From Brain Signals to Cognition

# EEG Workshop: Learning EEG Research Methods from Scratch

Time: 9 am – 1 pm, May 8, 2021 (Saturday) Mode: via ZOOM

By Dr Guang Ouyang, Assistant Professor, Academic Unit of Human Communication, Development, and Information Sciences, Faculty of Education, HKU

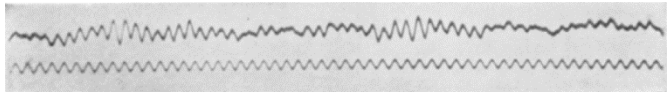
# Outline

- Basic concepts
- Major principles and methodologies
- Real-time demonstration of EEG data collection
- Data visualization and analysis
- Advanced topics

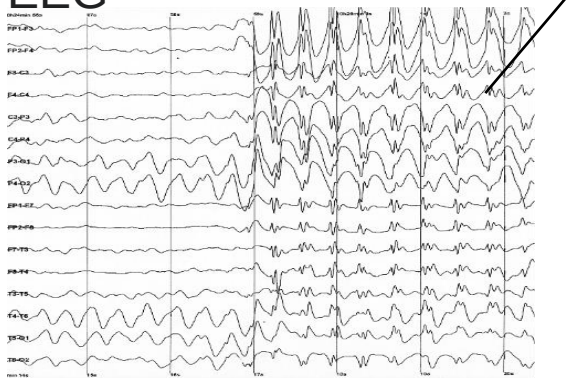
Feedback

# A dose of history and philosophy

Hans Berger (1873 – 1941) discovered brain EEG and its association with cognition

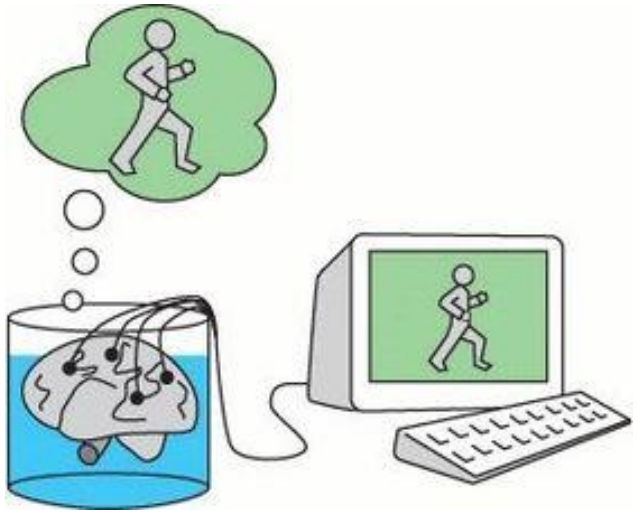


EEG



Cognition?

Brain in a vat



# What 100+ year of EEG research brings to us?

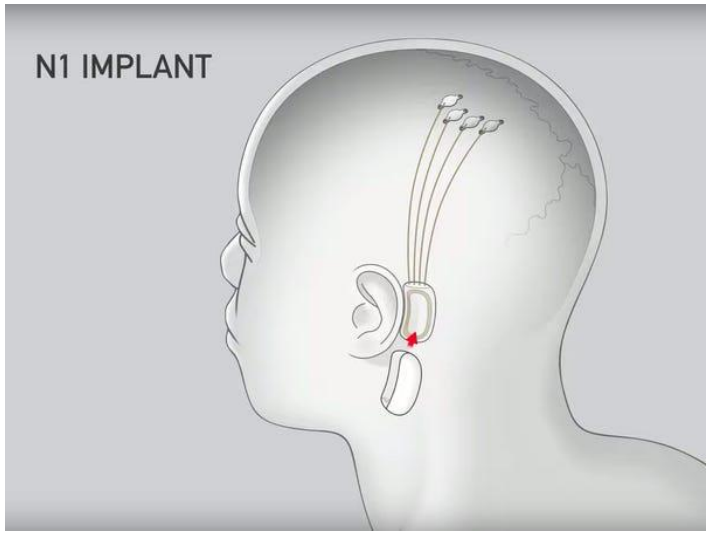
- Functional activities
- Cognitive activities
- Cognitive abilities
- Emotional states
- Mental states
- Pathological states
- Development/aging
- etc

# Some recent fancy stuff

Brain-activity-to-text decoder

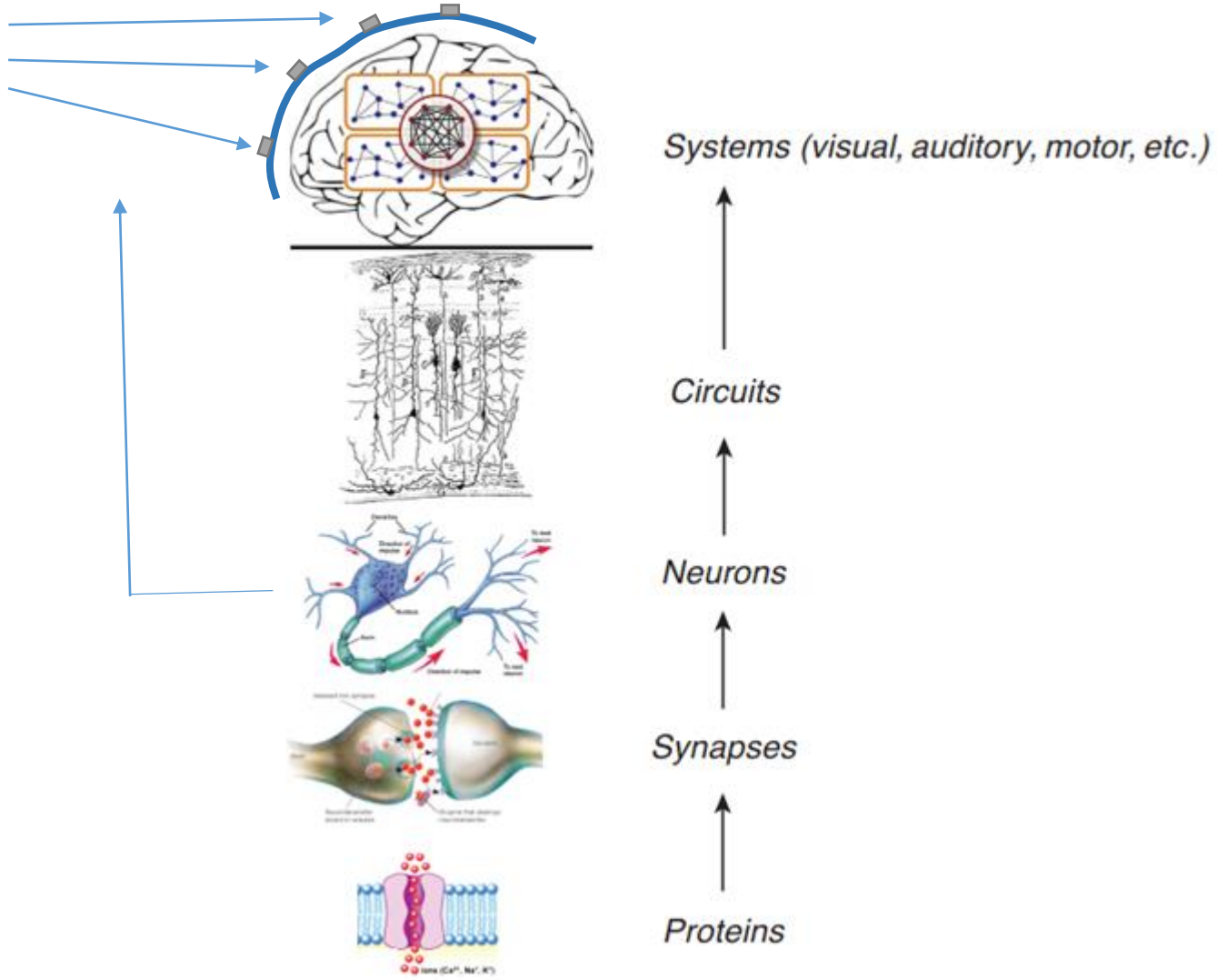
speech

Makin, J. G., Moses, D. A., & Chang, E. F. (2020). Machine translation of cortical activity to text with an encoder–decoder framework. *Nature neuroscience*, *23*(4), 575-582.

