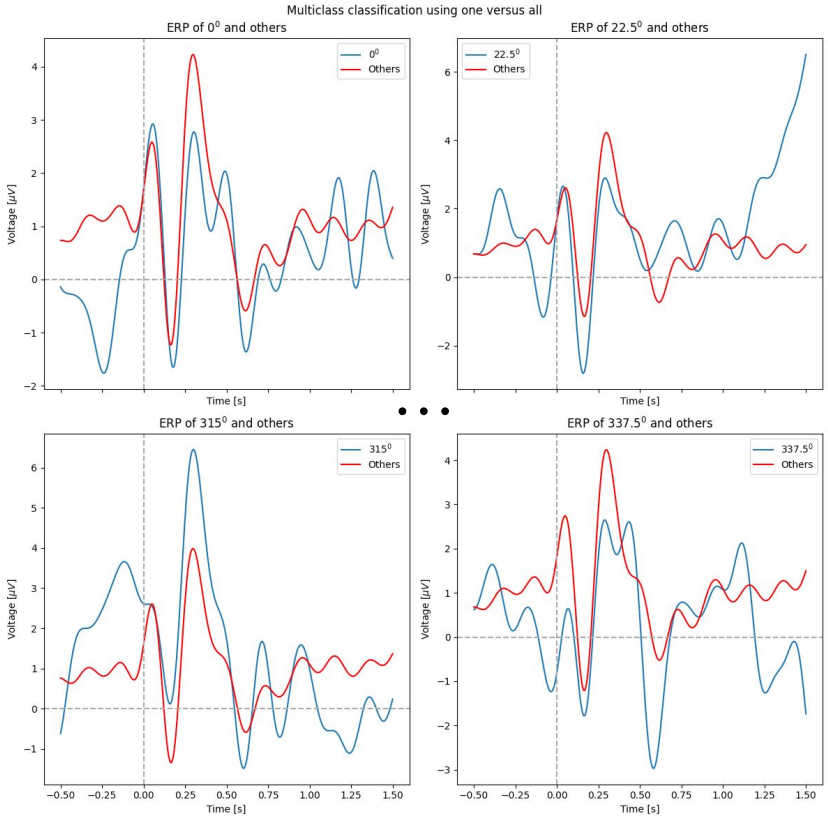
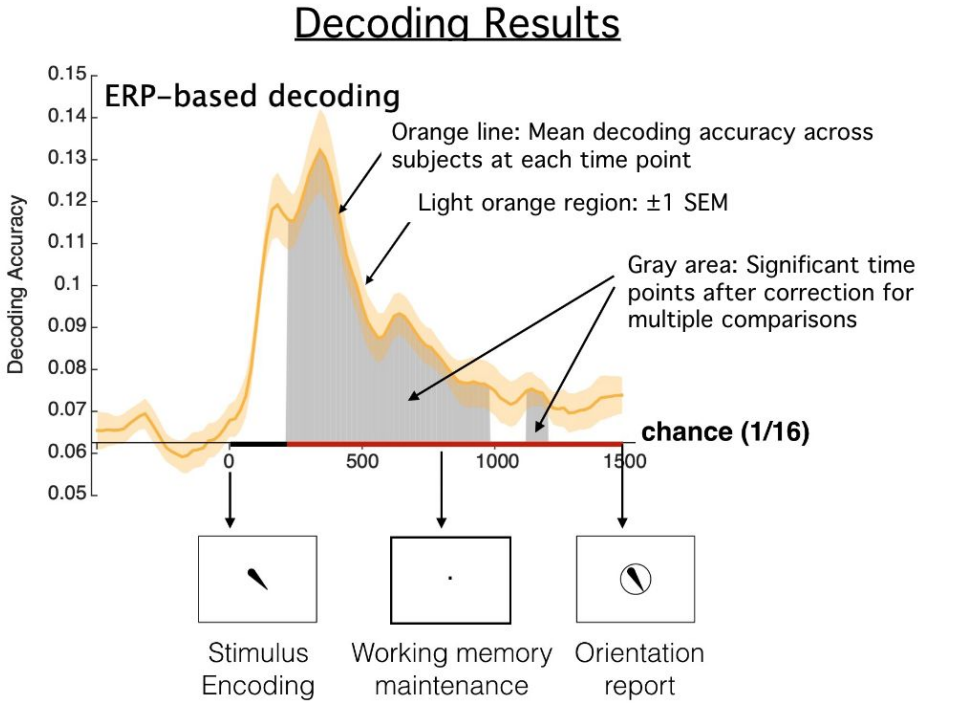
Orientation representation





