Experimental design, part A

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Mikkel C. Vinding

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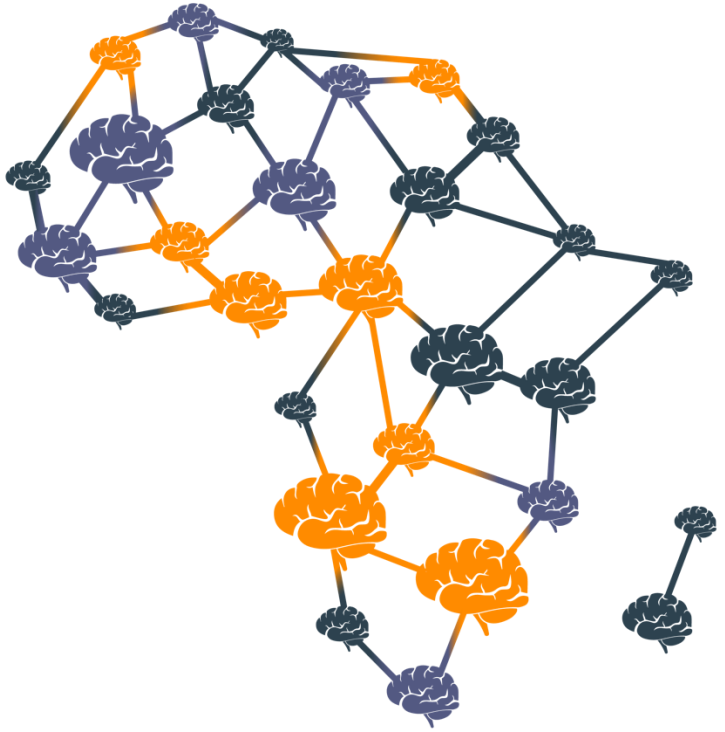
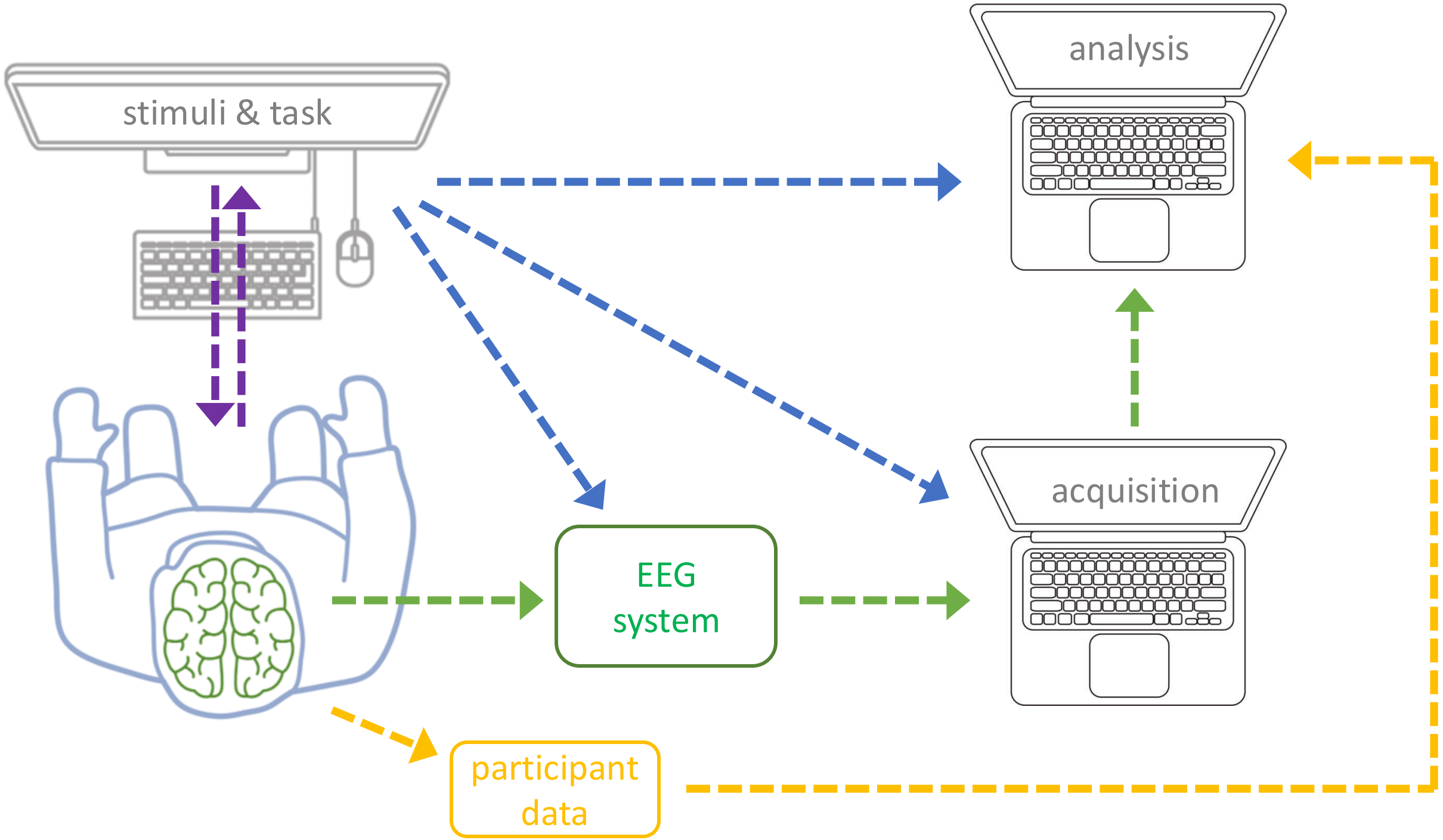
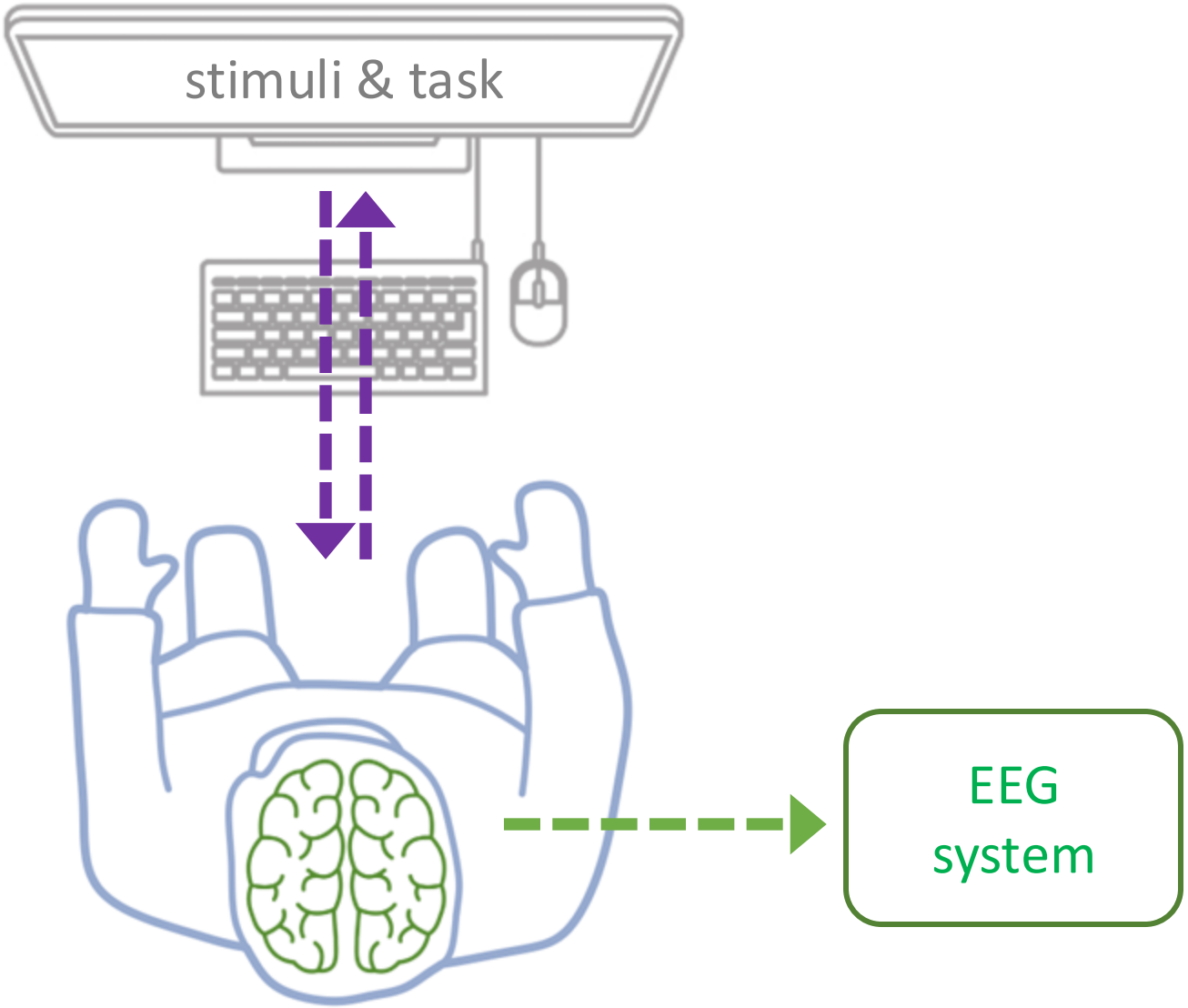