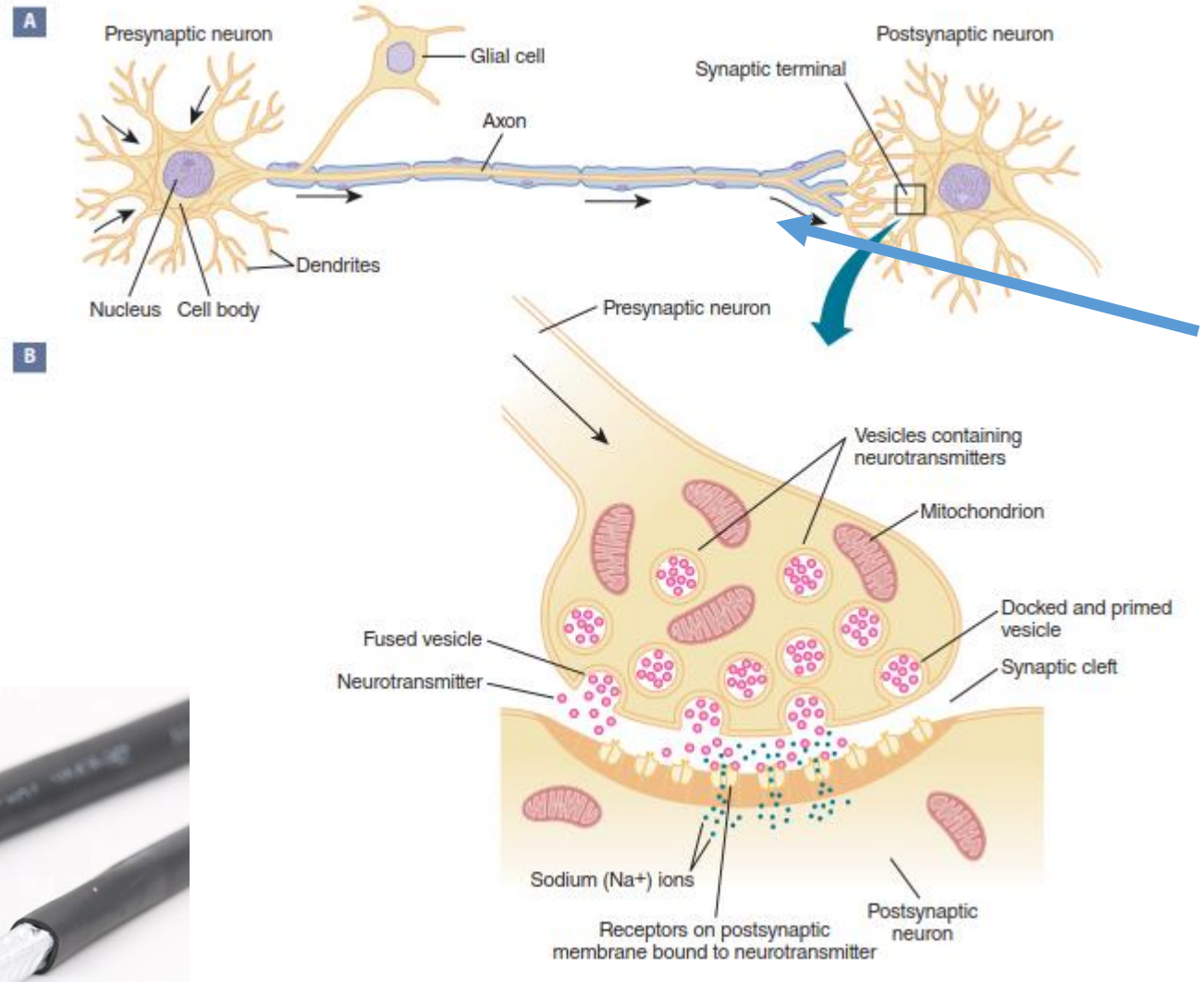


# Levels of neural system

EEG research



# What generates EEG?




Electrical signals

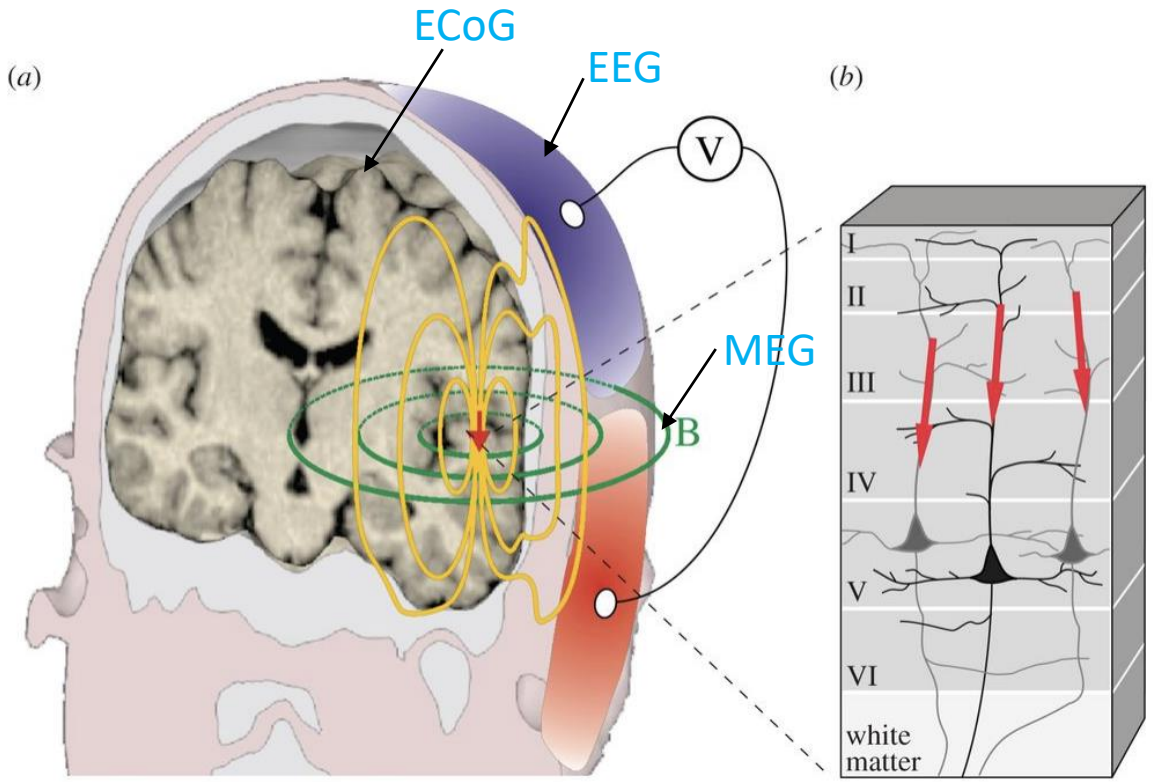
Related to cognitive activity

Electrical cable

Neuroanatomy for Speech-Language Pathology and Audiology, by Matthew H Rouse

# What generates EEG?

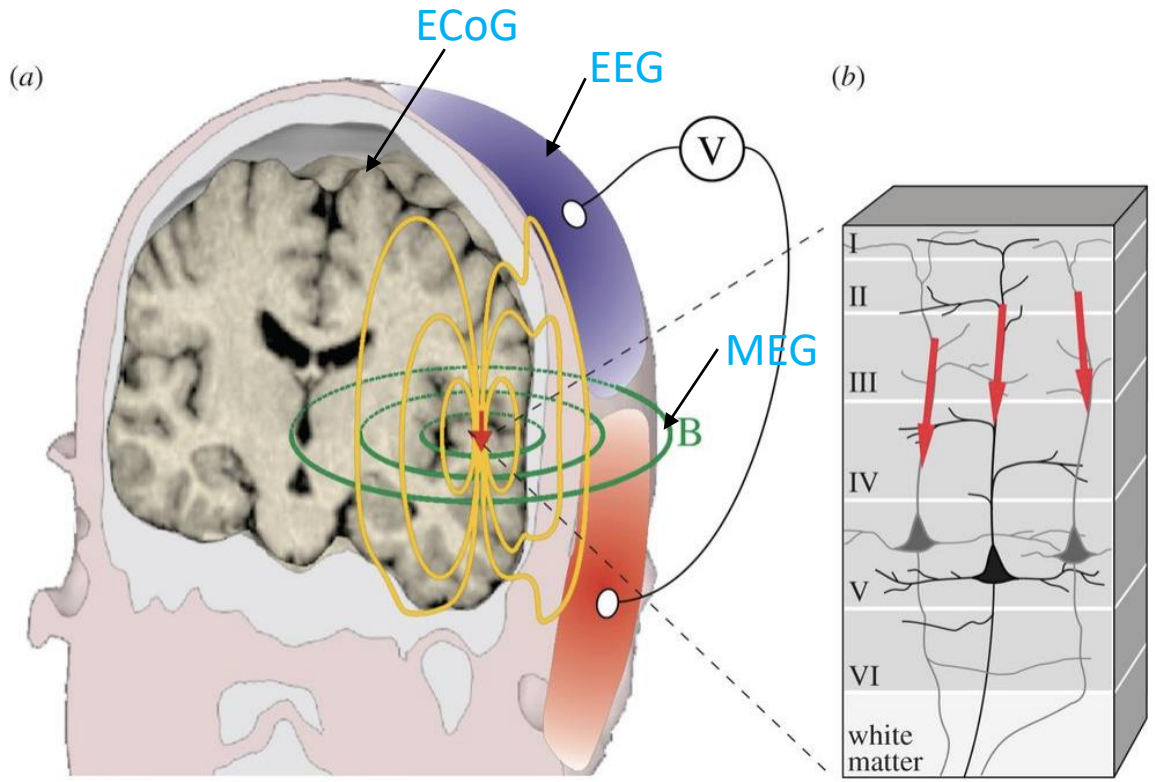
- **Mechanism:** parallelly oriented neurons generate current activity, causing fluctuations of electrical signals on the scalp (EEG) and cortex (ECoG). The current further induces magnetic field (MEG).




Hari, R., & Parkkonen, L. (2015). The brain timewise: how timing shapes and supports brain function. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1668), 20140170.

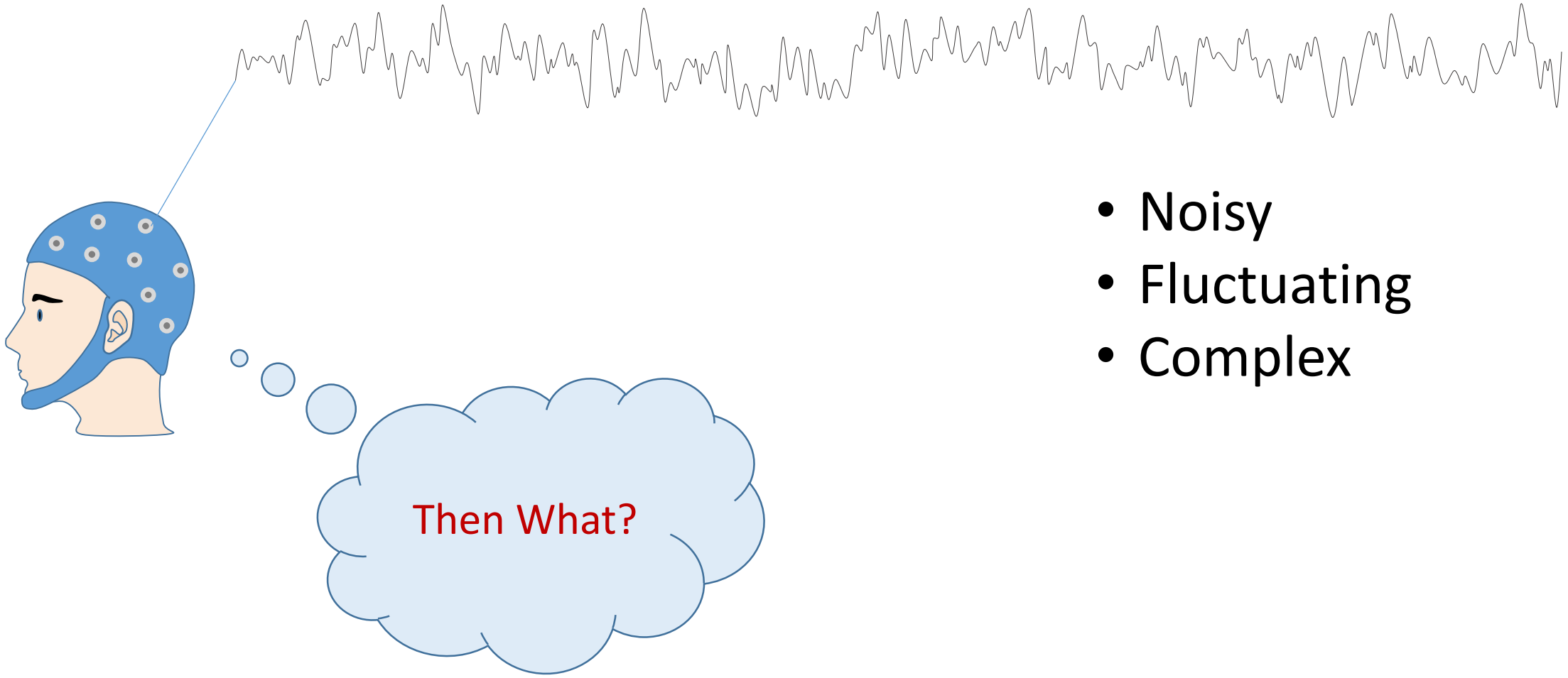
# An important note

- EEG/MEG directly measures neural activities.
- It possesses rich information in neural temporal dynamics (at milliseconds)
- which is not accessible by many other technologies (e.g., MRI, fNIRS) that measure hemodynamics




Hari, R., & Parkkonen, L. (2015). The brain timewise: how timing shapes and supports brain function. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1668), 20140170.

# Basic features




- Noisy
- Fluctuating
- Complex

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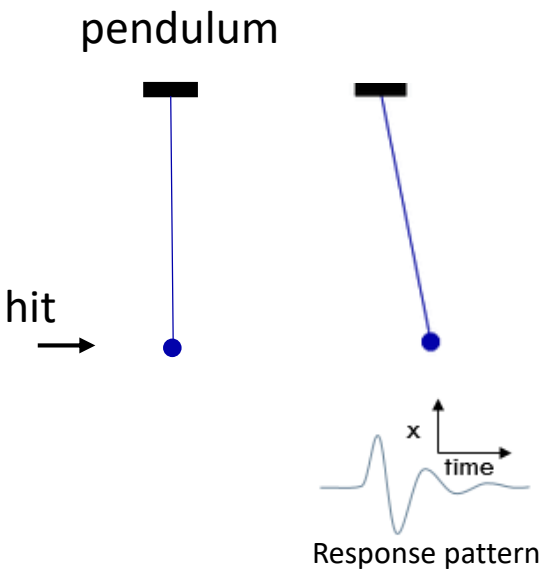
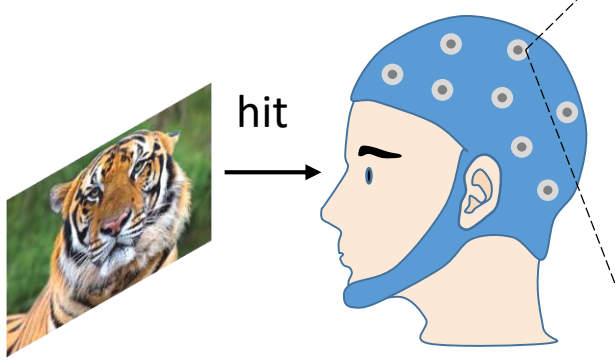
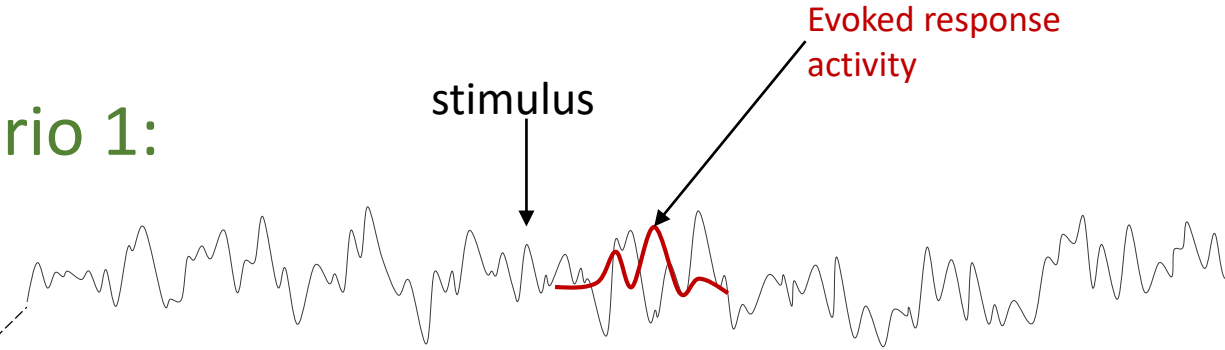
# How to do cognitive research using EEG?

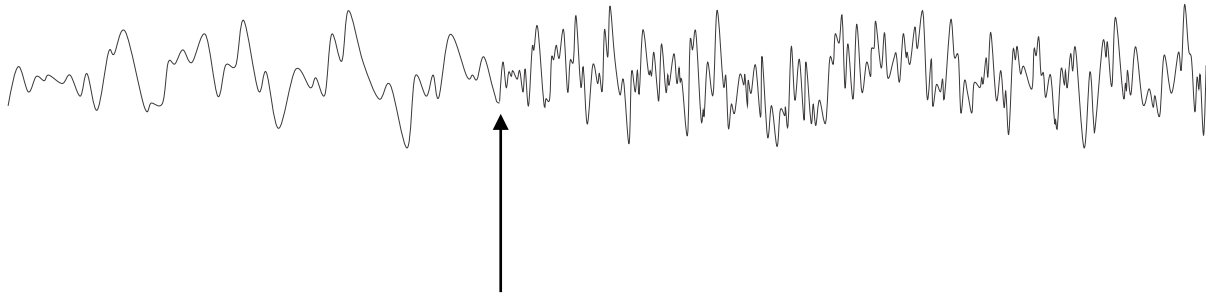



Scenario 1:



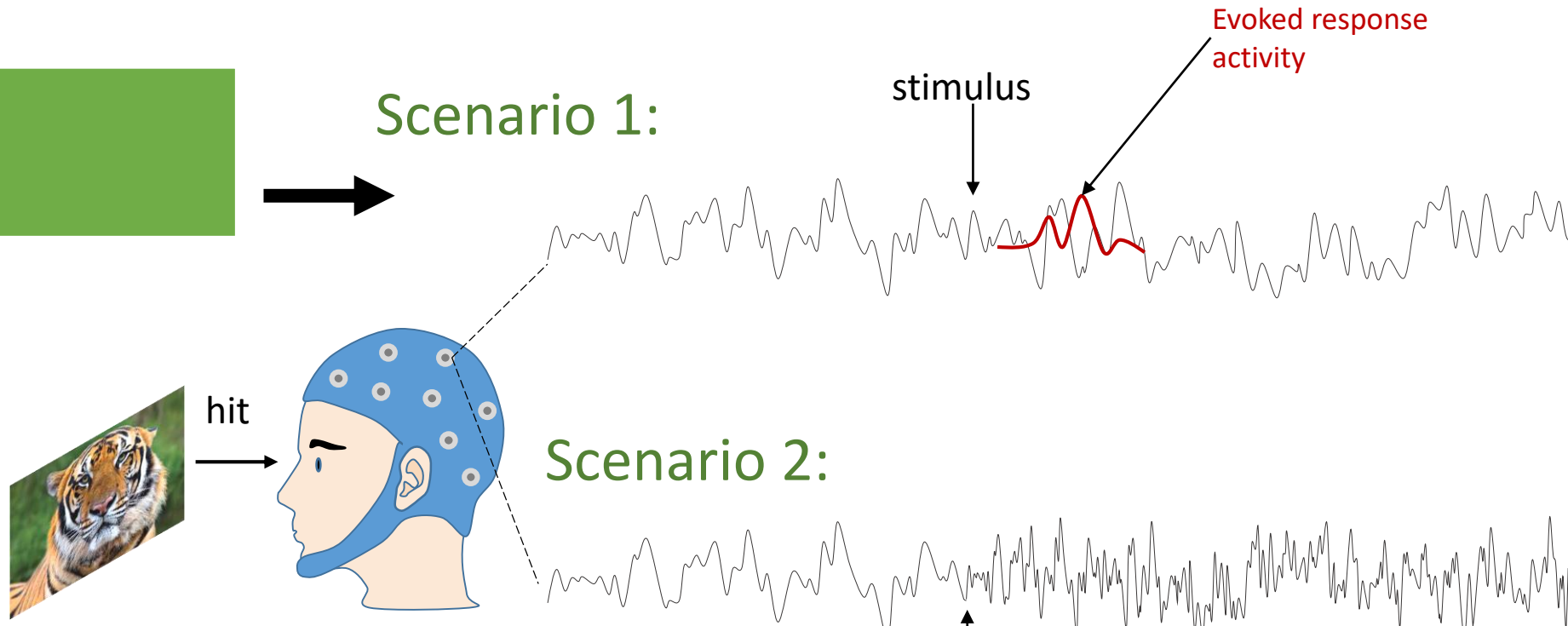

Scenario 2:



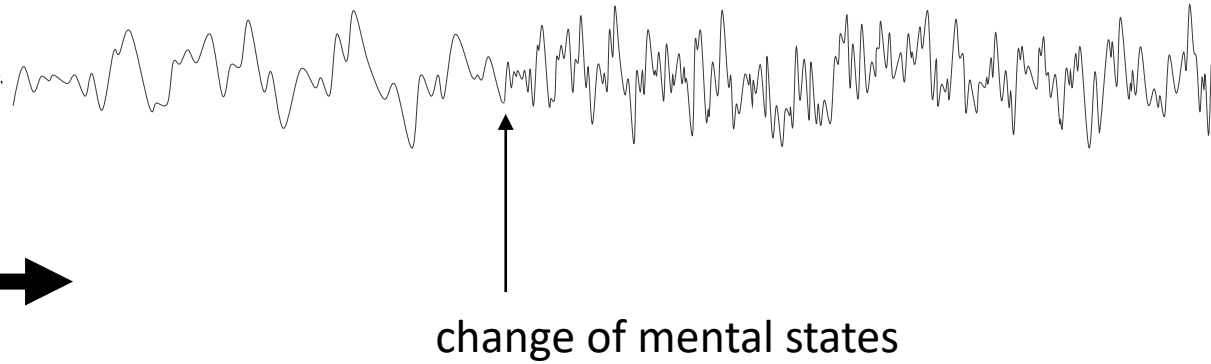
# How to do cognitive research using EEG?

## 1. ERP method
(Event-related potential)

Scenario 1:

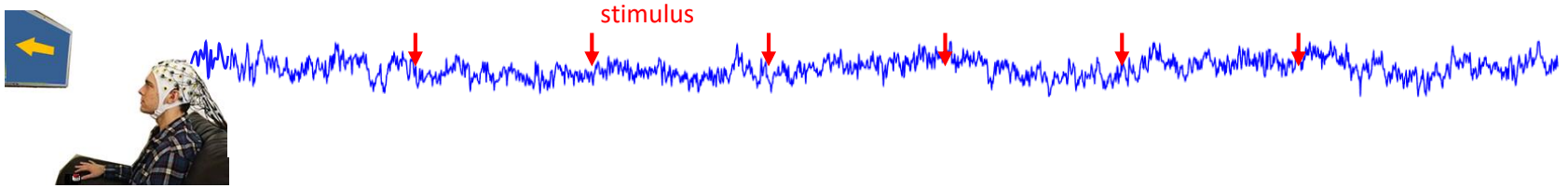


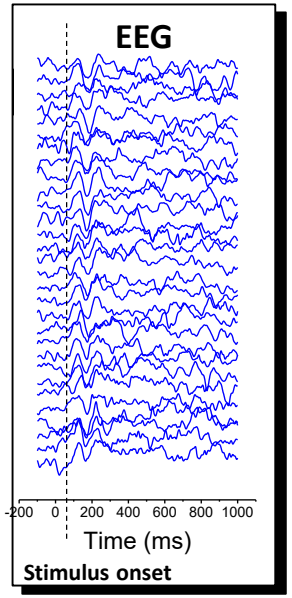

Scenario 2:



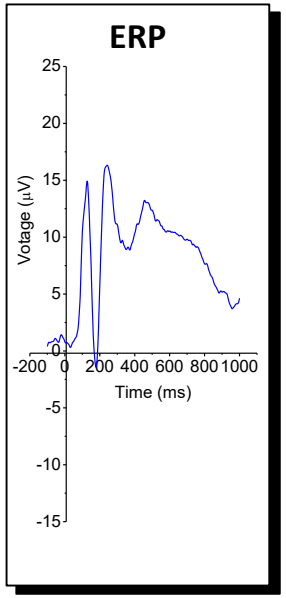

## 2. Spectrum analysis method

# ERP method



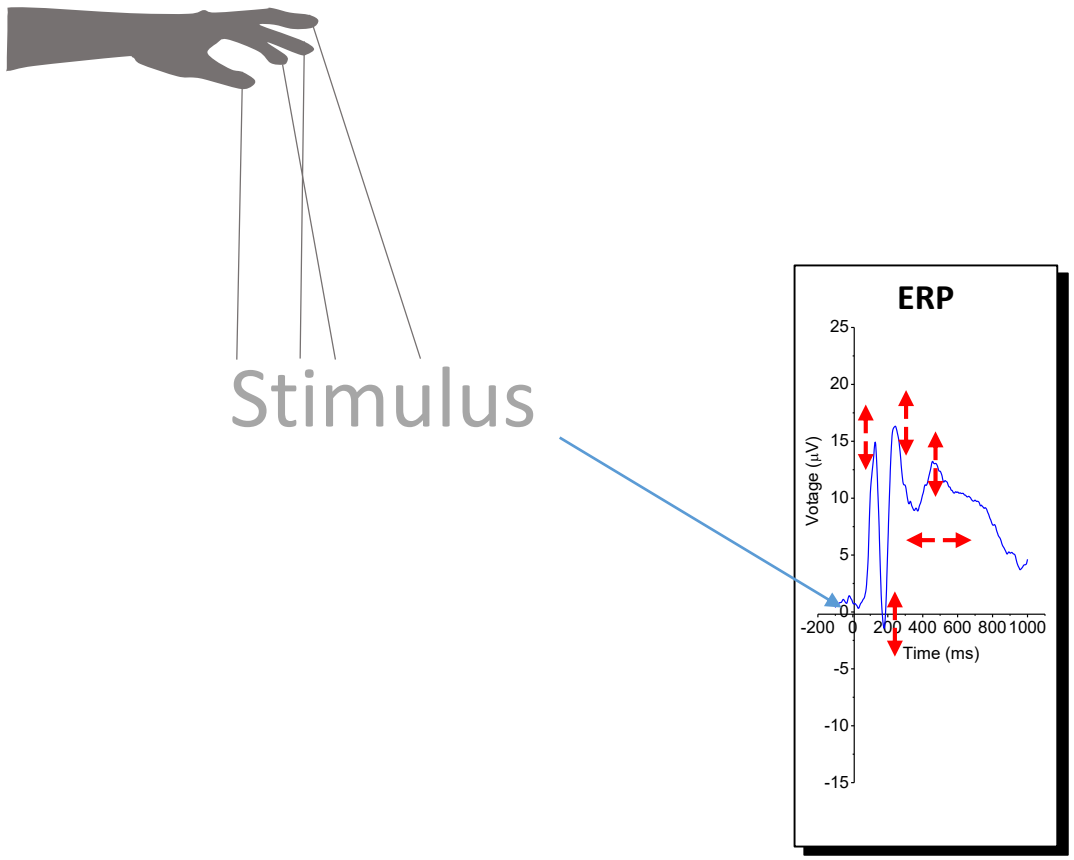




average




ERP (Event-related Potential)

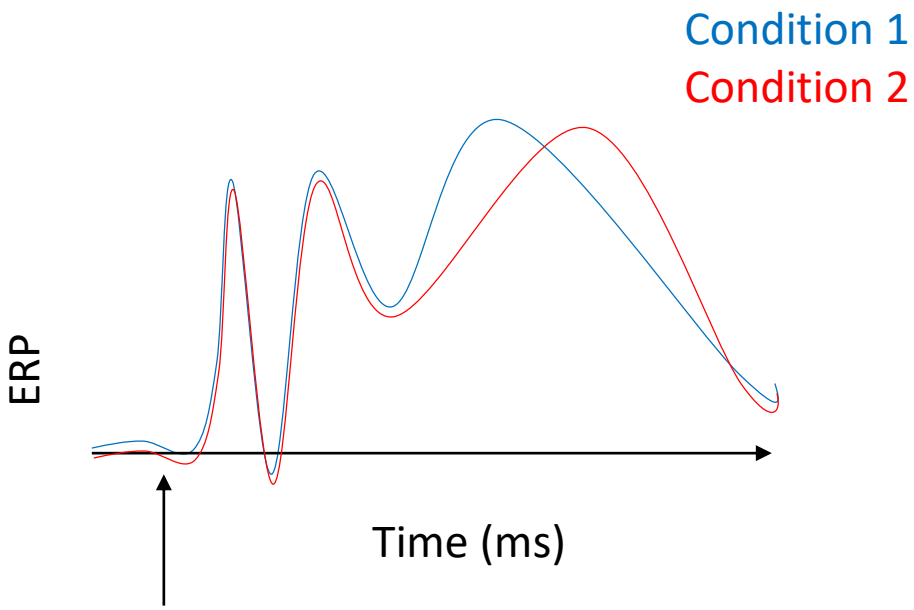
# ERP method



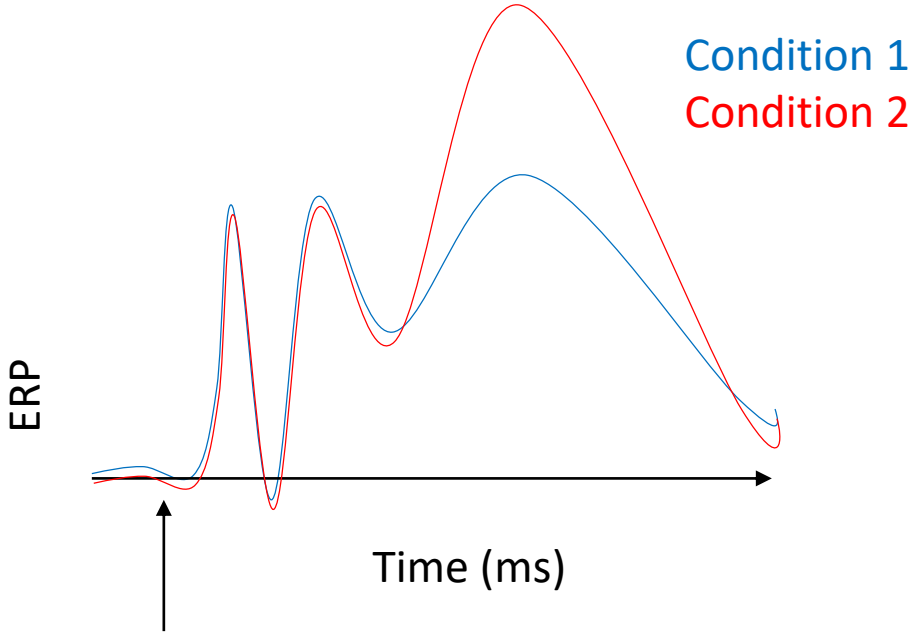

ERP (Event-related Potential)

# ERP method

## Change in timing
(reflects cognitive processing speed)




## Change in amplitude
(reflects cognitive effort)

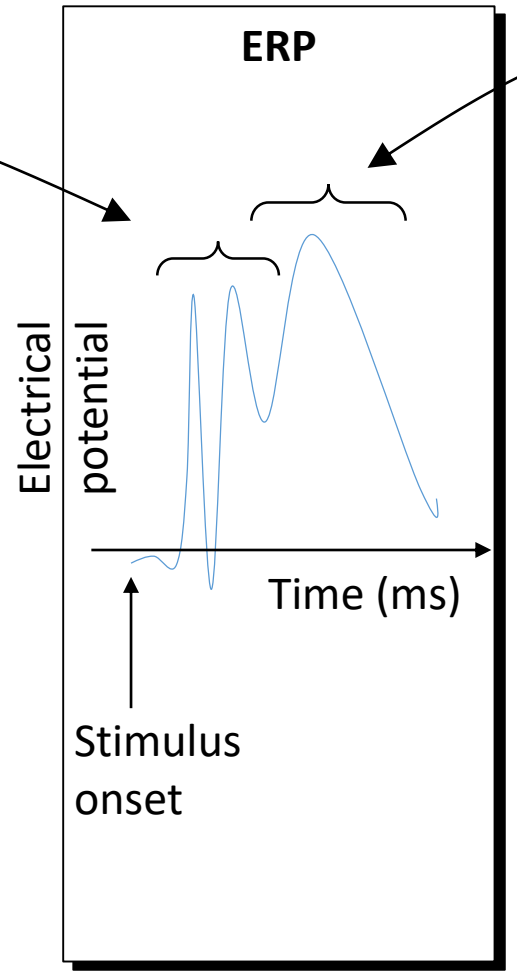


# ERP method

How ERP components reflect cognitive activity?

**Early components**

- Low level processing, e.g., size, luminance, sound intensity, etc
- Sometimes by top-down modulation, e.g., emotion, attention, etc.




**Late components**

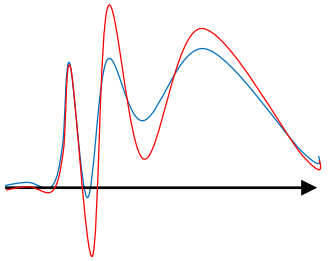
- Medium to high level processing, e.g., conflict processing, surprises, emotion, memory recollection, etc.