Bae & Luck (2018, J Neuroscience)

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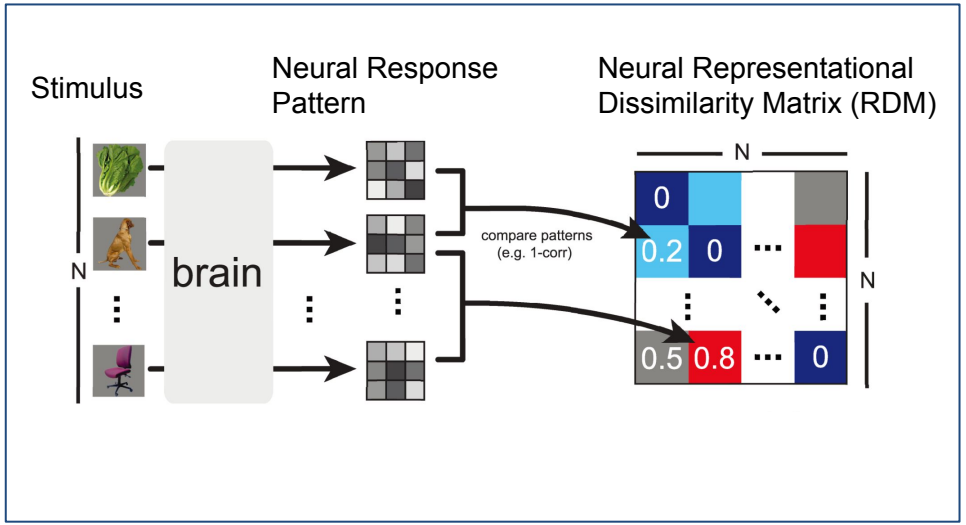
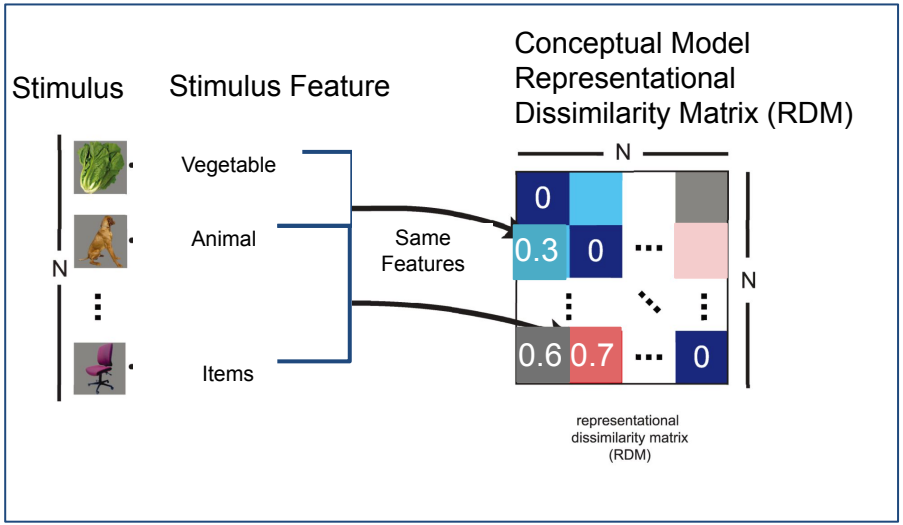
RSA-based Decoding