African Brain Data Network

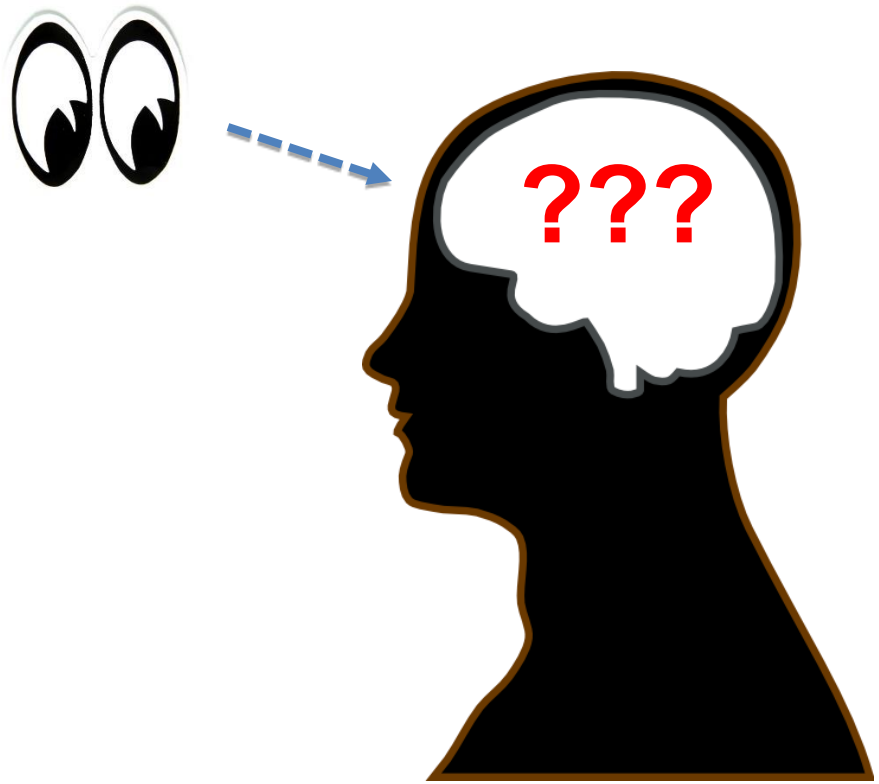
Outline

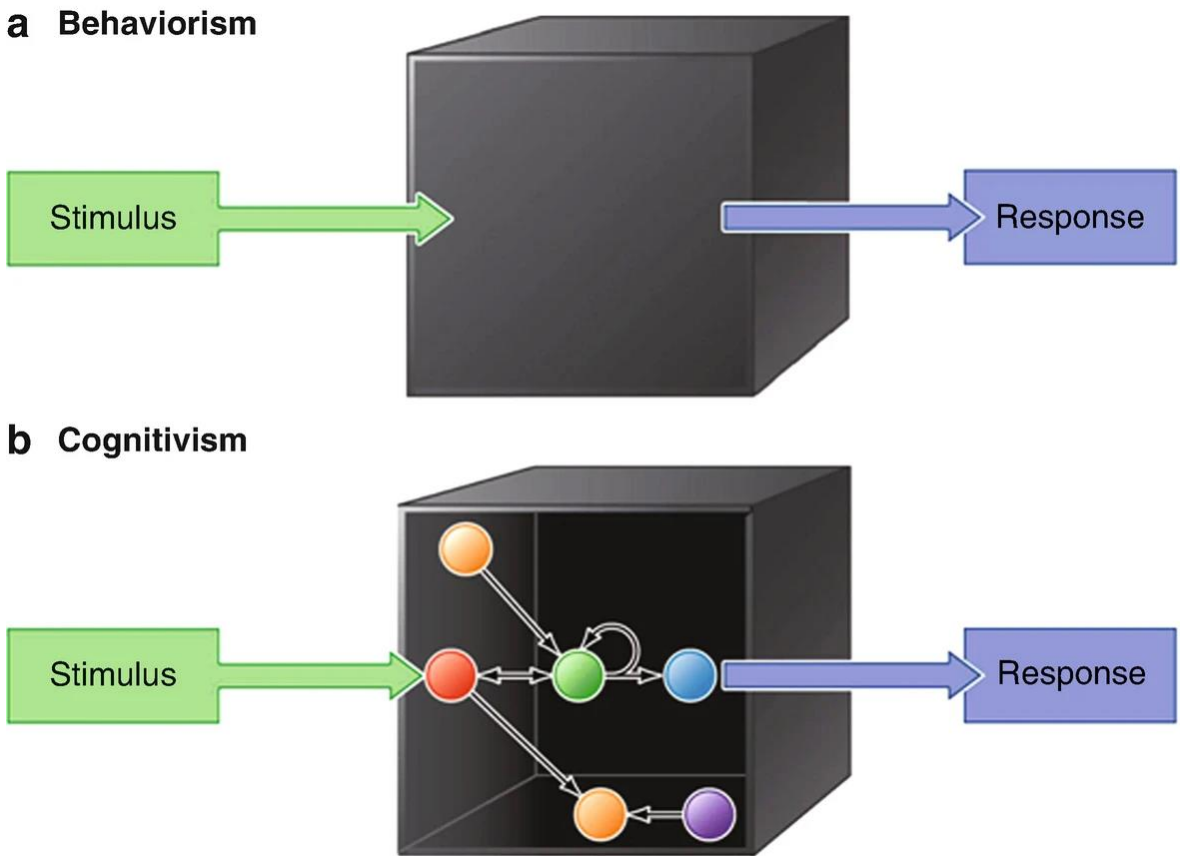
- Using EEG to understand the brain and mind
  - How to think about “EEG tasks”
- What to look for in EEG data
  - Thinking analysis into experimental design
- What we can (and cannot) conclude from EEG data


stimuli & task
analysis
acquisition
EEG
system
participant
data

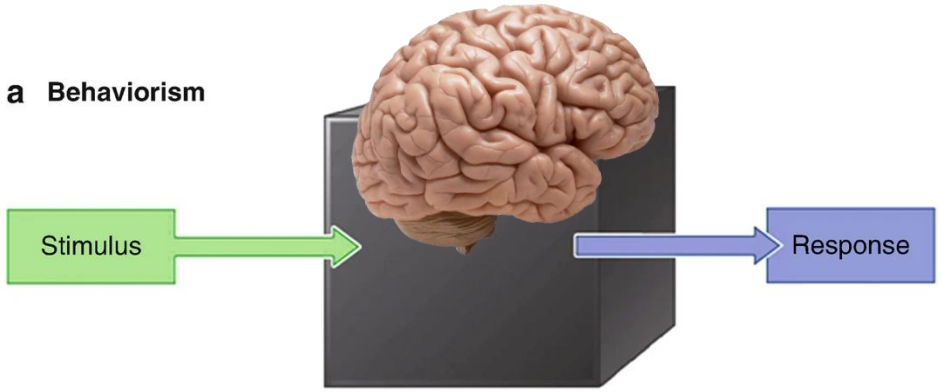

stimuli & task
EEG
system

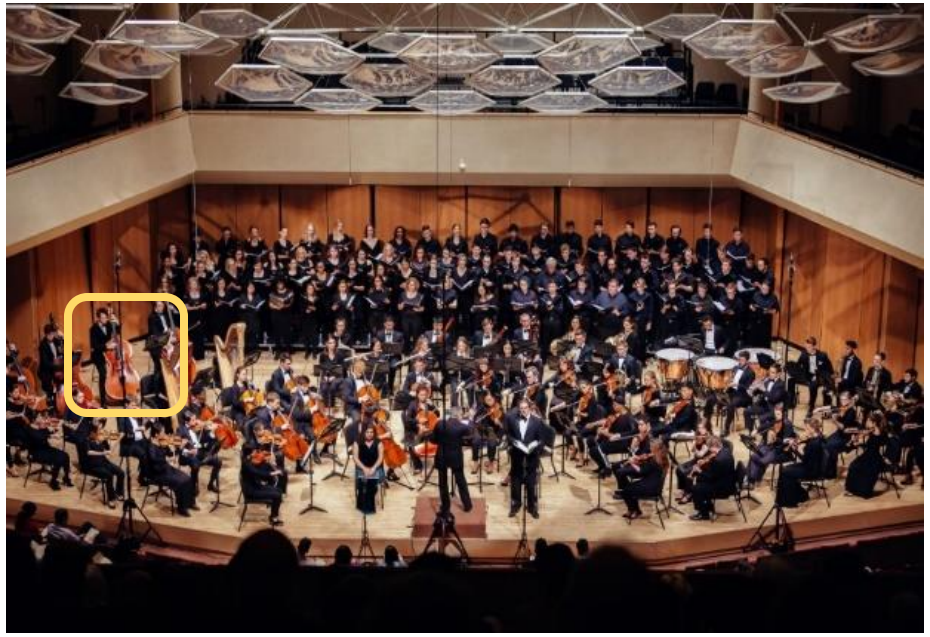
Brain and behaviour





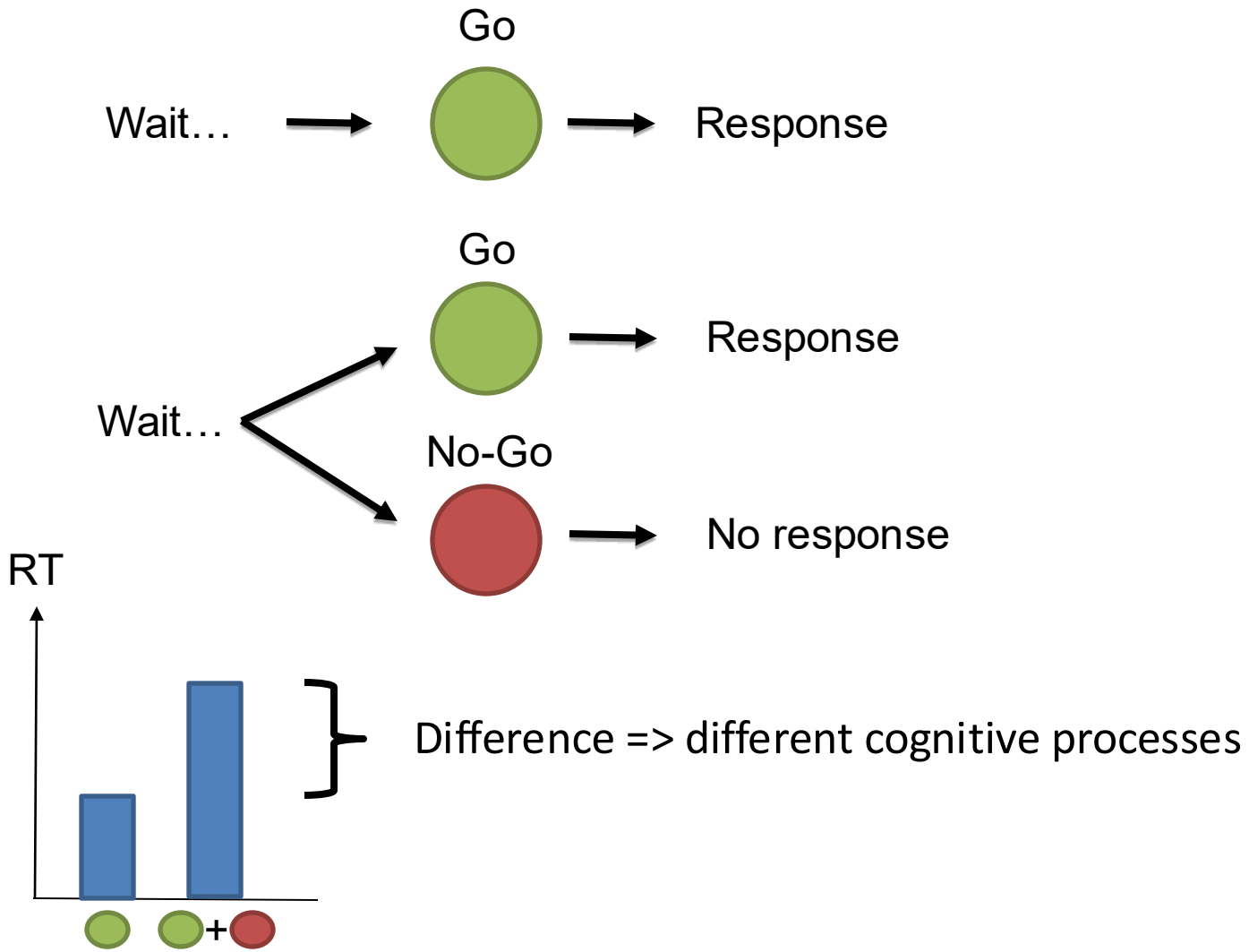
Brain and behaviour



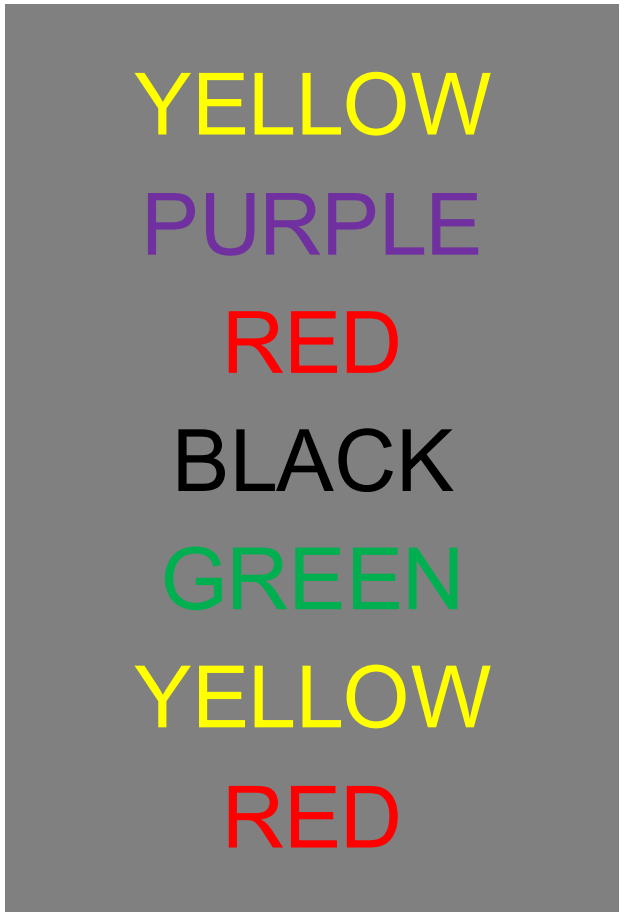


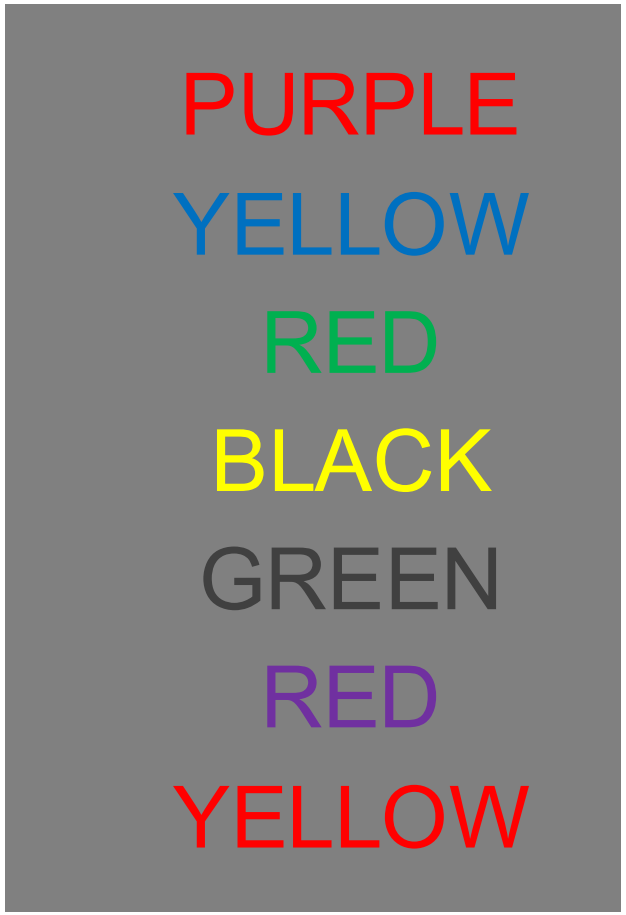
Inferring cognitive states: *the contrastive method*