ERP (Event-related Potential)

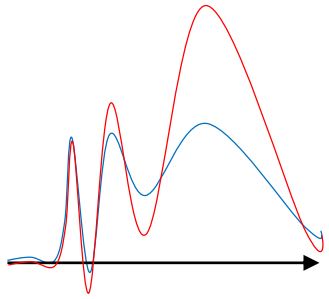
# ERP method

## Examples of stimulus manipulation

Luminance: high, low

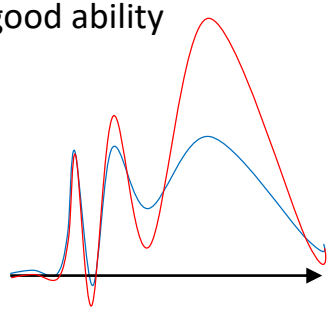


Occurrence probability of stimulus:
low, high

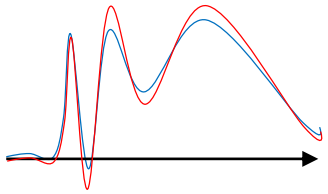


Tone/note differentiation
do do do do re do do

People with good ability



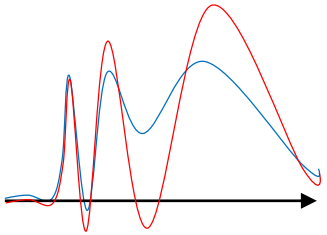
People with bad ability



Condition 1
Condition 2

Semantic violation

**I like to eat coffee**

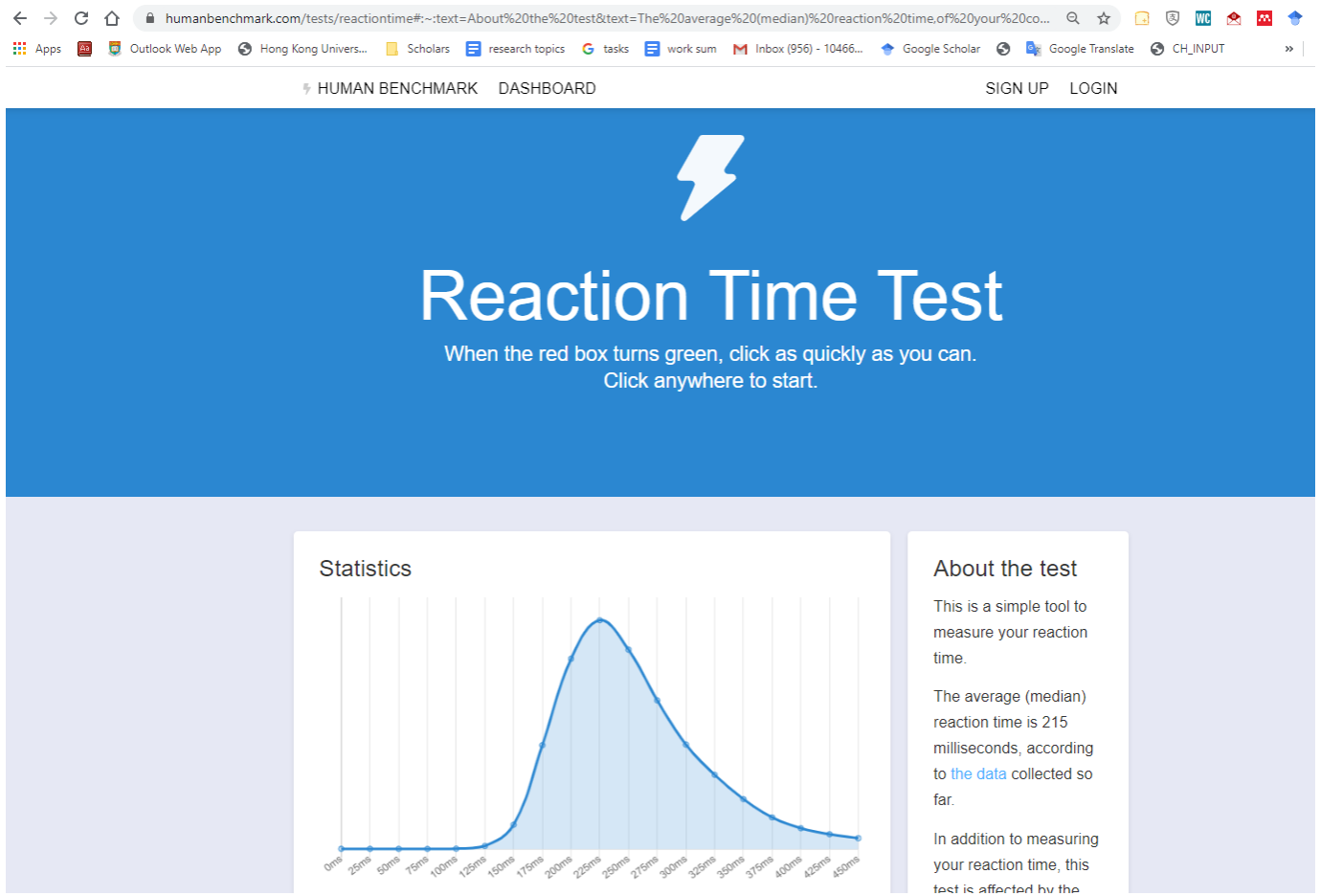


# ERP method

Why do I need to check ERP when I can already see relevant information in behavior?

1. You don’t know yourself that well (subjective feeling can be imprecise)
2. Much information is not available in behavioral data

# Test the your mental speed!




https://humanbenchmark.com/tests/reactiontime

Reaction Time

light

sound

odor

...

Sensation → Perception → Evaluation → Response selection → Behavioral action

motor processes

central processes

sensation

timing

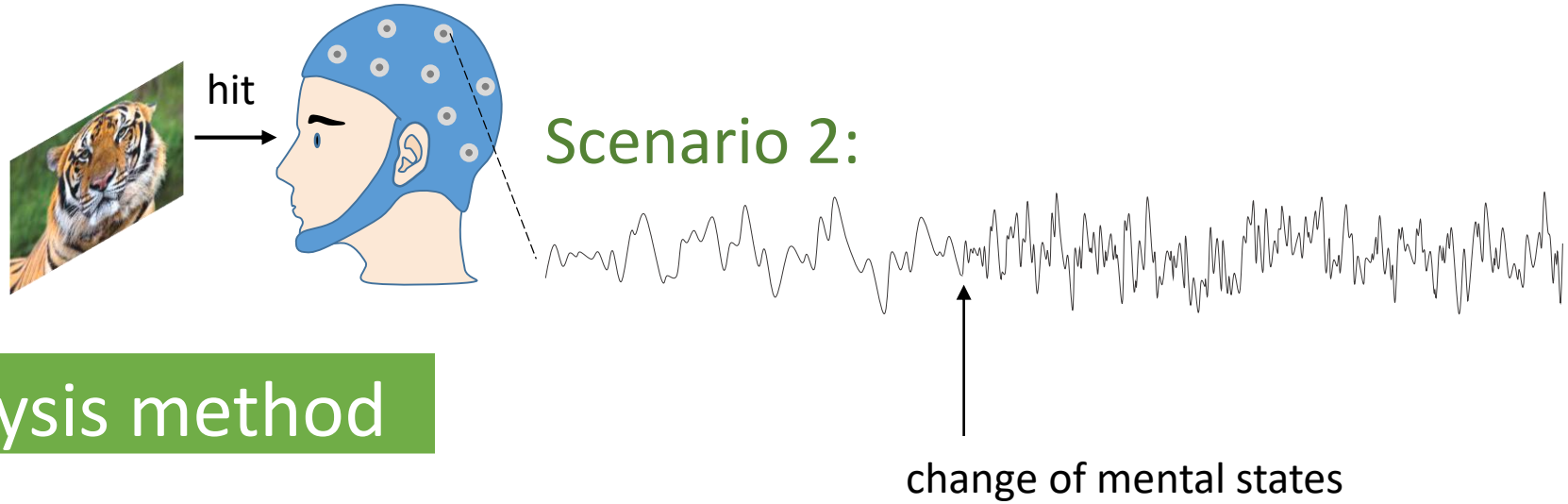
Brain activity

Onset of stimulus

time

# Spectrum analysis method

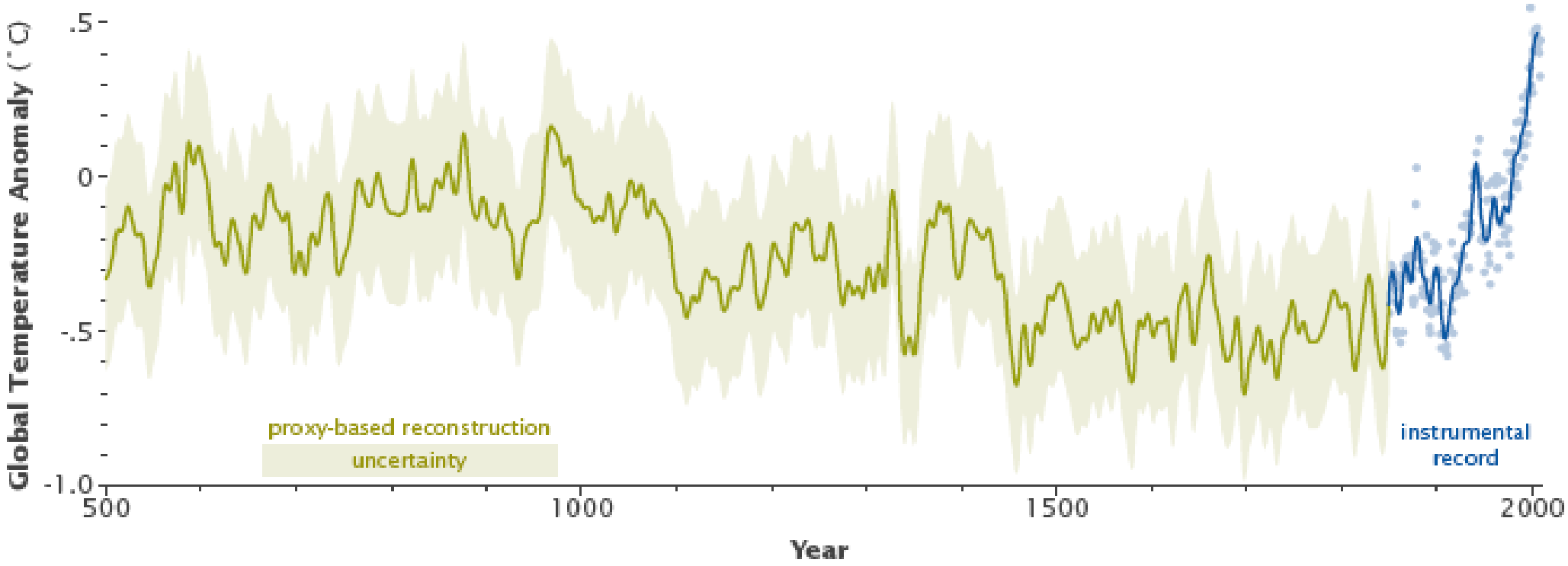
- Change of brain's internal state in a long-lasting way
- Examples:
  - Feeling excited/alerted/anxious/calm/drowsy…
  - Mood/emotion change
  - Cognitive load change
  - Meditation exercise
  - Different vegetative level
  - …