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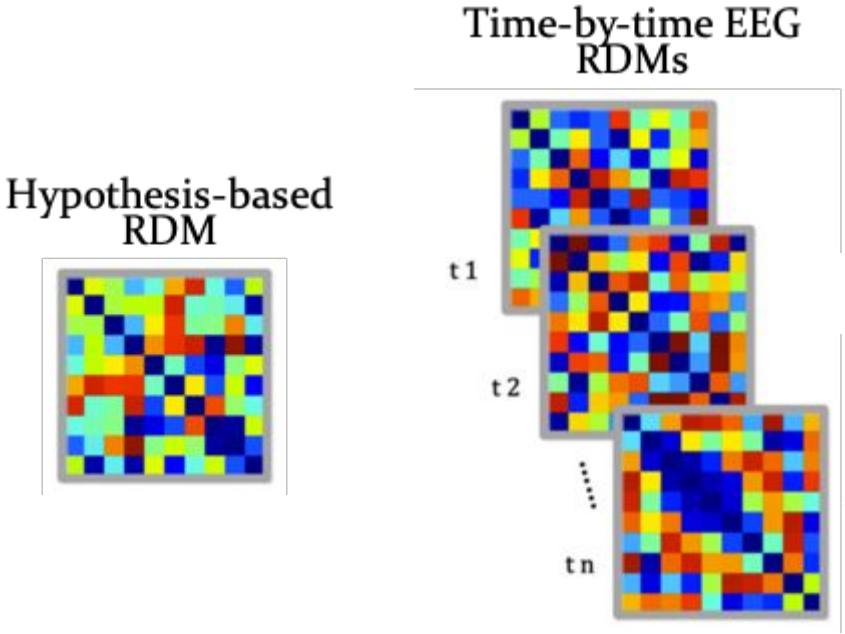
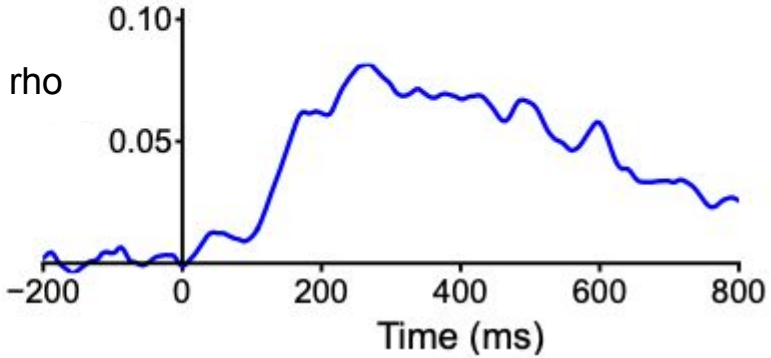
Source: https://www.baihan.nyc/proj/dynRSA/

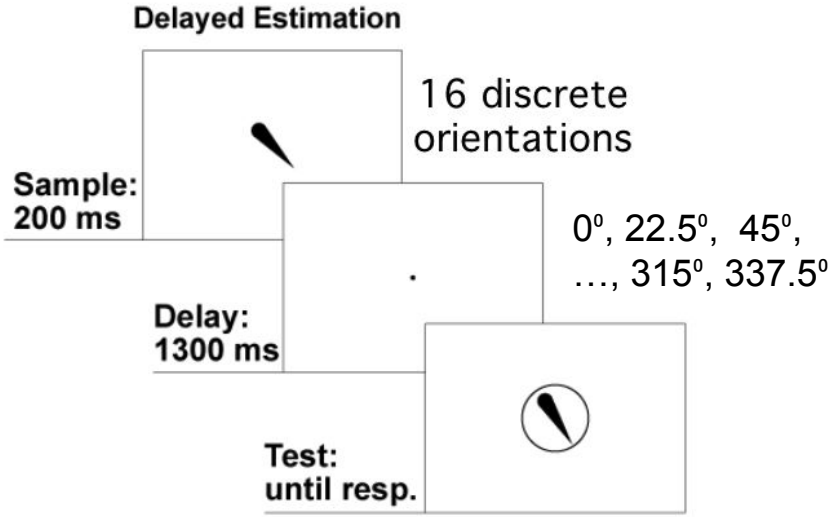
Compare between Hypothesis-based RDM and neural RDM