Franciscus Cornelius Donders (1818–1889)

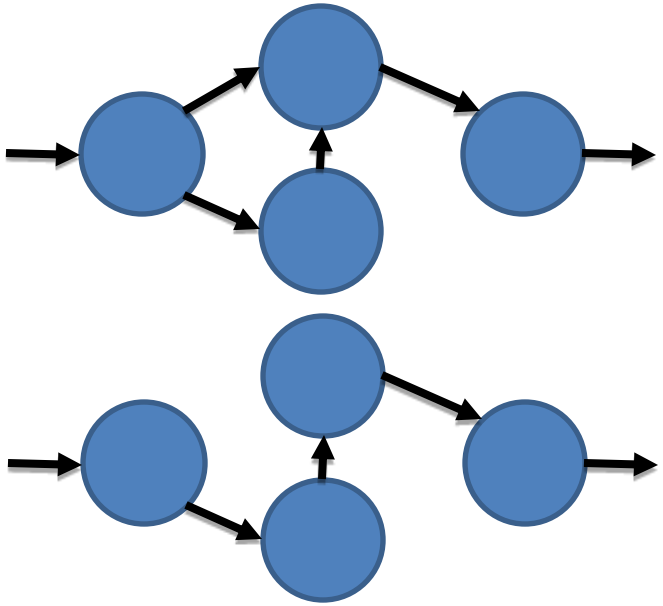


Say the colour of the word





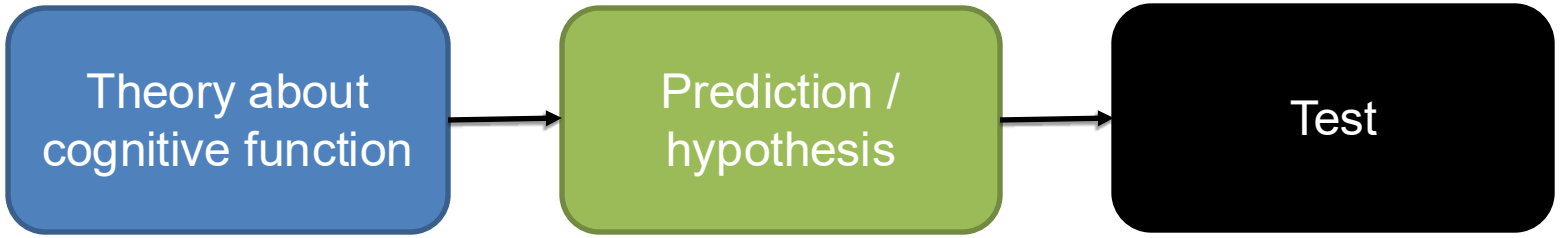
Theory about cognitive function → Prediction / hypothesis → Test

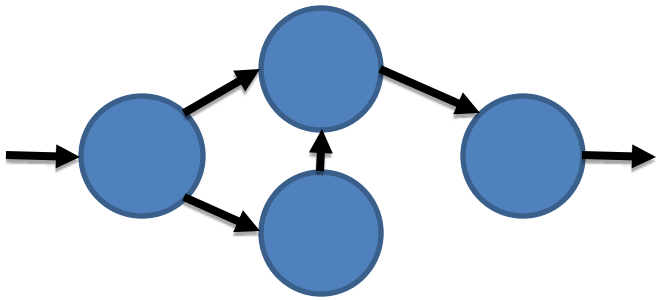


”Faster on congrurrent trials”

”Equally fast”

Measured responses





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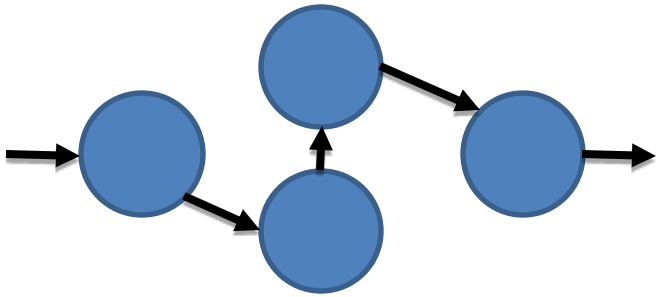
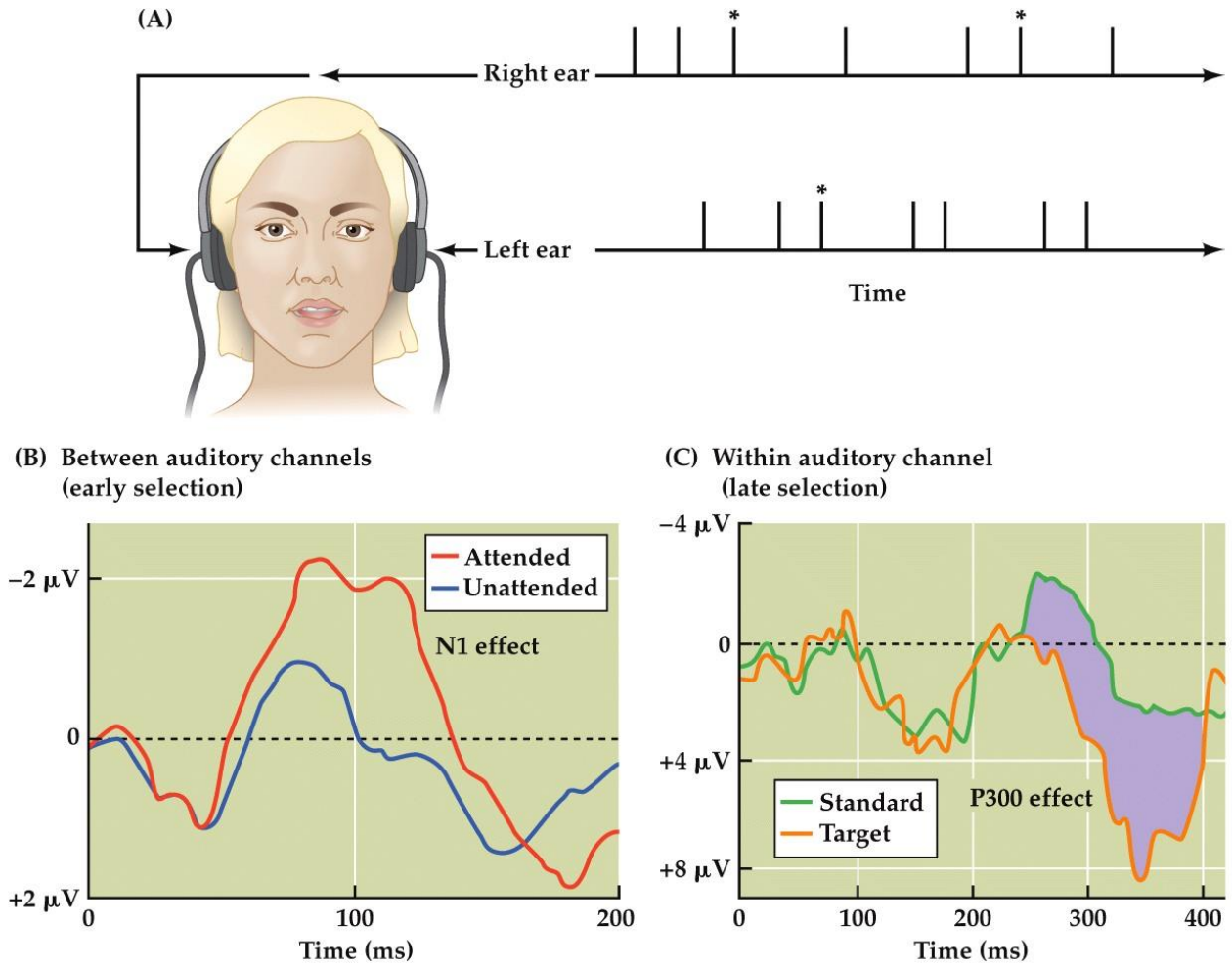
Measured responses



”Equally fast”

Brain response…



***PRINCIPLES OF COGNITIVE NEUROSCIENCE 2e*, Figure 6.7**

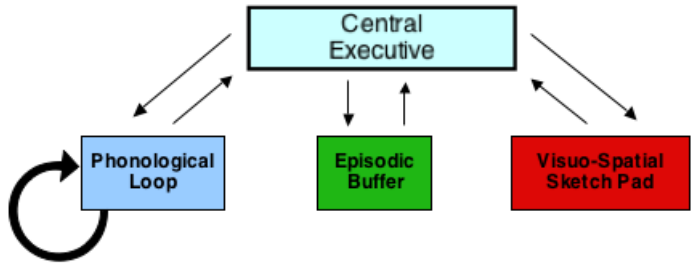
Cognitive theories and brain activity

Concept | **Cognitive model** | **Cognitive modelling**

Attention

Memory

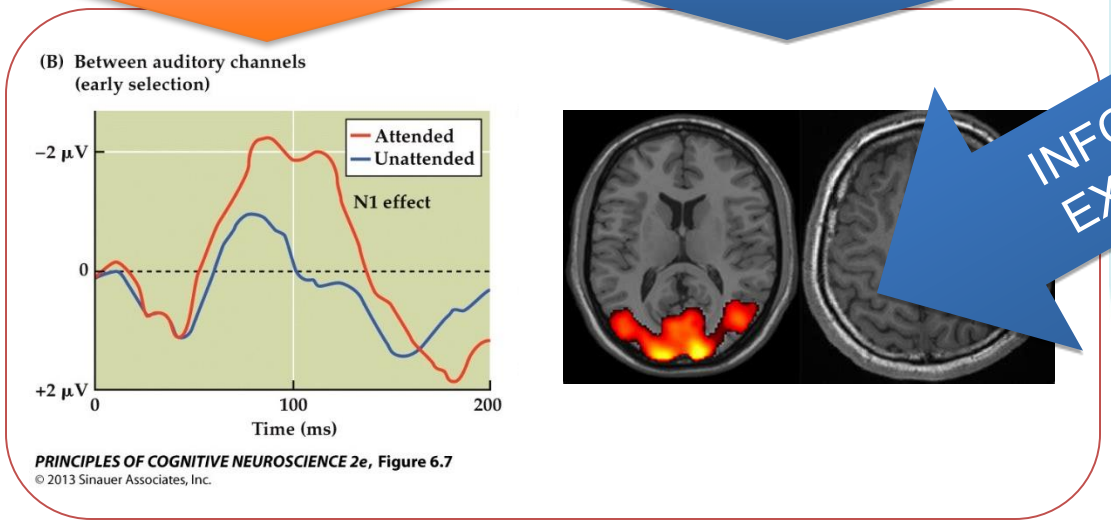
Decision

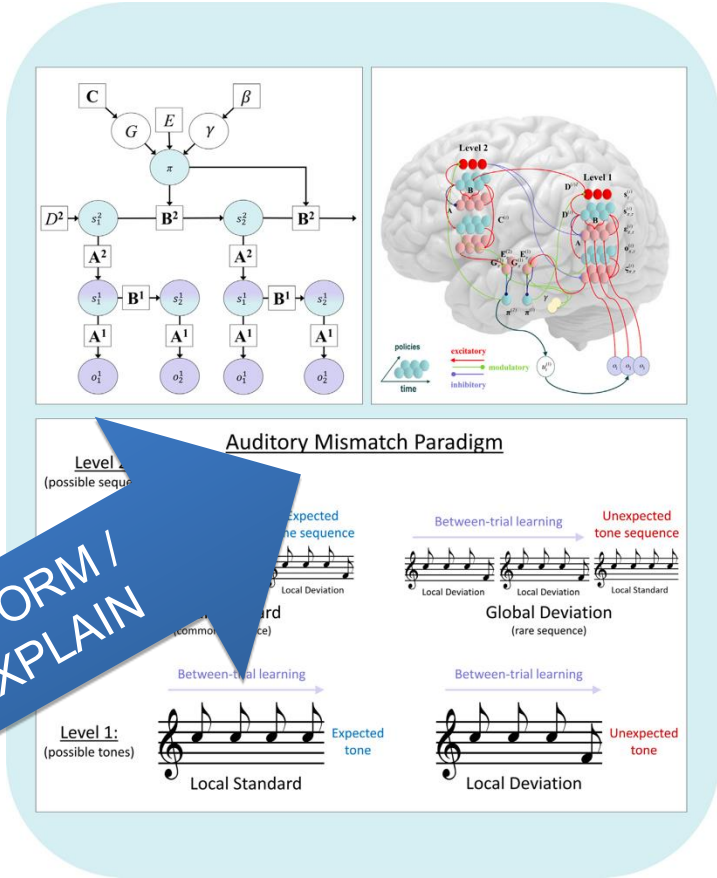


MAPPING

TEST

INFORM / EXPLAIN

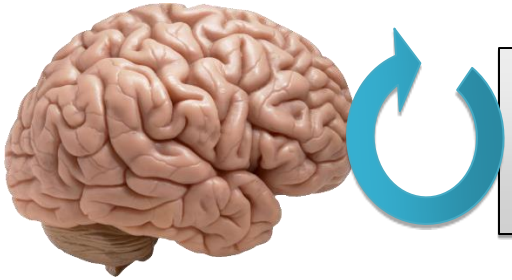




http://mercercognitivepsychology.pbworks.com

Smith et al. (2022)