## 2. Spectrum analysis method

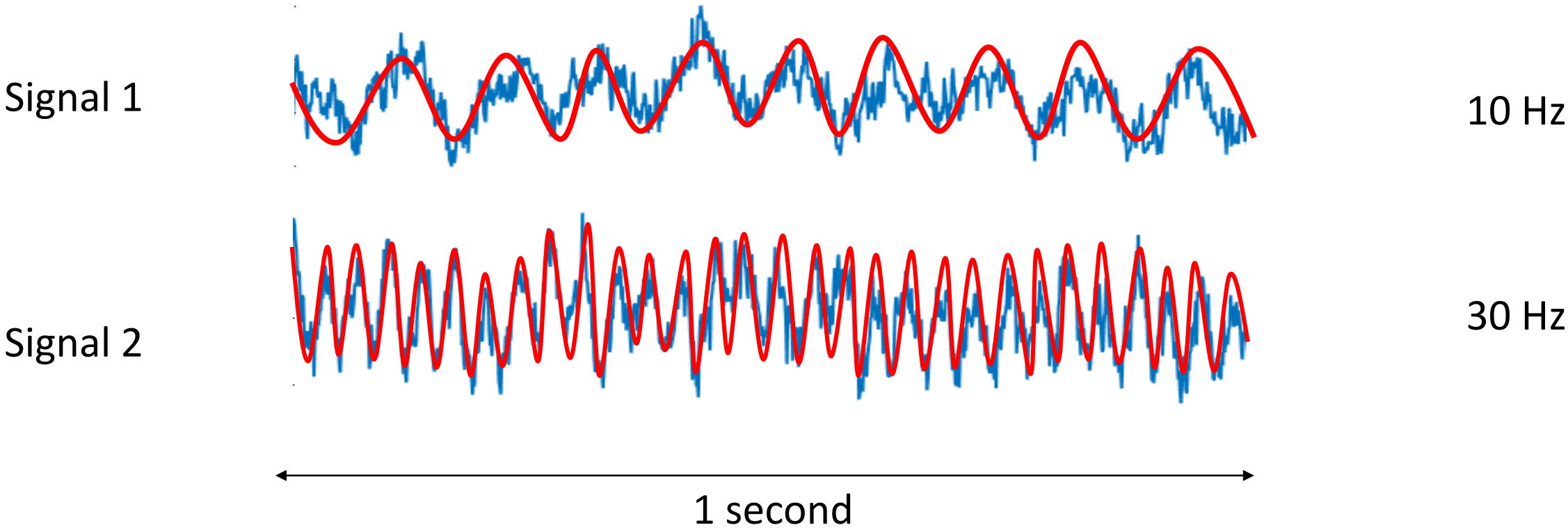
# Spectrum analysis method

## Oscillation




Source: internet

# Spectrum analysis method



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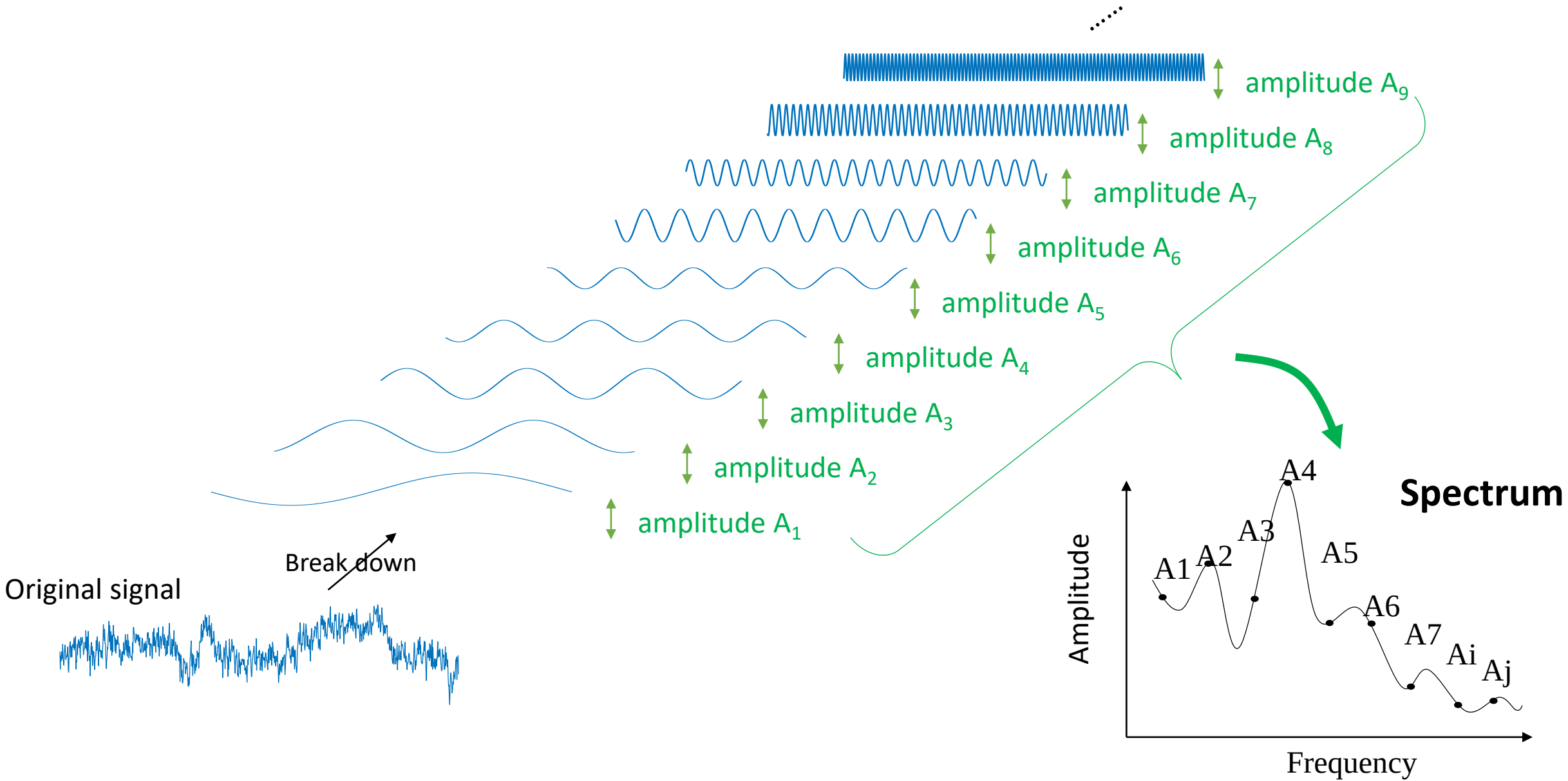
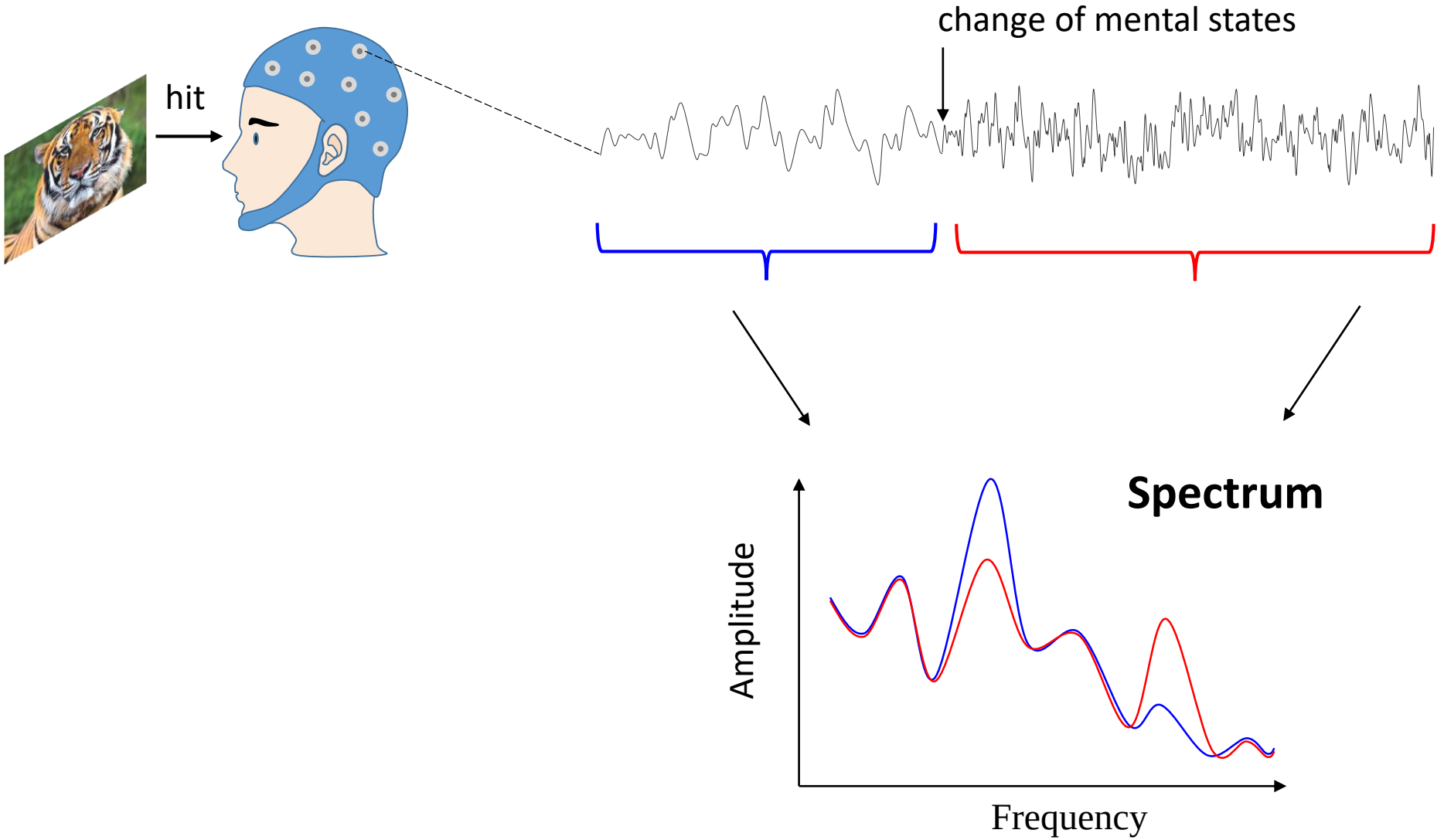


# Spectrum analysis method



# Spectrum analysis method

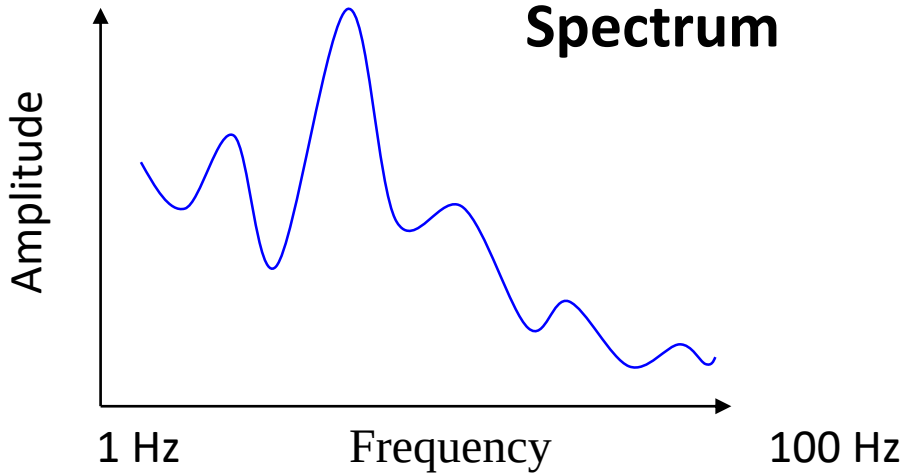
**Delta wave (1-3Hz)**
Functional association
- Sleep wave
- mixed

**Theta wave (4-7Hz)**
Functional association
- Active control
- Attention

**Alpha wave (8-12Hz)**
Functional association
- Idle state
- Cognitive load

**Beta wave (13-30Hz)**
Functional association
- Voluntary movements

**Gamma wave (>30Hz)**
Function
Functional association
- Cognitive load
- Intense neural computation
- Increased sensorimotor activity



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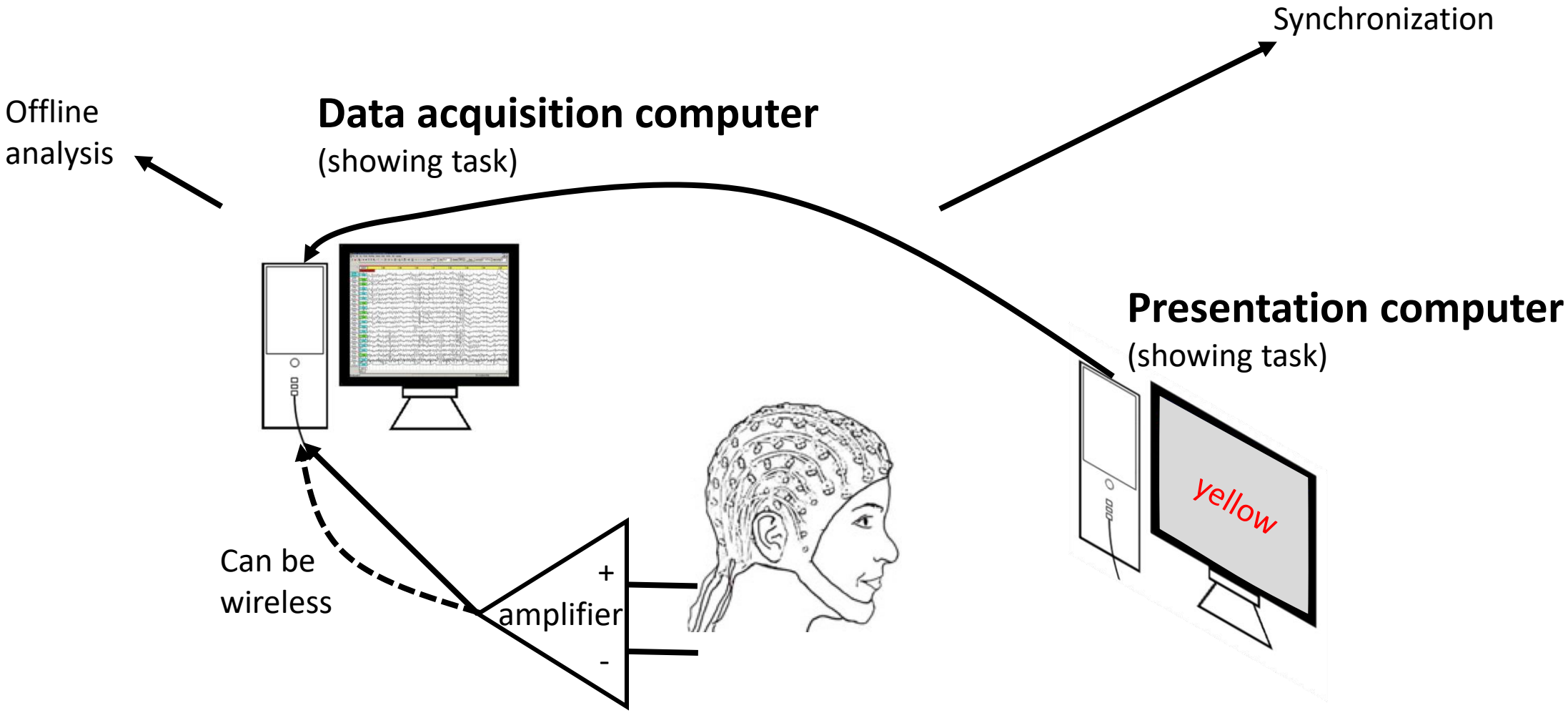
Demonstration

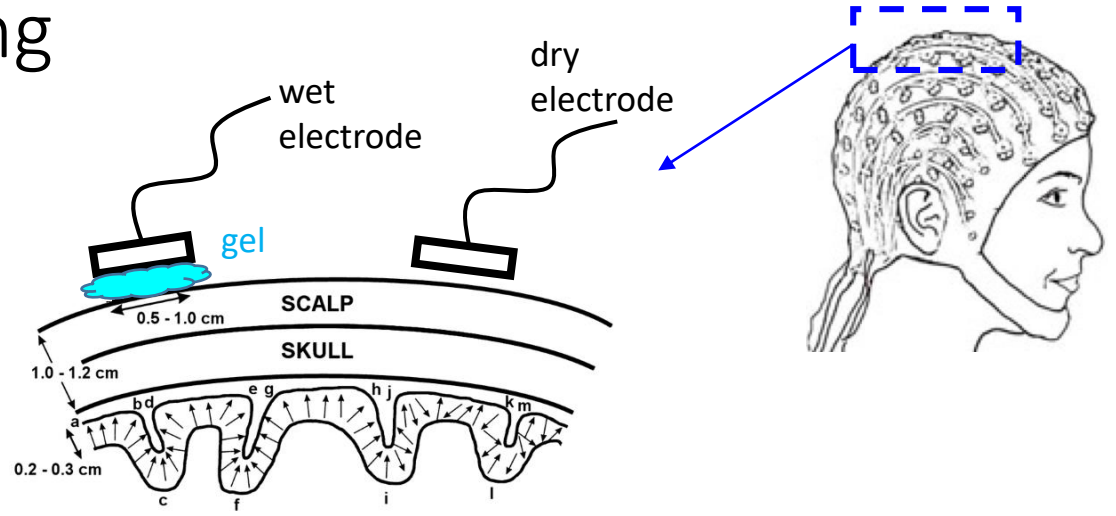
# Set-up of an EEG acquisition system

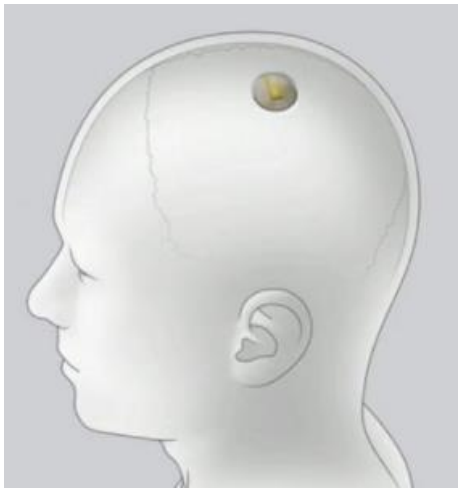


Demonstration

# Some technical points worth mentioning

- Ambient noise, environmental signal
- Gel-based (wet) electrode, dry electrode, semi-dry electrode
- Lab EEG, portable EEG, Indoor & outdoor
- Some latest fancy technologies:
  - Unobtrusive EEG
  - Concealed EEG
  - Earphone/earbud EEG
  - Headset EEG
  - Connecting with smartphones