Source: NeuroRA

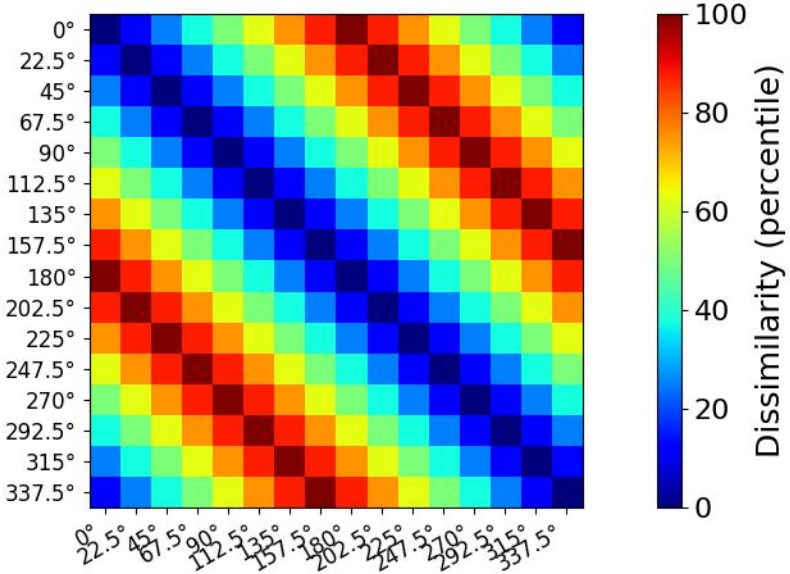
Working Memory



Bae and Luck, JNeuro, 2018

How to use RSA to decode 16 orientations from EEG?

Hypothesis-based orientation RDM



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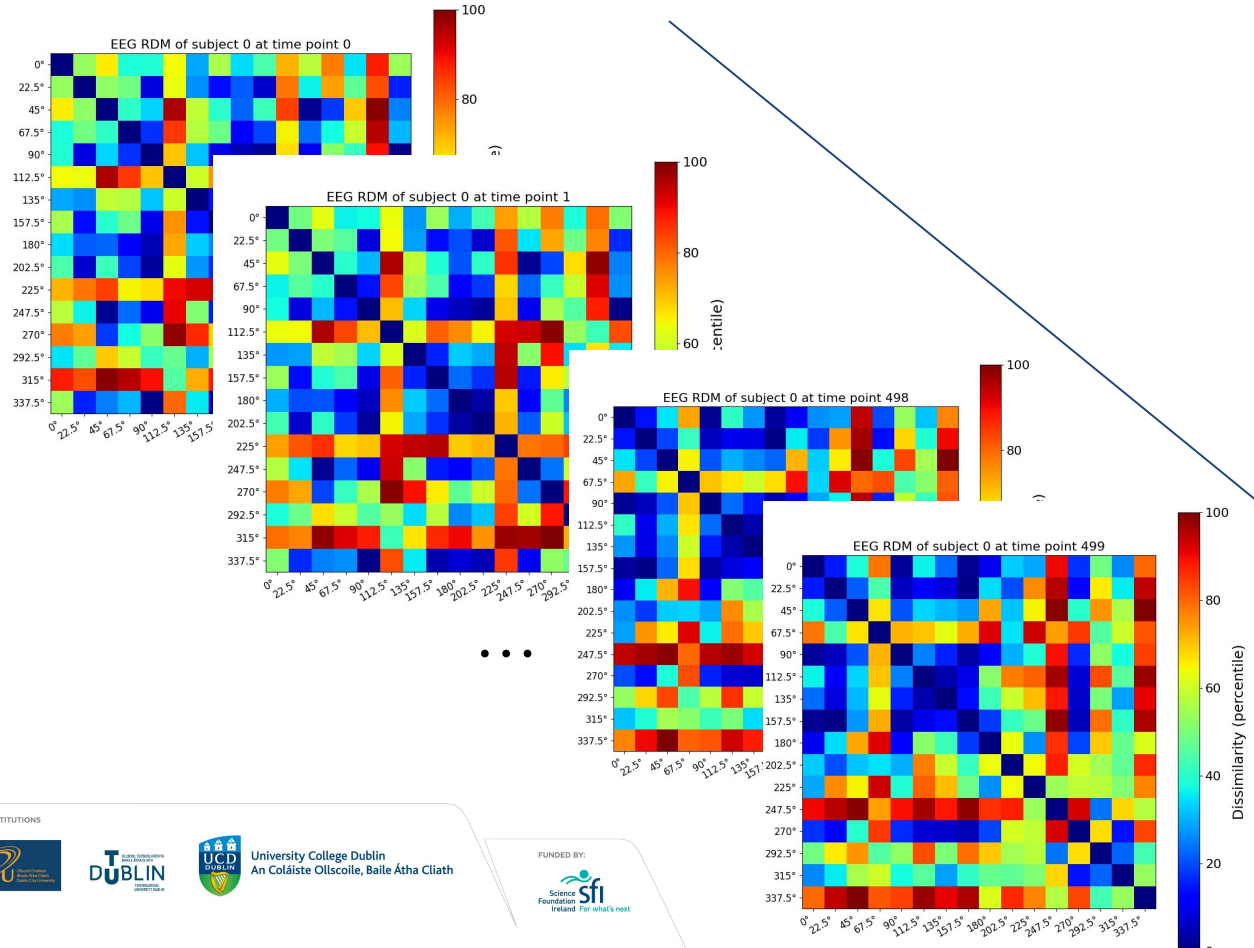
EEG Representational Dissimilarity Matrices