Cognitive theories and brain activity



Cognition

Brain process

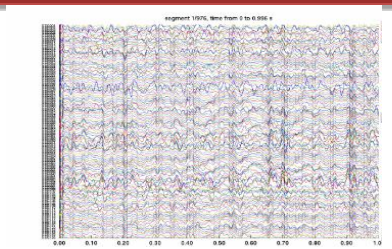
Measurement method

Recorded signal

Cognitive theory

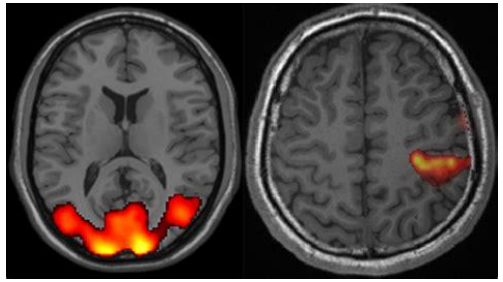
Cognitive task

Observed behaviour



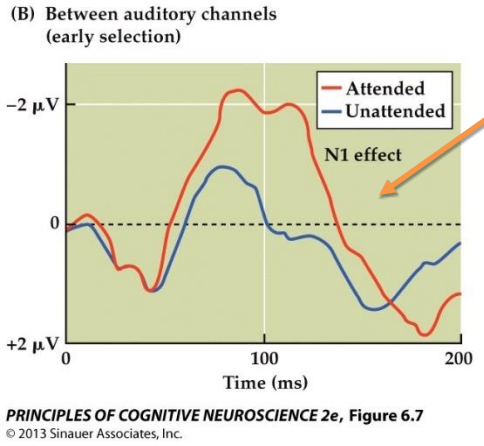
Correlation?

RT, performance, etc.



Now the brain is doing *F*

This is where the brain is doing *F*



PRINCIPLES OF COGNITIVE NEUROSCIENCE 2e, Figure 6.7

To do

- Conclusion about involvement
- Test specific hypotheses about *F* (or *F*s)
- Infer differences between cognitive functions F_1, F_2 (given X_1, X_2)

Typical experimental designs

Within-participant design

Different conditions, same person

Accounts for person-level noise

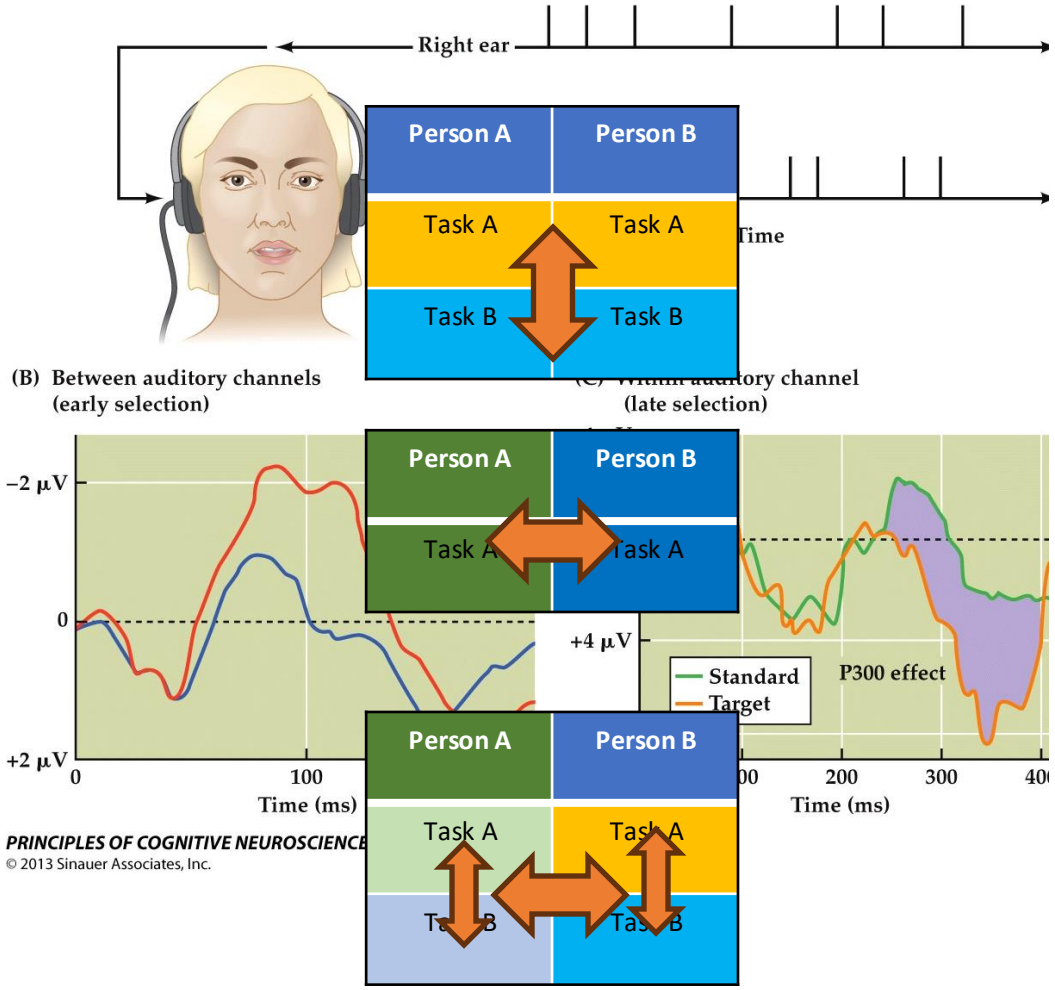
Between-participant design

Same task, different groups

Be aware of between group “noise”

“Mixed” design

Different conditions, same person, difference in within-participant difference groups



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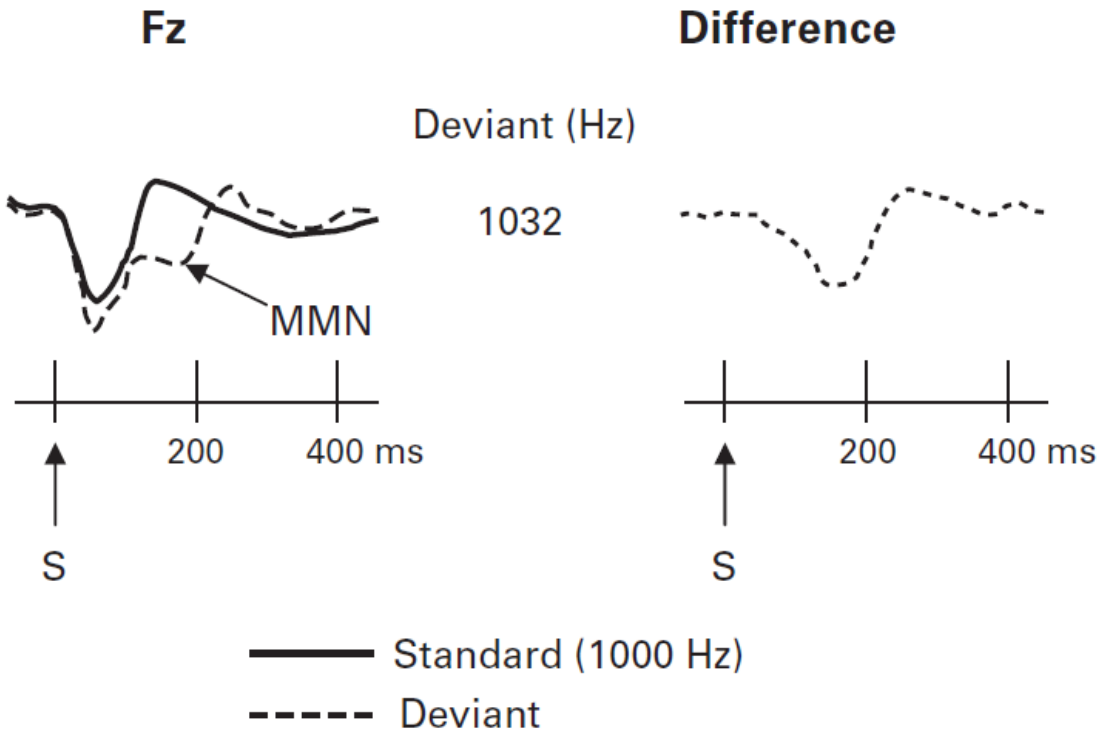
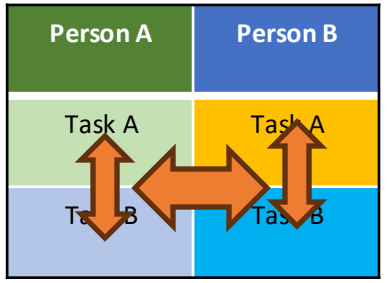
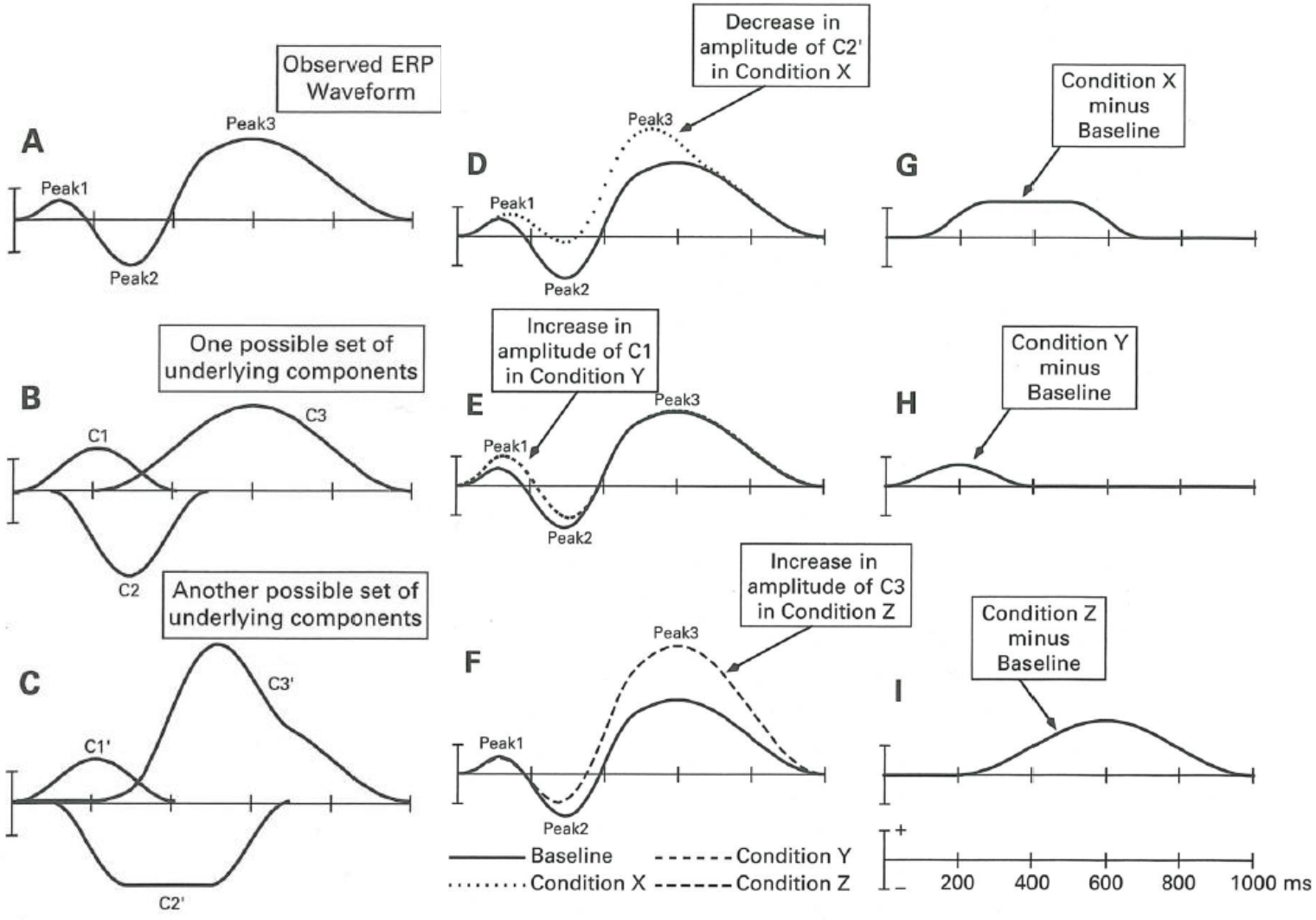




