IV. FREQUENCY DOMAIN ANALYSIS

EEG-TRAINING

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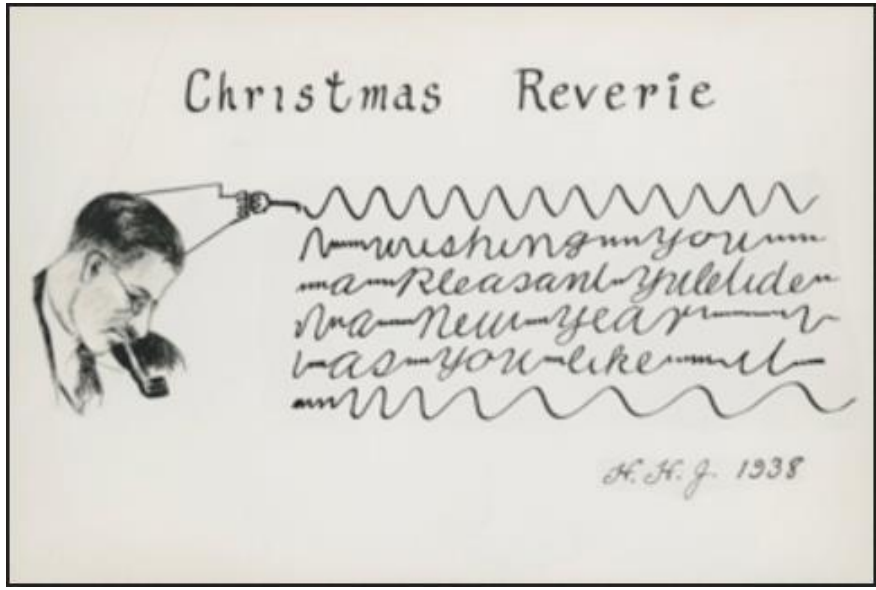
OUTLINE

1. Oscillations in the brain
2. Goal
3. Time-frequency analyses
4. Method
    1. Frequency of interest
    2. Baseline normalization
5. Application: motor-imagery BCI

1) OSCILLATIONS IN THE BRAIN

Emergence of brain oscillations

- These emerge when neurons connected together regulate each other: some neurons are excitatory, some are inhibitory, and they dominate alteratively
- Interesting bibliography:
  - Buzsáki, G. *Rhythms of the brain*. Oxford ; New York: Oxford University Press, 2006. (the "official textbook of neural oscillations)
  - Mike X. Cohen. *Cycles in mind: How brain rhythms control perception and action*. Sinc(x) press, 2015 (an easier primer on brain oscillations)



Christmas Reverie, Herbert H. Jasper, 1938, Deutsches Museum

1) OSCILLATIONS IN THE BRAIN

Classification of brain oscillations by frequency band and function

- Throughout time, some brain functions have been matched with activity in a specific frequency range
- Delta rhythms: 0.5-3Hz: sleep
- Theta rhythms: 4-8Hz: memory
- Alpha rhythms: 8-13Hz: passive attention, sensory gating
- Beta rhythms: 13Hz-25Hz: active attention
- Gamma rhythms: >25Hz: sleep spindles (RAM sleep), sensory encoding
- Other frequency bands, other names for the same frequency bands depending on the exact function and location in the brain (eg: alpha rhythms refered to as mu-rhythms in some fields of neuroscience s.a. motor control).
- In fact, the brain functions listed are the ones one would encounter on general public sources. The reality is, these are not entirely true, not restrictive, and a large undermining of their full range of function
- Can vary across and within subject!

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1) OSCILLATIONS IN THE BRAIN

Entrained oscillations

- Interestingly, oscillations in the brain can also be driven by external oscillating stimuli
- E.g.: flickering lights, perioding auditory trains
- Stead-state visually evoked potentials, auditory steady-state response (used by auditory brainstem response)
- Warning: such visual stimuli can be harmful at certain frequencies and for certain people (risk of seizure)

2) GOAL

- In the case of ERP analysis, we have seen that activity may not be extracted because not phase-locked
- This condition is not necessary to observe frequency components
- Frequency domain analysis is an umbrella term for many types of analyses, and offer a wide range of possibilities, from global estimate of brain frequency response to connectivity between brain areas
- A goal we will explore in tutorial: detect **event-related spectral perturbation (ERSP):** compared to a baseline, how the power in a certain frequency range changes as a response to an event
- Many other methods that we will not cover here. Refer to Cohen, Mike X. *Analyzing neural time series data: theory and practice*. Issues in clinical and cognitive neuropsychology. Cambridge, Massachusetts: The MIT Press, 2014. if you are interested