# Demonstration

Product: **mBraintrain smarting system**
https://mbraintrain.com/

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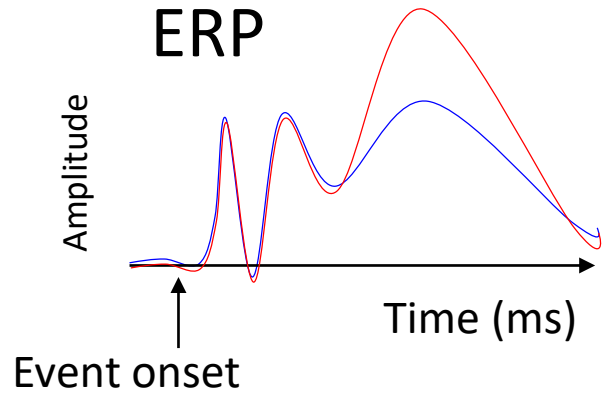
# Data visualization and analysis

## 1. ERP method (event-related potential)

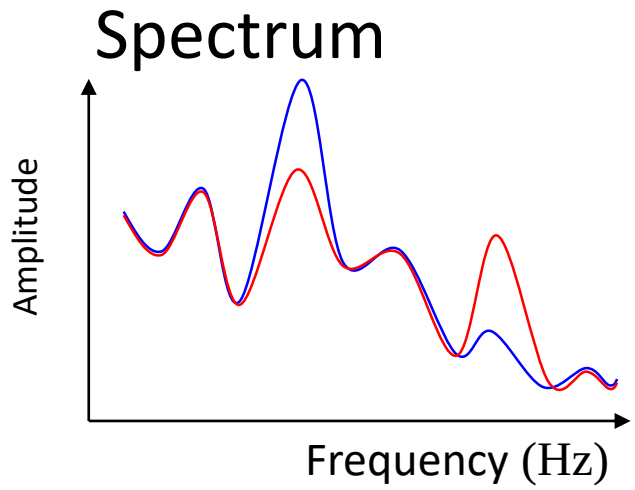
Analyzing the brain's response to a specific event




## 2. Spectrum analysis method

Analyzing the change in the brain state during a long period of time

Condition 1
Condition 2



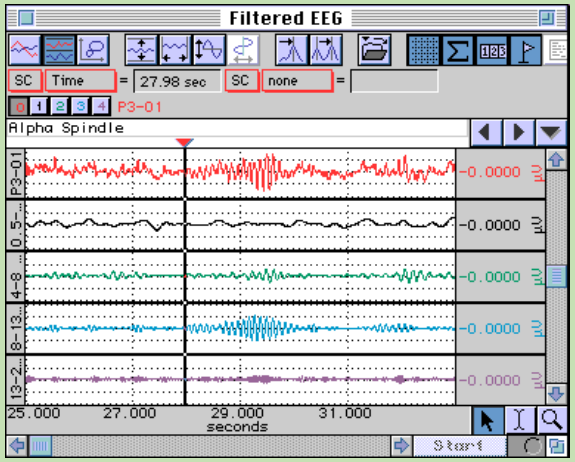
# Data visualization and analysis

More convenient
Less flexible

Raw EEG data

## Processing and analysis

### UI based

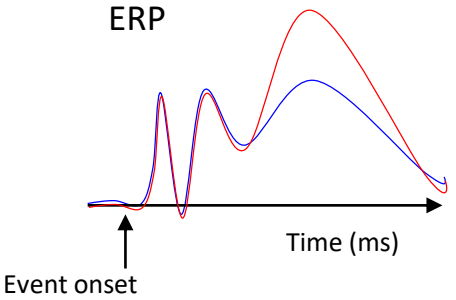



### Script based

```
clear;
eeglab nogui

%% data loading
data_path = 'D:\EEG_workshop\data\';
%need to change to your actual data path

parti = 'sample_visual_oddball';
EEG = pop_loadset('filename',[parti,'.set'],'filepath',data_path);


%% pre-processing

%bandpass filtering
EEG = pop_eegfiltnew(EEG, 'locutoff',1,'hicutoff',45,'plotfreqz',0);
%detect bad channel and interpolate
std_temp= std(EEG.data,1,2);
ol = find(isoutlier(std_temp,'ThresholdFactor',4)&std_temp>mean(std_temp));
if ~isempty(ol) EEG = pop_interp(EEG, ol, 'spherical');end
%average referencing
EEG = pop_reref( EEG, []);
%run ica (the stop criterion usually needs to be lower)
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended',1,'stop',0.001,'interrupt','on');
%automatically detec artifacts and clean the data
[comps,info] = MARA(EEG);
EEG = pop_subcomp( EEG, comps, 0);


%% generate ERP
epoch_twd = [-200,1000];%epoch time window
bl_twd = [-200, 0]; %baseline time window

ERPs = get_ERP_func(EEG,epoch_twd,bl_twd,{{'S 21'},{'S 22'}});

ch = find(strcmpi({EEG.chanlocs.labels},'Pz'));
figure;plot(ERPs.t_axis,squeeze(ERPs.ERPs(ch,:,:)));
xlabel('time after stimulus (ms)');
ylabel('amplitude (\muV)');
title('brain response pattern');
```

Less convenient
More flexible

Results



# Data visualization and analysis

## Understanding the mechanism of coding even if you don't code

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```

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EEG = pop_eegfiltnew(EEG, 'locutoff',1,'hicutoff',45,'plotfreqz',0);
%detect bad channel and interpolate
std_temp= std(EEG.data,1,2);
ol = find(isoutlier(std_temp,'ThresholdFactor',4)&std_temp>mean(std_temp));
if ~isempty(ol) EEG = pop_interp(EEG, ol, 'spherical');end
%average referencing
EEG = pop_reref( EEG, []);
%run ica (the stop criterion usually needs to be lower)
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended',1,'stop',0.001,'interrupt','on');
%automatically detec artifacts and clean the data
[comps,info] = MARA(EEG);
EEG = pop_subcomp( EEG, comps, 0);
```
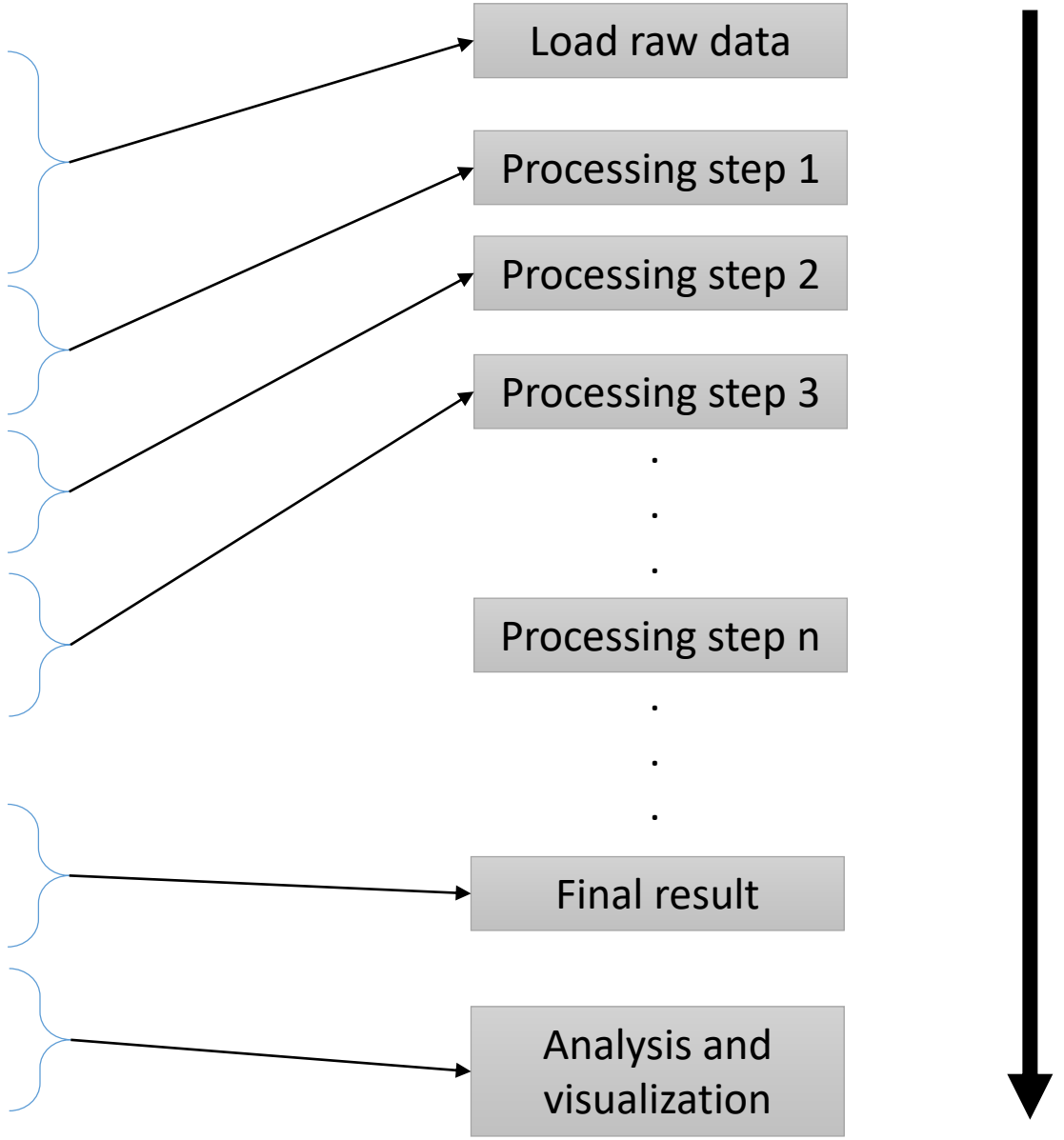

```
%% generate ERP
epoch_twd = [-200,1000];%epoch time window
bl_twd = [-200, 0]; %baseline time window

ERPs = get_ERP_func(EEG,epoch_twd,bl_twd,{{'S 21'},{'S 22'}});