Difference waves to isolate components

- Difficult to infer process from scalp potentials
- Waveform changes does not map 1:1 to change in the underlying processes
- Match conditions -> substract waveforms



Difference wave **= Condition A – Condition B**

Luck (2014)

Ideally, the only difference between experimental conditions *X* and *Y* is the brain/cognitive process *F* of interest

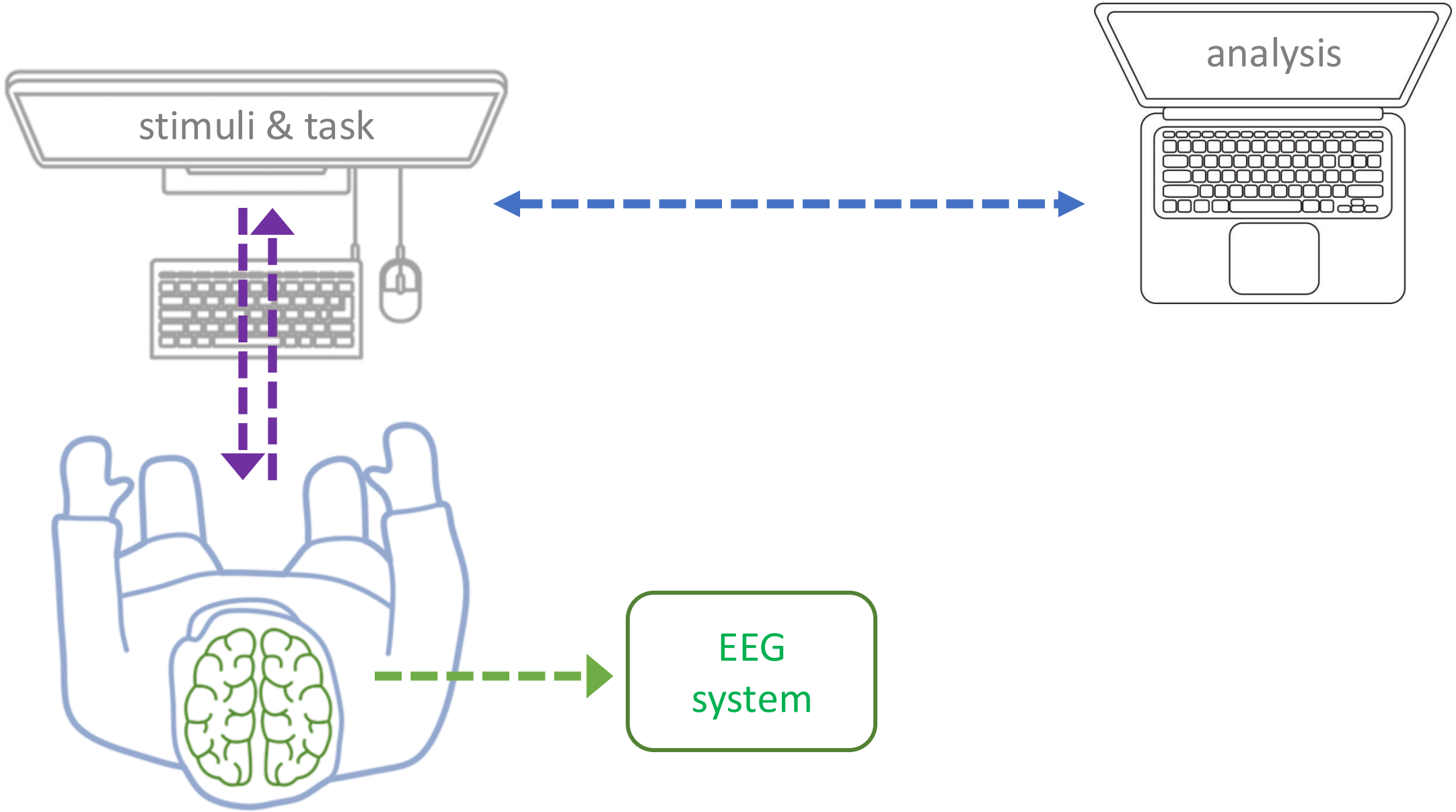
- Common experimental confounds:
  - Stimulus features -> Match stimuli features, “sham” stimuli
  - Engagement -> Match task requirements (as much as possible)
  - Attention -> Balanced designs, intermixed trials, catch tasks, breaks, …
  - Behavioural responses, RT -> Delayed response (if possible), incorporate RT in analysis

- Common EEG-specific confounds:
  - Blinks -> Match stimuli features, “blink screen”
  - Environment noise -> Keep stable measurement setting, “sham” stimuli
  - Muscle noise -> Ensure participant comfort
  - Vigilance/sleepiness -> Balanced designs, breaks (as appropriate), experiment length

Experimental design: linking brain and behaviour

- What brain/cognitive function do I want to investigate?
- What is the relation between task and function?
- How can I isolate the brain function of interest?
- *What EEG responses should I look for?*

What EEG responses should I look for?


stimuli & task
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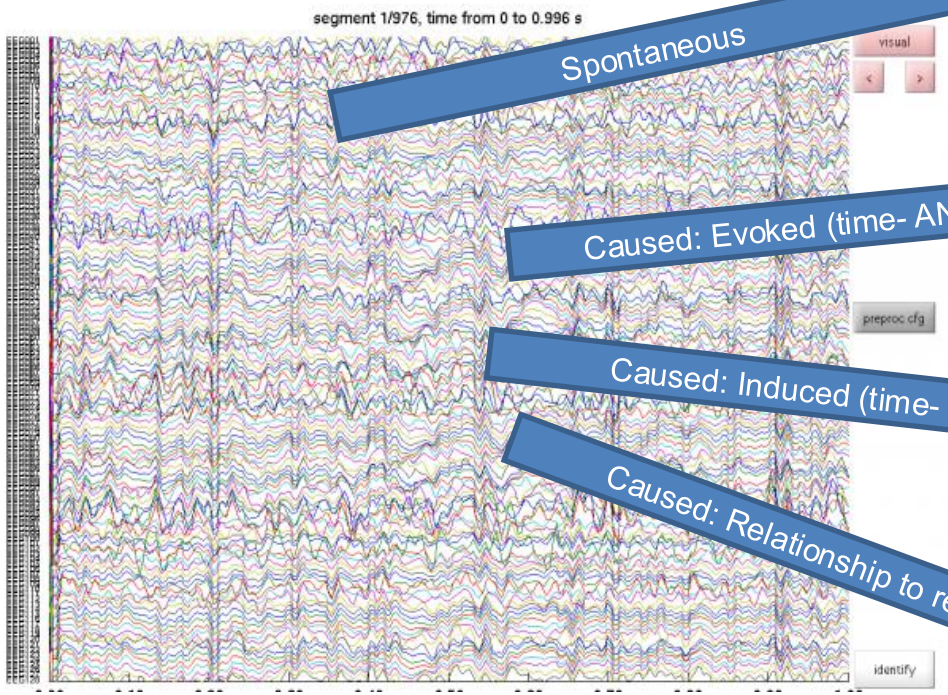


Spontaneous

Caused: Evoked (time- AND phase- locked)

Caused: Induced (time- NOT phase-locked)

Caused: Relationship to reference signal

Spontaneous activity
- Oscillatory activity
  - Delta, Theta, Alpha, Beta, Gamma
- ”Events”

Evoked responses
Event-related fields
All sensory modalities

Induced responses
Event-related modulation of oscillations
All sensory modalities
Brain stimulation

Frequency tagging
Coherence to motor / kinetics
Most sensory modalities

EEG design questions (you should ask yourself)

What to look for?

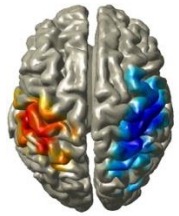
- Event-related or spontaneous?
  - E.g., event-related potentials or resting state?
- At what location?
  - Specific electrode site?
- At what latency?
- Time-domain or frequency-domain?
  - Event-related potentials

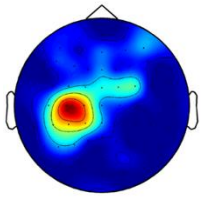
Hypotheses

- How does the EEG signal relate to the function?
- Where and where do we expect an effect?
  - Specific latency and/or electrode?
  - Specific component?
  - Frequency specific?
  - Open-ended?

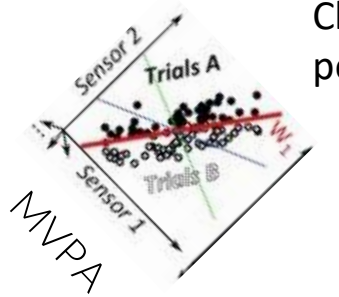
Dimensions of EEG analysis

Location:
Signals from different locations

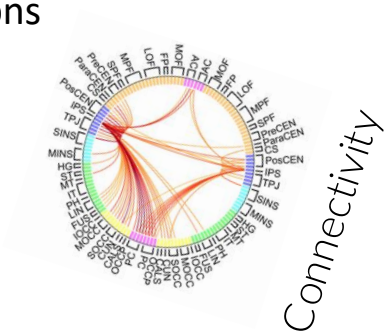


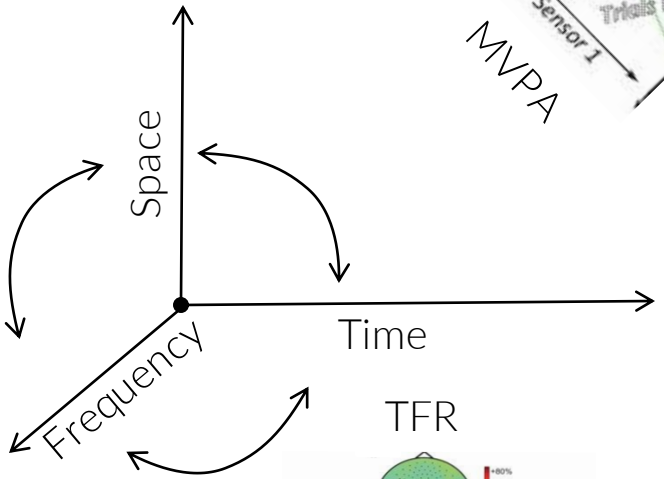


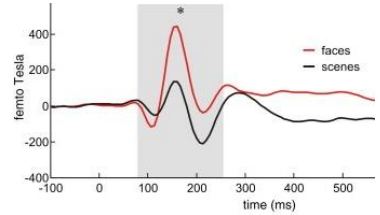
MVPA:
Classification/spatial filter per sensor and time point



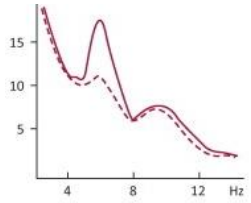
Connectivity:
Relationship between signals from different locations