3) TIME-FREQUENCY ANALYSIS

- In fact, ERSP are observed in the time-frequency domain
  - Allows to correlate the event to the spectral activity in time
- Time resolution not as good as with ERPs. But the higher the sampling frequency, the better
- Compromise between the time and frequency precision (Heisenberg uncertainty principle)

4) FREQUENCY OF INTEREST

- Hypothesis driven: you know exactly, based on literature, that the phenomenon you are observing occurs at a specific pre-defined frequency range
  - You can opt for simply extracting the band of interest
- Exploratory: you assume that there is an ERSP but you do not know its frequency range
- The feature we are interested in is the power:
  1. Filter the data around your frequency band of interest
  2. Alternatively, filter the data several times in a bank of frequency ranges
  3. Compute the power at each time-frequency-electrode sample: $power = sample^2$

4) BASELINE NORMALIZATION

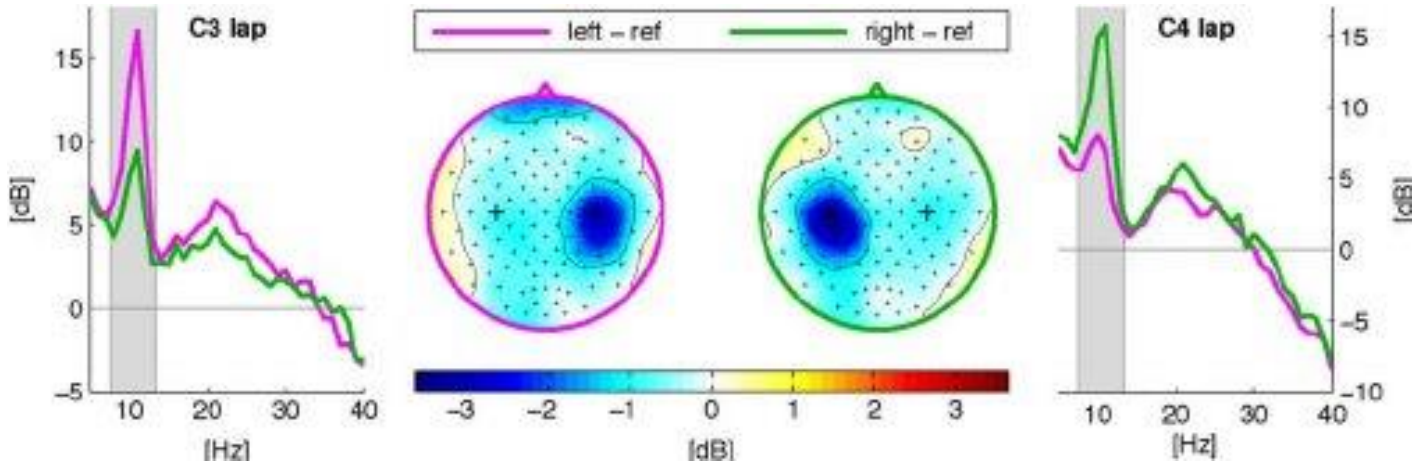
- We are not interested in absolute power, but rather in power changes (event-related spectral **perturbation**)
- Like in the time-domain, we first need to identify an appropriate baseline:
  - In that period participants are not presented with the target stimulus (nor other stimuli), or are not performing a task like in the target period

4) BASELINE NORMALIZATION

- This time, we are interested in a change compared to the baseline
- Change ratio: $C = \frac{activity_{tf} - \overline{baseline_f}}{\overline{baseline_f}}$
- dB-deviation: $dB_{tf} = 10\log_{10}(\frac{activity_{tf}}{\overline{baseline_f}})$
- $\overline{baseline_f}$= temporal mean of the power in the baseline at frequency f
- Other methods for normlization in chapter 18 of Cohen, Mike X. *Analyzing neural time series data: theory and practice*. Issues in clinical and cognitive neuropsychology. Cambridge, Massachusetts: The MIT Press, 2014.

5) APPLICATION: MOTOR-IMAGERY

- SMR (sensorimotor rhythm): alpha-like activity
- ERD: event-related desynchronisation: while imagining movements, alpha power drops in the contralateral motor area (ie if imagine movement on the left, ERD on the right lobe)



Taken from Maeder CL et al., 2012

Research directions: command of prosthetic devices, post-stroke rehabilitation, study of motor learning,…

CONCLUSION

- Event-related activity with neurophysiological meaning
- Also analyses not related to a specific event
- Computationally heavier than time-domain analysis
- Next time, we will see how to assess the significance of such observations

BIBLIOGRAPHY

- Maeder CL, Sannelli C, Haufe S, Blankertz B. Pre-stimulus sensorimotor rhythms influence brain-computer interface classification performance. IEEE Trans Neural Syst Rehabil Eng. 2012 Sep;20(5):653-62. doi: 10.1109/TNSRE.2012.2205707. Epub 2012 Jul 11. PMID: 22801528.