ch = find(strcmpi({EEG.chanlocs.labels},'Pz'));
figure;plot(ERPs.t_axis,squeeze(ERPs.ERPs(ch,:,:)));
xlabel('time after stimulus (ms)');
ylabel('amplitude (\muV)');
title('brain response pattern');
```



# General routine

To be covered in another focused workshop

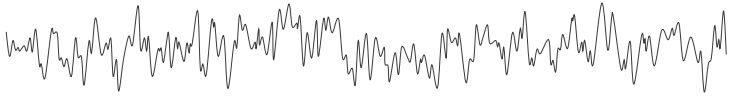
**Raw data** → **Preprocessing**

May include:
- Re-sampling
- Re-referencing
- Band-pass filtering
- Removing artifactual components
- etc

→ **Visualization and Analysis**
- ERP
- Spectrum
- Statistical analysis

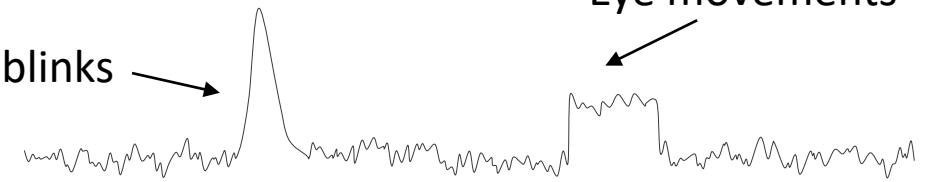
# Examples of artifacts (fake brain signals)

Typical:

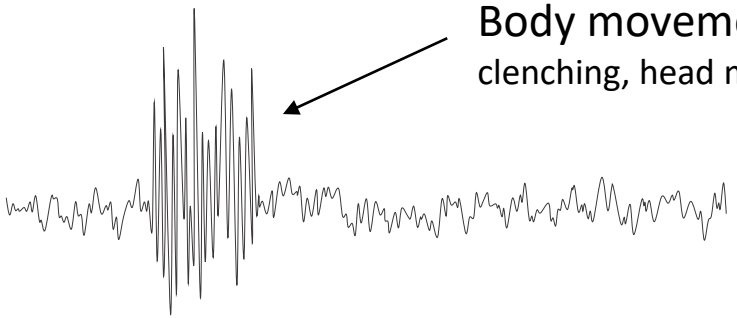


Eye blinks

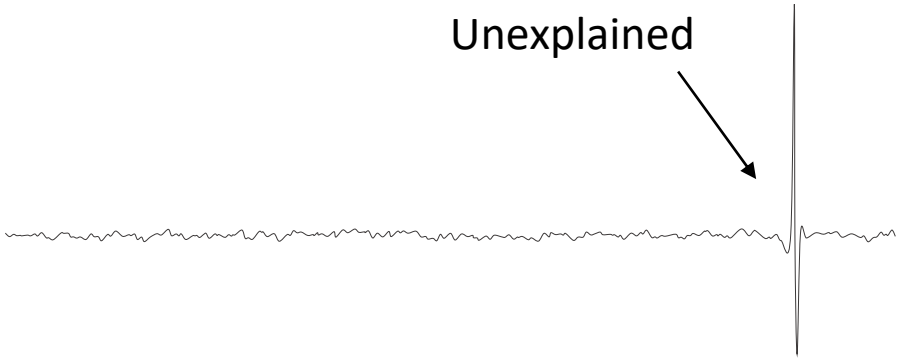
Eye movements



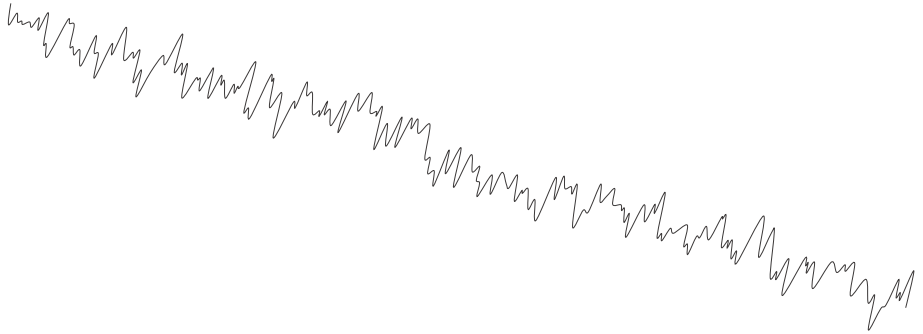
Body movements (swallowing, teeth clenching, head movement, etc)



Unexplained



Drifting

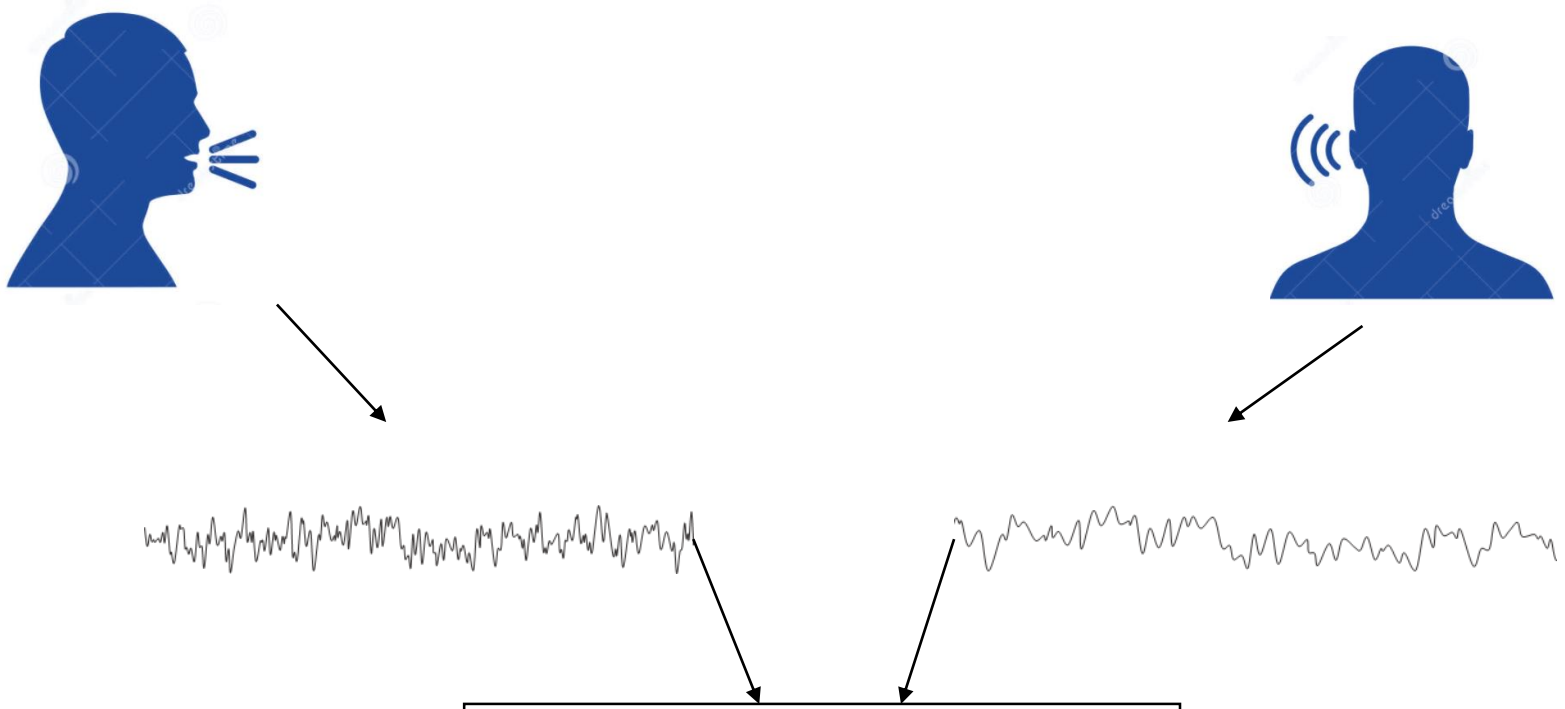


Disconnected:

# Reason why we need to deal with artifacts

Condition 1 (task 1): speaking

Condition 2 (task 2): hearing a speech



Difference can be merely from the fact that the first one is speaking and the second one is not.

# EEG analysis softwares

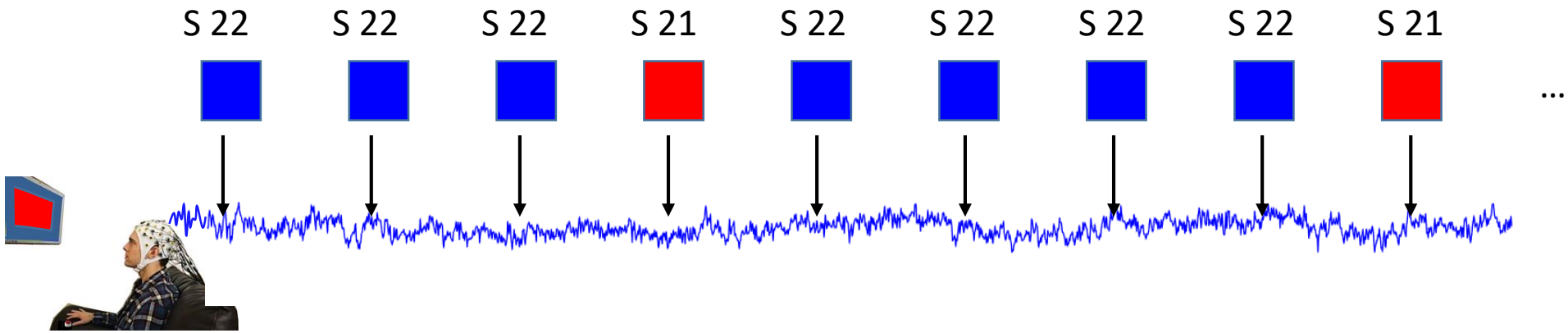
- Commercial softwares from EEG equipment companies
- Matlab + EEGLAB
- Matlab + Letswave
- Matlab + Fieldtrip
- Matlab + Brainstorm
- MNE-Python
- Many others

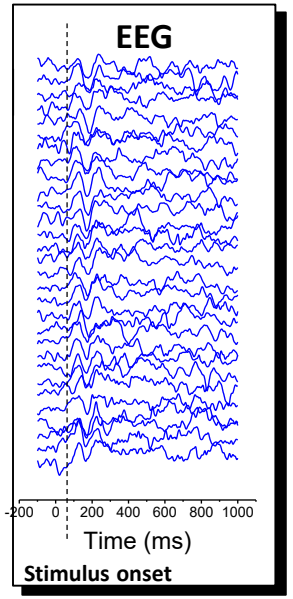
1. ERP analysis
2. Spectrum analysis

# 1. ERP analysis

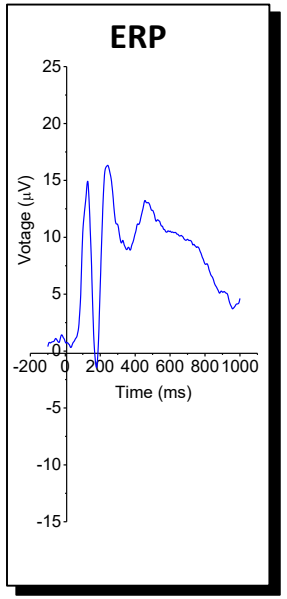


Based on a visual oddball task:




average

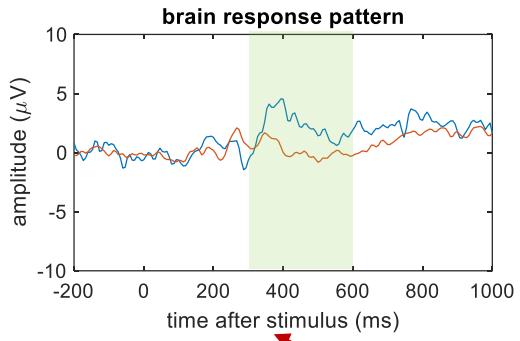


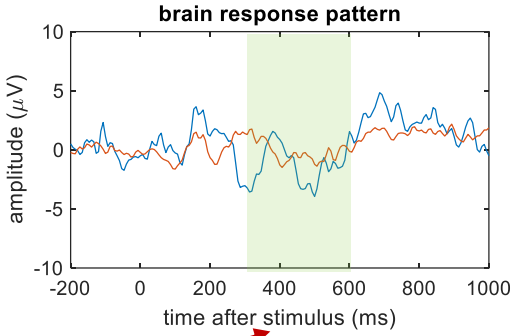

ERP (Event-related Potential)

**Code and materials:**

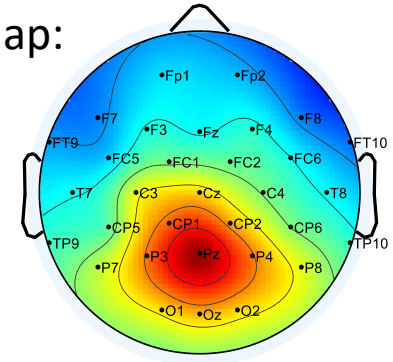
https://github.com/guangouyang/EEG_workshop

# Data visualization and analysis

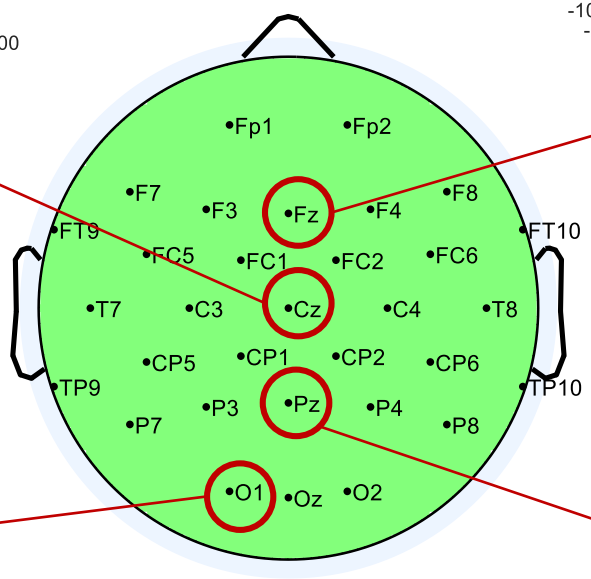


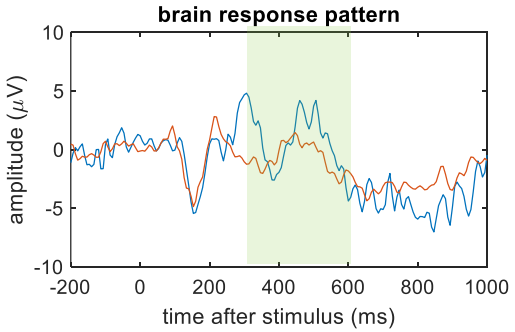



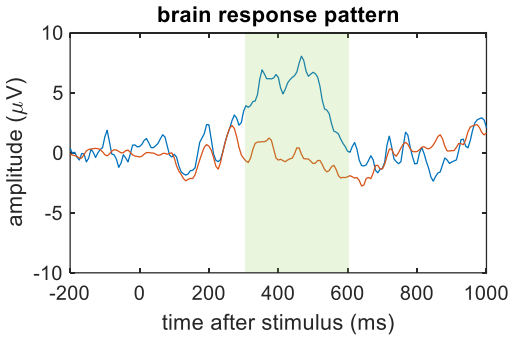

Difference map:

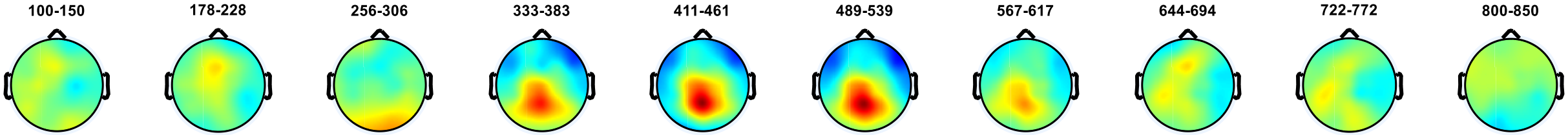



[300ms-600ms]



# Statistics

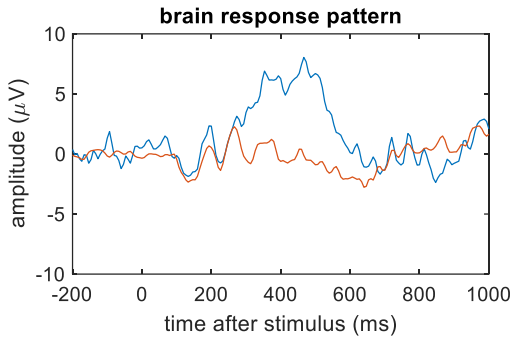