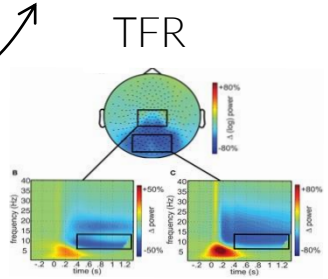




Evoked responses :
Time- and phase-locked
= Amplitude per time point



Frequency responses :
Frequency-specific
= Power per frequency band



Time-frequency responses :
Time and frequency-specific
= Power per frequency band over time

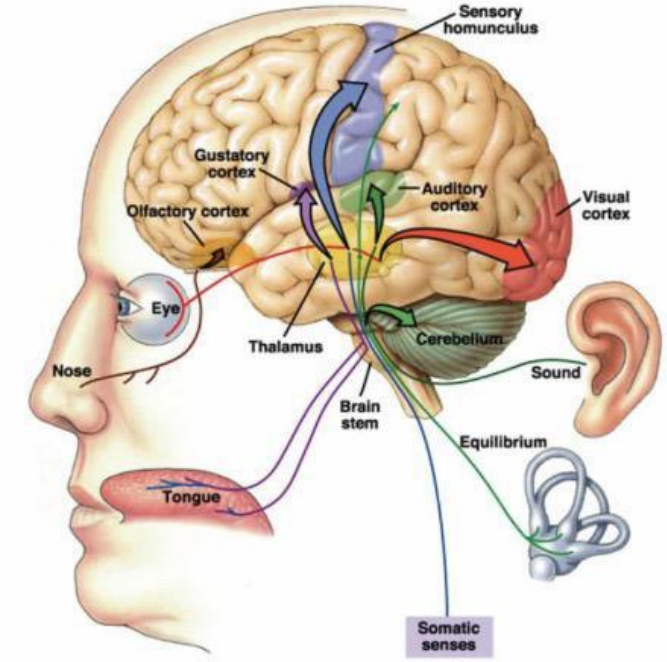
Design considerations: stimulus

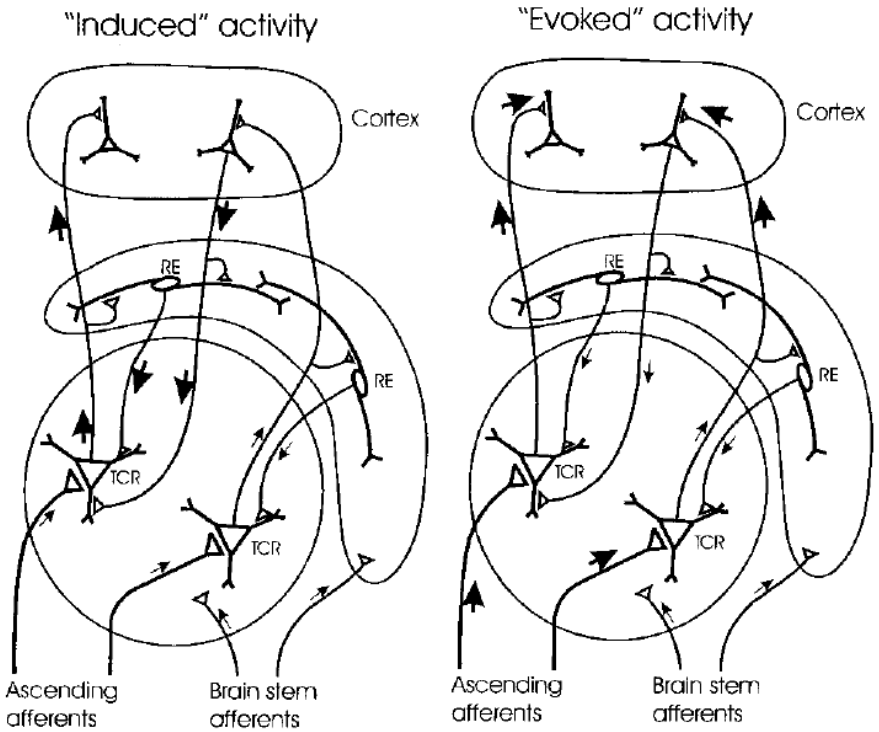
Primary sensory stimulation

- Visual
- Auditory
- Olfactory
- Tactile/motoric
- …

Secondary/cognitive stimulation

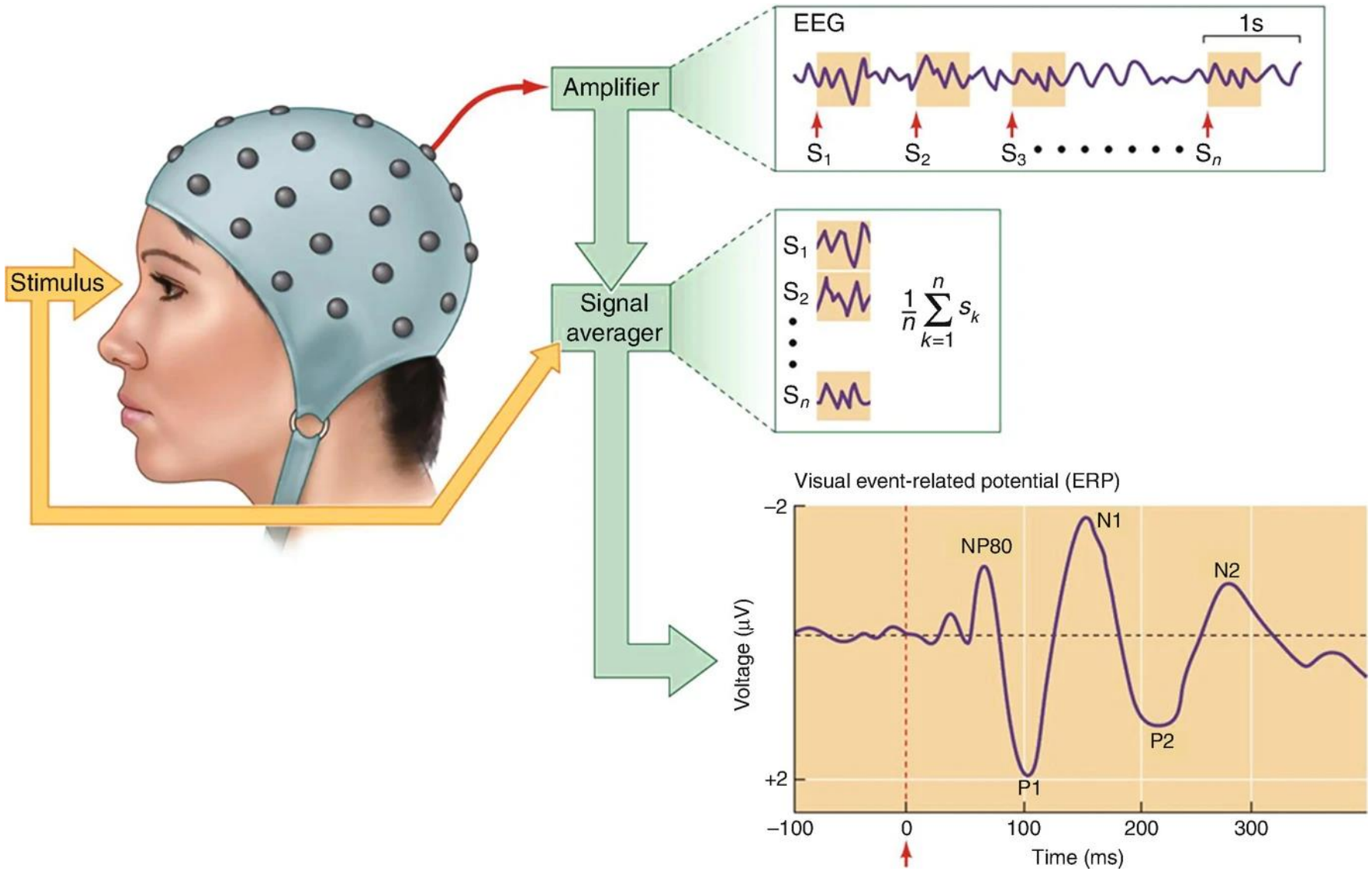
- Reward processing
- Conflict monitoring
- Decision-making
- Word comprehension
- …





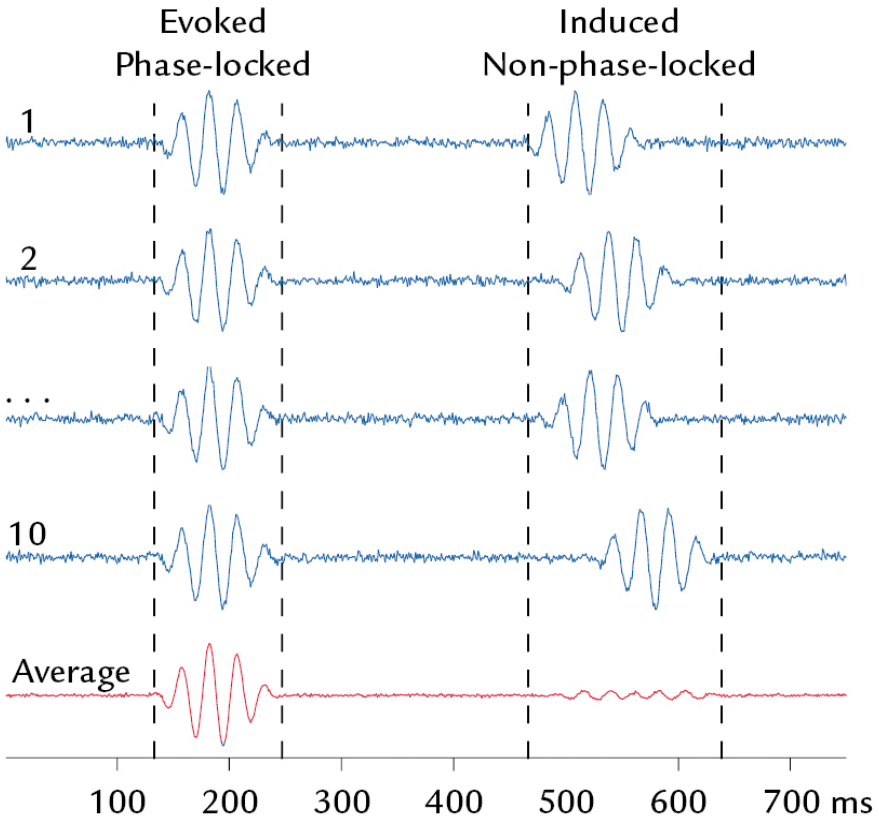
Pfurtscheller & Lopes da Silva (1999)

EEG recording and trials



Martin & Huettel (2022)

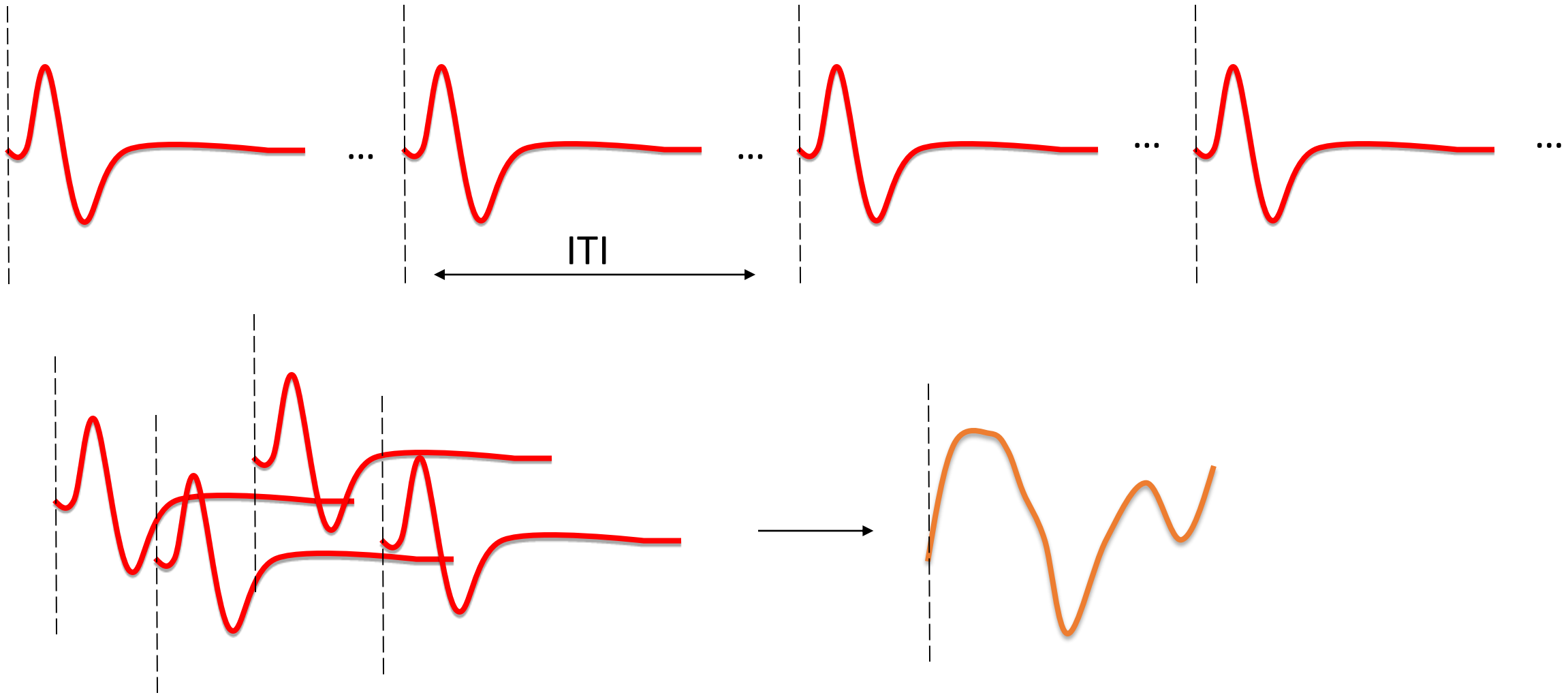
Design considerations: time-locked designs



- Type of response to stimuli?
- Timing events (triggers)
- Required number of events
- Time between events
  - What is the time for the brain response to go back to baseline?
- Repetition effects
- Overlapping components

Hari & Puce (2017)

Inter-trial interval Time between events



How many trials do I need?