Time points

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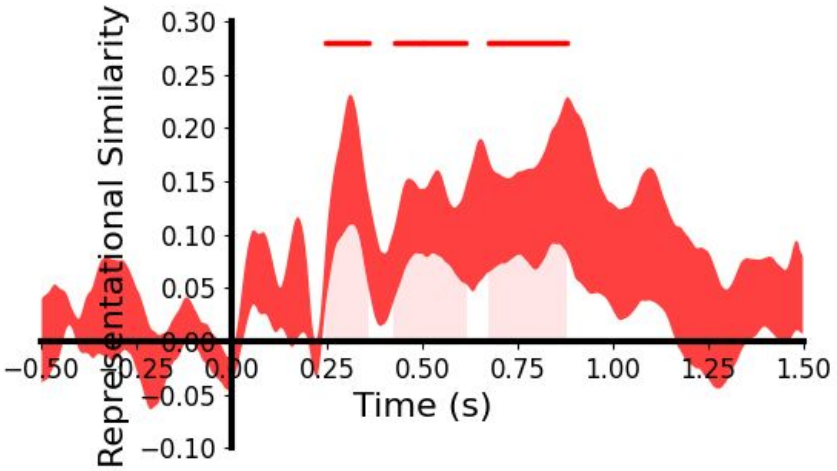
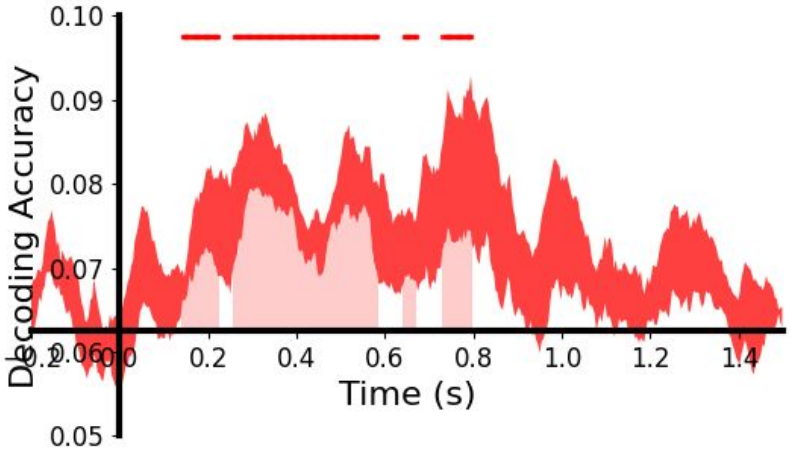
RSA-based decoding result

RSA-based decoding



Classification-based decoding



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Thank you!

Discussion