on large data sample

Individual events
Anecdotal findings
Special cases
Personal experiences
Intuitive feeling

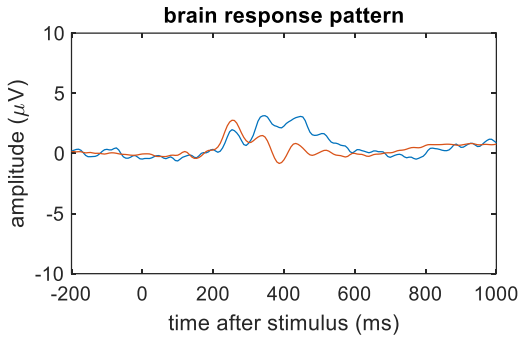
Generalizable effects
Universal principle
Theories
Scientific evidences

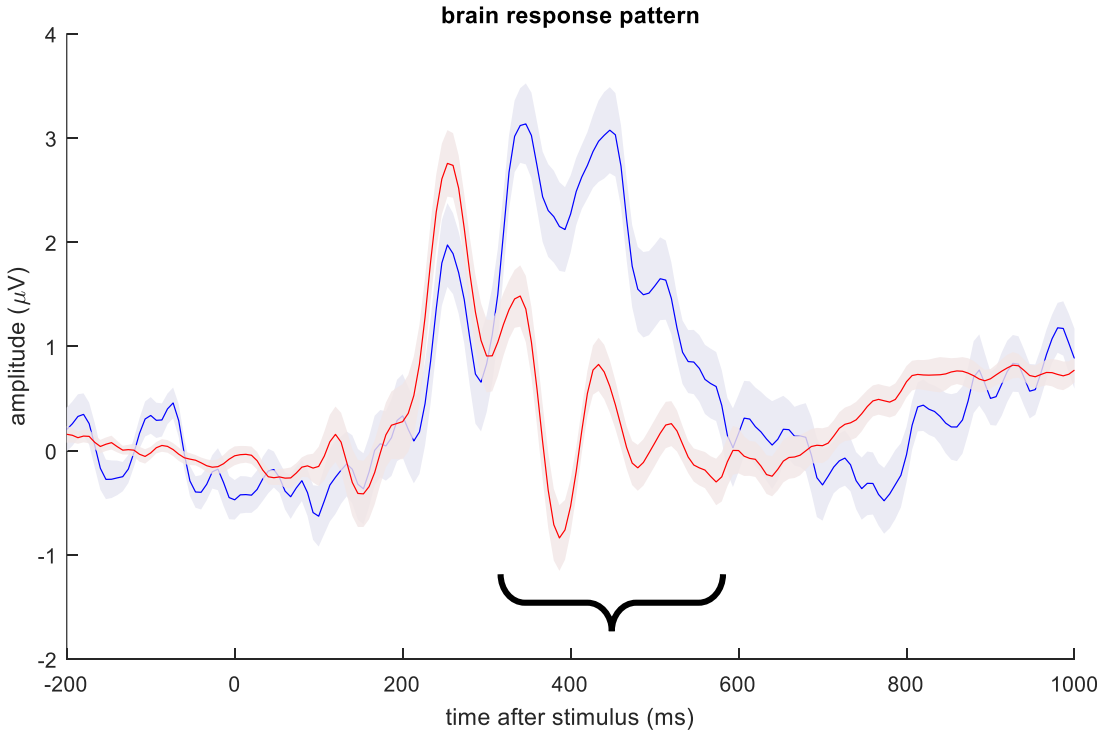
# Data visualization and analysis

From an individual subject:



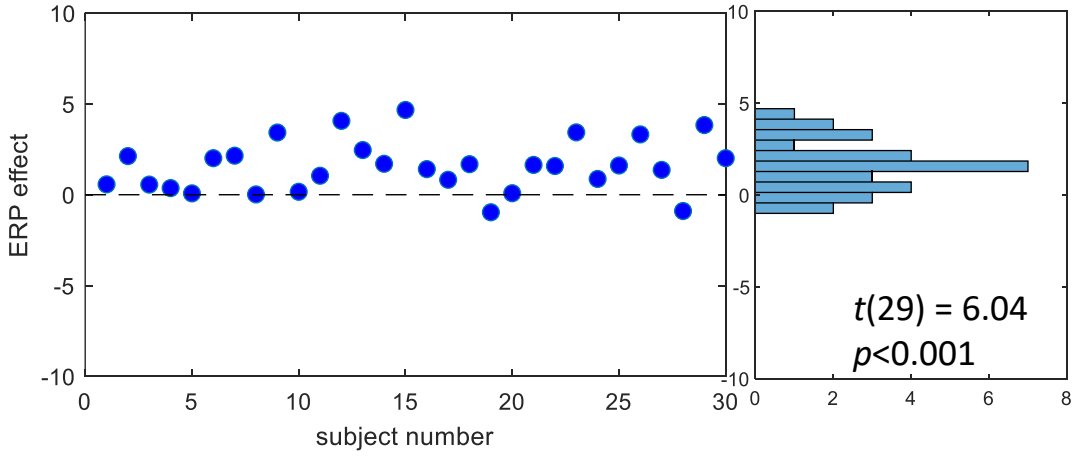

Averaged from 30 subjects:




ERP amplitude difference (300-600ms) for all subjects

Prob. Dist.

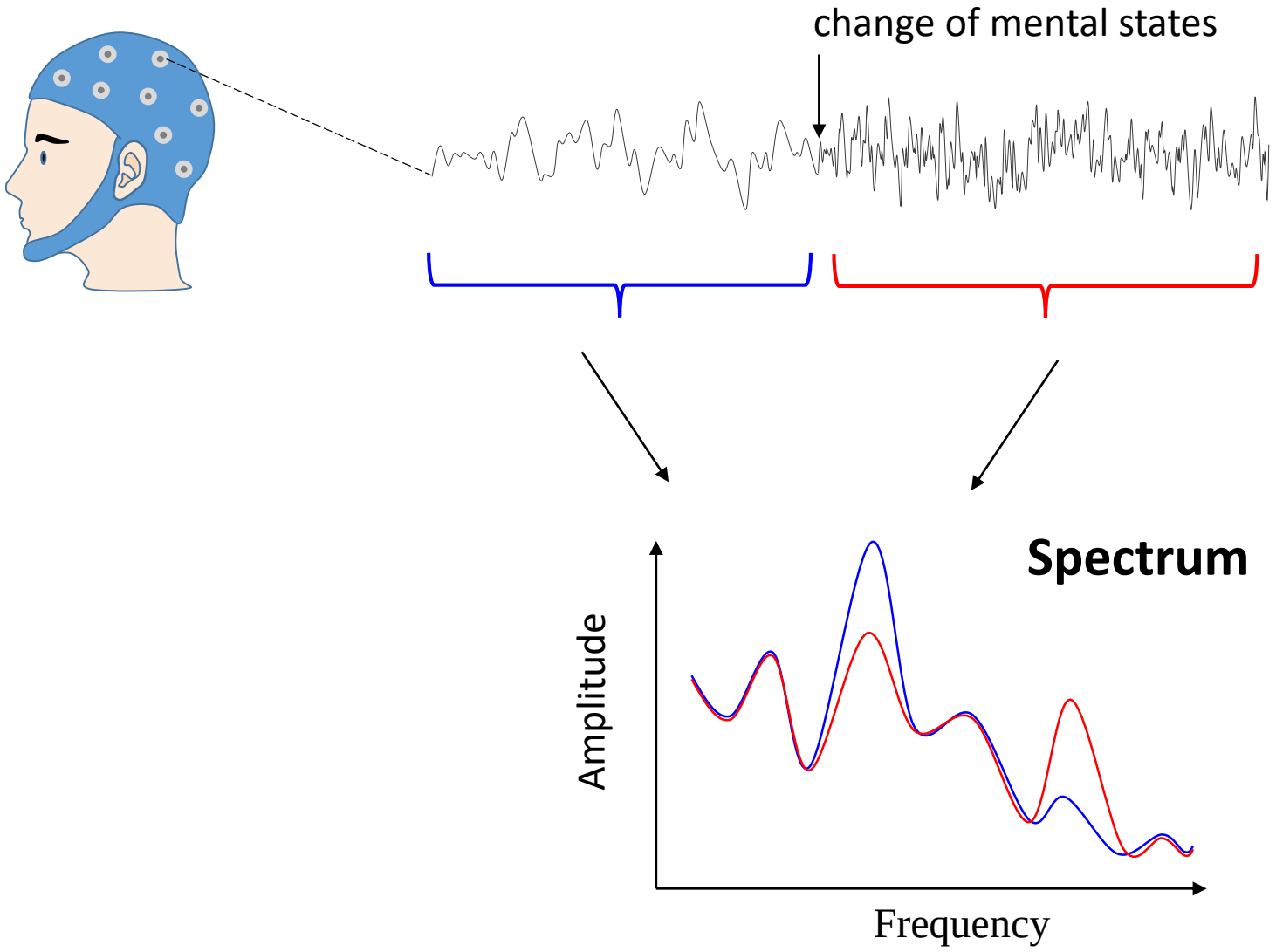


# Advanced statistical analyses

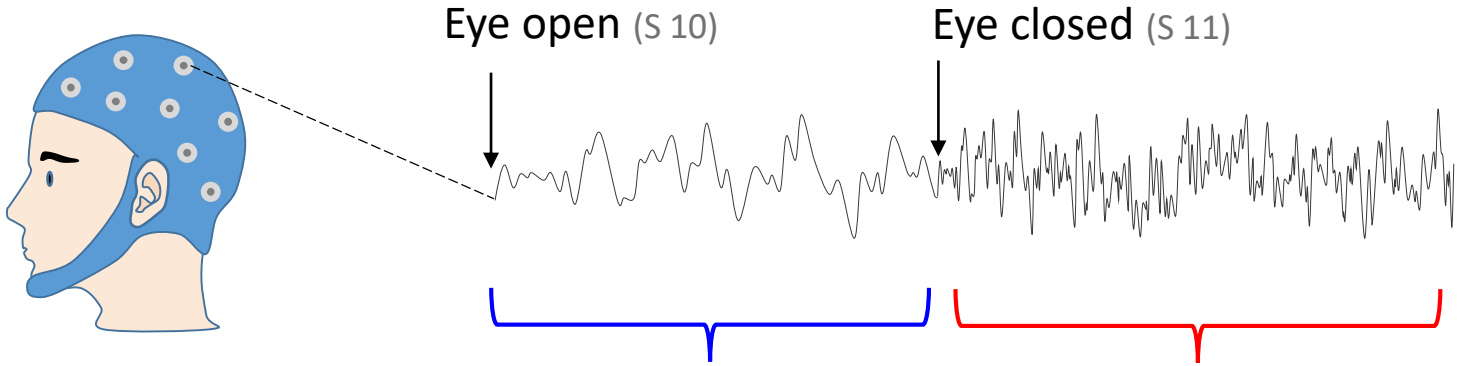
The EEG data collection and preprocessing will generate data that are not different from any other kinds of data in other fields
e.g., humanity and social sciences, biological sciences, psychology, educational sciences.
So, after processing and parameterizing your data, you can apply any kinds of statistical analysis depending on your experimental design.

- Correlation
- ANOVA/ANCOVA, etc
- Linear mixed model
- Factor analysis
- Structural equation modeling
- etc

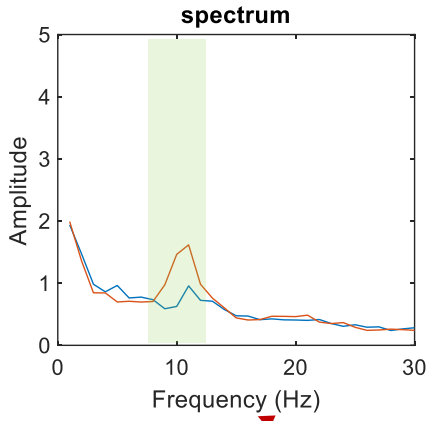
# 2. Spectrum analysis

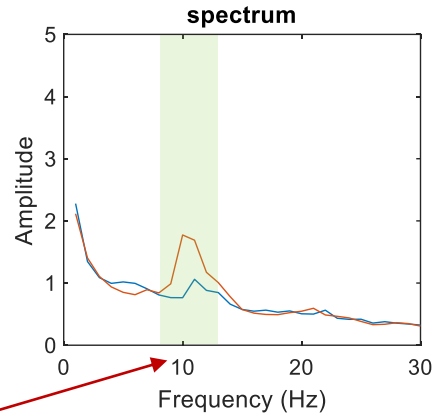


# Sample data

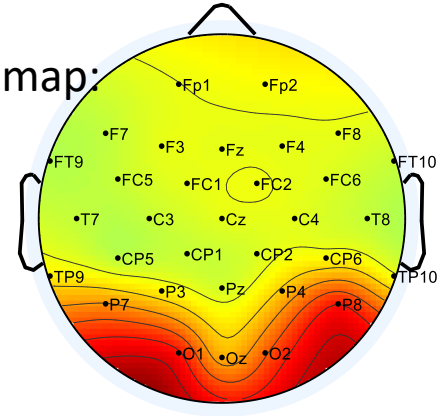


# Data visualization and analysis

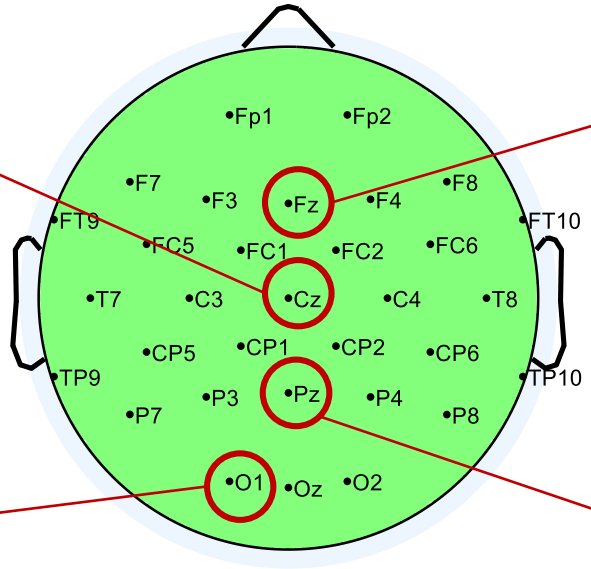


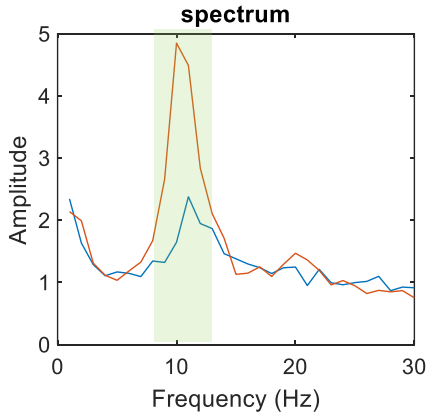



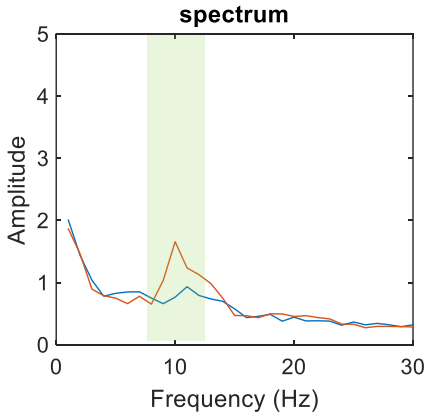

Difference map:




[8-12Hz]



# Outline

- Basic concepts
- Major principles and methodologies
- Real-time demonstration of EEG data collection
- Data visualization and analysis
- Advanced topics

# Advanced topics

Upon acquiring the basic skill sets and understanding of EEG data and technology, you can further …

- Conduct sophisticated analyses
  - Time-frequency analysis, network/connectivity analysis, extract complex features (e.g., entropy), dynamical modeling, advanced statistic modelling, etc
- Study complex questions
  - Real-life scenes, social interaction, teaching and learning, classroom setting, complex problem solving, complex decision making, etc

Give your feedback