Number of trials/events (per condition)	
Exceptionally few:	1-10
Unusually few:	10-50
Normal range:	50-500
Typical range:	*150-300*
Unusually many:	500-10000
Exceptionally many:	10000-100000

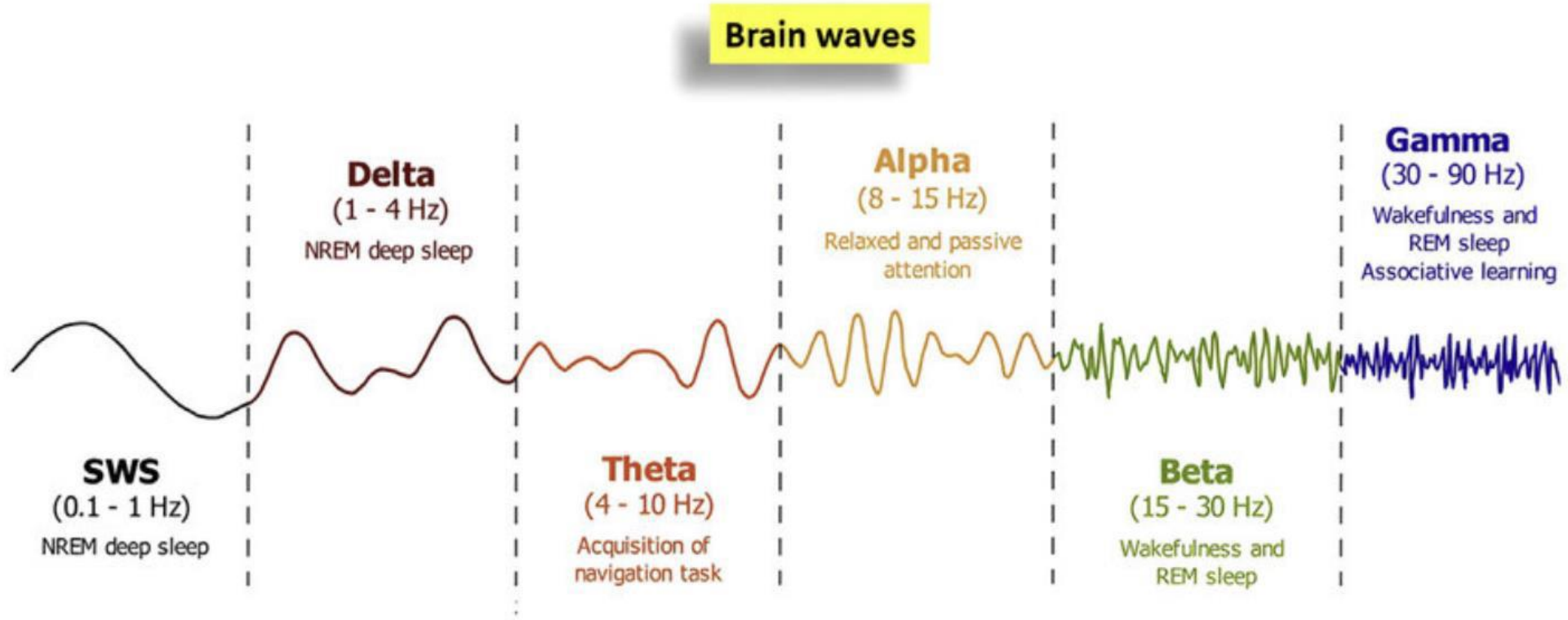
How many trials *can* I do (in 1 hr)?

Inter-trial interval (2 conditions): 1hr	
Exceptionally few:	1800s – 180s
Unusually few:	180s – 36s
Normal range:	36s-3.6s
Typical range:	12s-6s
Unusually many:	3.6s-0.18s (5.5 Hz)
Exceptionally many:	0.18s-0.018s (55 Hz)

When do I do what?

When?
Spontaneous (IEDs in epilepsy)
Emotion
Attention (mismatch negativity)
Cognition (tasks with responses)
Perception
Sensory and steady-state

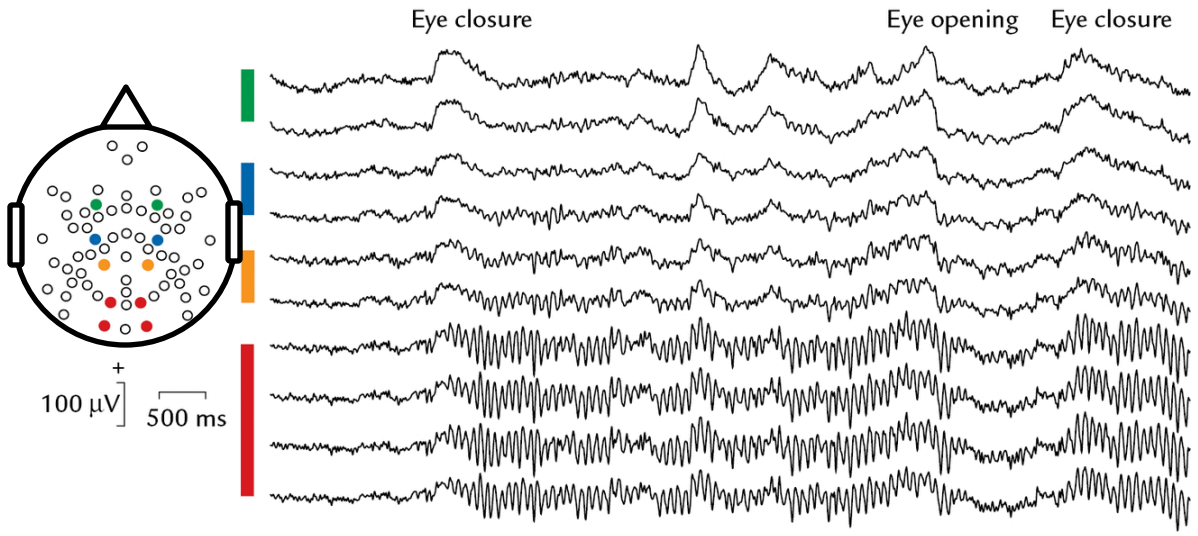
Design considerations: frequency analyses



The six major brain waves in the human electroencephalogram The brain waves are distinguished by their different frequency ranges, amplitude and meaning, in alpha (8-12 Hz), beta (15-30 Hz), gamma (30-90 Hz), delta (1-4 Hz), theta (4-10 Hz), and slow (<1 Hz) waves, reporting the related physiological functions.

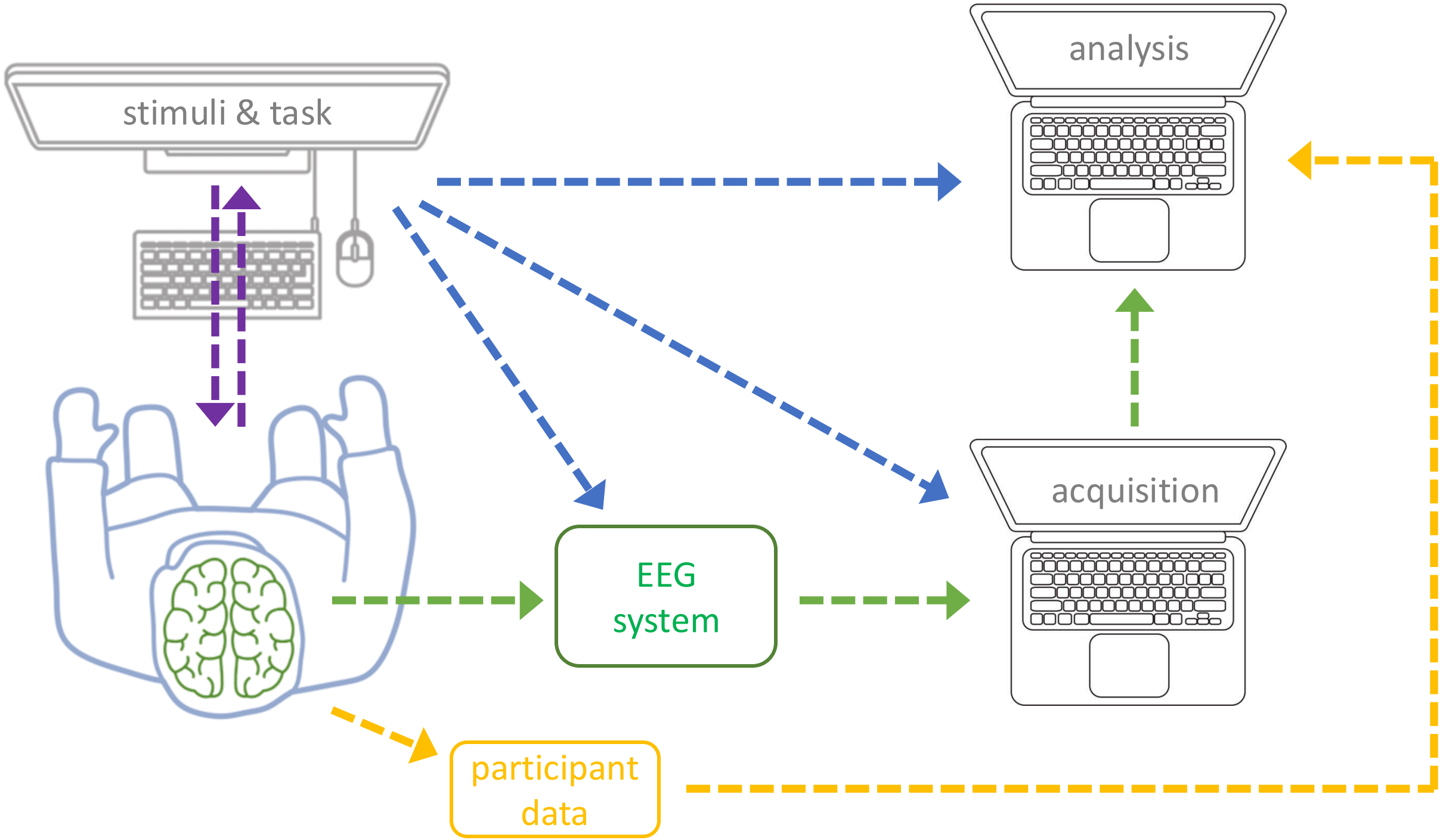
Pavan et al. (2022)

Design considerations: frequency analyses



Oscillatory brain activity: here in the alpha band (8-12 Hz)

- Sufficient window length (most relevant for time-frequency)
- Stability of rhythms over time
  - Mind wandering, “default mode-ing”
  - Vigilance/sleepiness
- Cross-frequency contamination
  - Frequency “leakage” (harmonics, filter effects, etc.)
  - Spatial “leakage” (e.g., alpha)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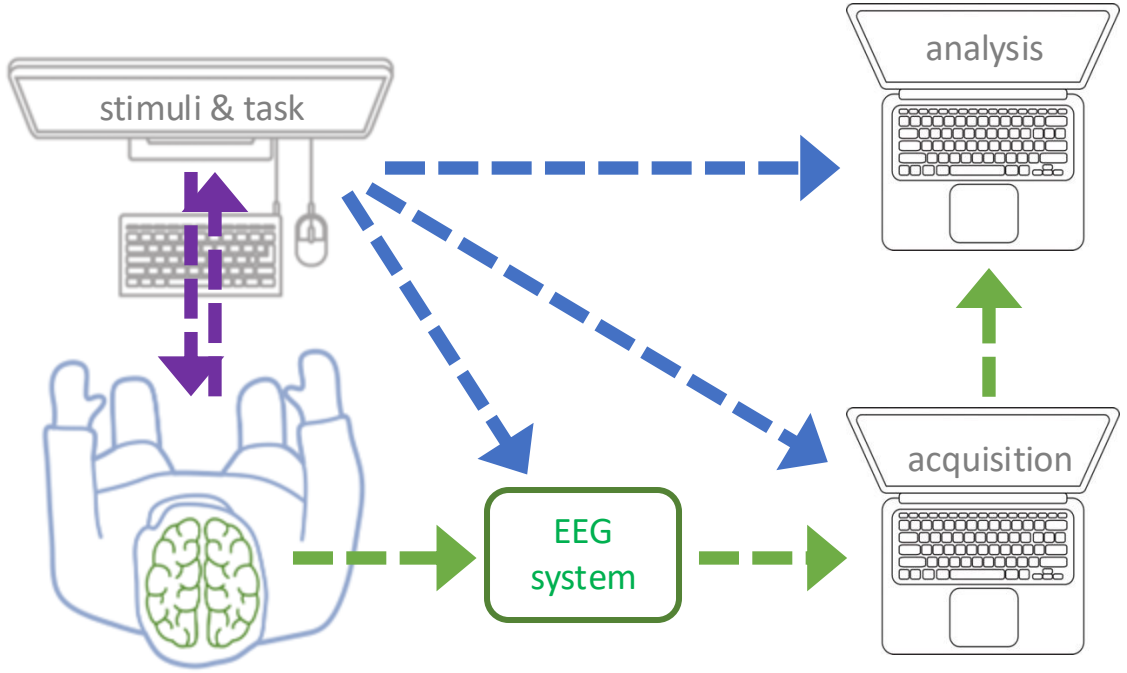
Design considerations: additional measures

Typical secondary measurements

- EOG, EMG, ECG (as appropriate)
- Behavioural responses (reaction time, performance/accuracy)
- Eye-tracking
- GSR
- Video, audio, etc.
- …

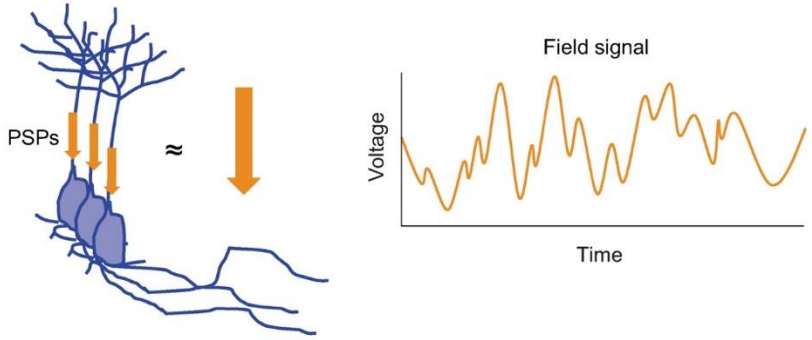


Offline measurement

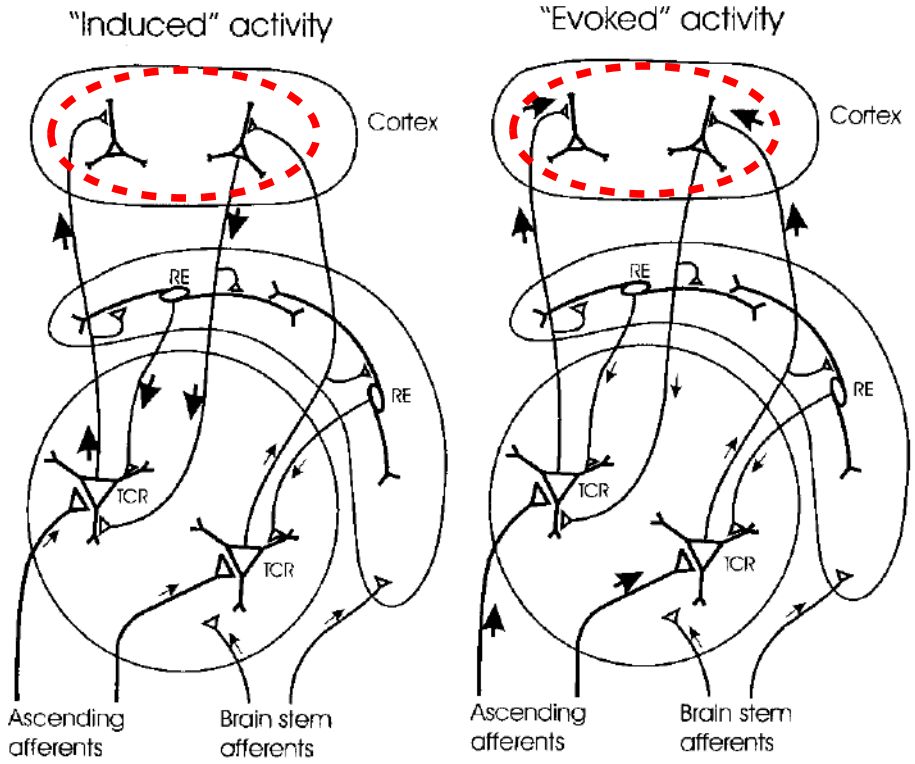
- Demographics data (age, sex, handedness, health status, etc.)
- Psychometric/neurological tests
- Interview/questionnaire data…
- *(whatever relevant data you need for your study)*

participant data

What we measure (and what we don't)



EEG measures the activity of populations of (primarily) pyramidal neurons in the cortex.



Pfurtscheller & Lopes da Silva (1999)

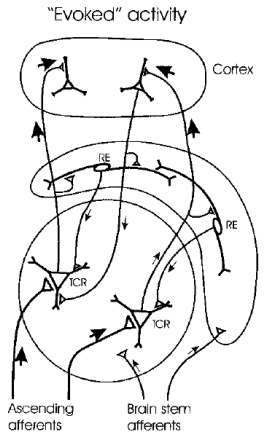
Common mistakes in EEG

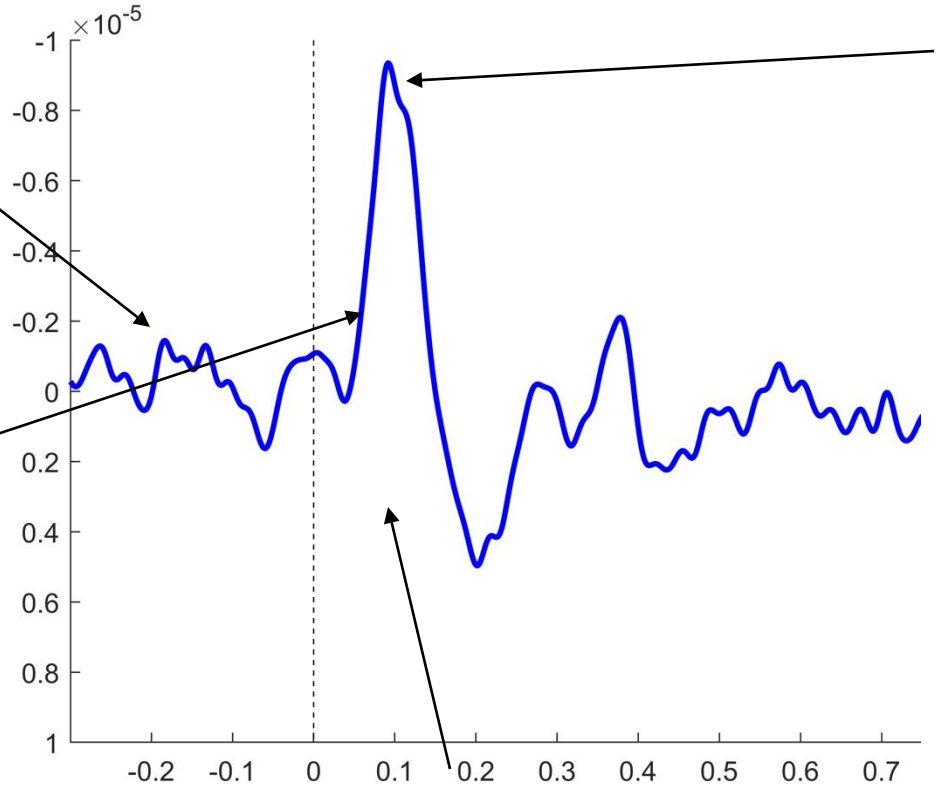
”No brain activity”

”*No stimulus dependent activity*”
There should not be!

”Here processing begins”

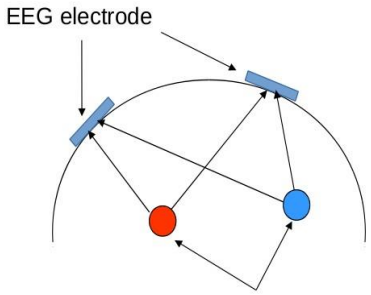
”*First cortical response*”
Remember what we measure

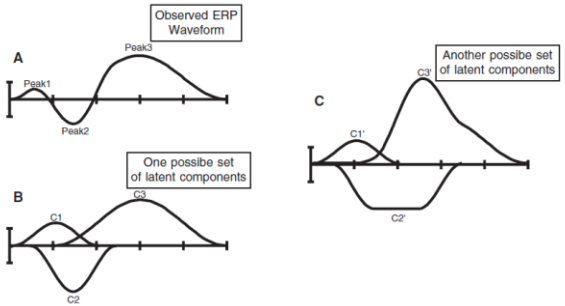




”The peak ERP component”

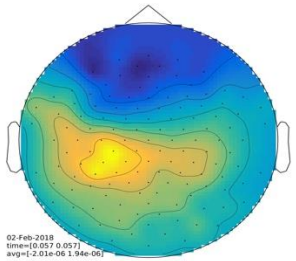
”There is nothing unique about the peak voltage” (Luck 2014)





”Stimulus is associated with negative activity”

Might be true locally, but every dipols has a positive and negative pole



Discussion

Knowing more about the EEG experiment design, discuss the ideas you had previously:

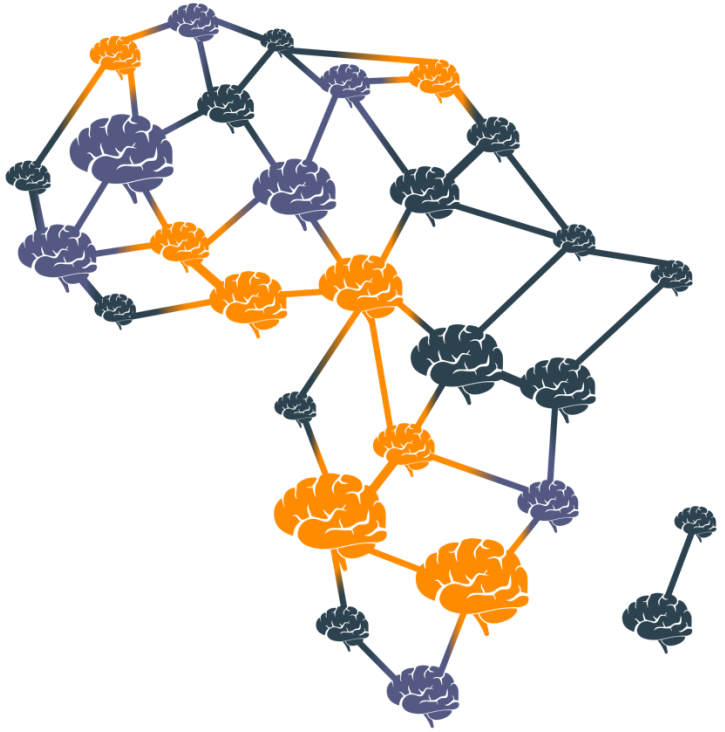
- How could an experiment of your idea look?
- What EEG response would you look for and why?
- Is there any special considerations for your experiment

Experimental design, part A

Robert Oostenveld

Mikkel C. Vinding

9-14 June 2025
Port Harcourt, Nigeria



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