EEG study of workload while doing the n-back task & implementation for BCI

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BCI –
Brain-Computer-Interface

- communication pathway between brain and device

- captures neural signals from the brain

  → converts and interprets them to be used by devices

- non-invasive (EEG) and also invasive variants (electrodes inside the brain)

BCI - active vs. passive BCIs

active BCIs

- Uses brain signals that reflect user’s voluntary intention
- direct control commands
- e.g control robotic arm

passive BCIs

- monitor unintended brain activity
- affective/cognitive states of the brain
- collecting information about the user’s state

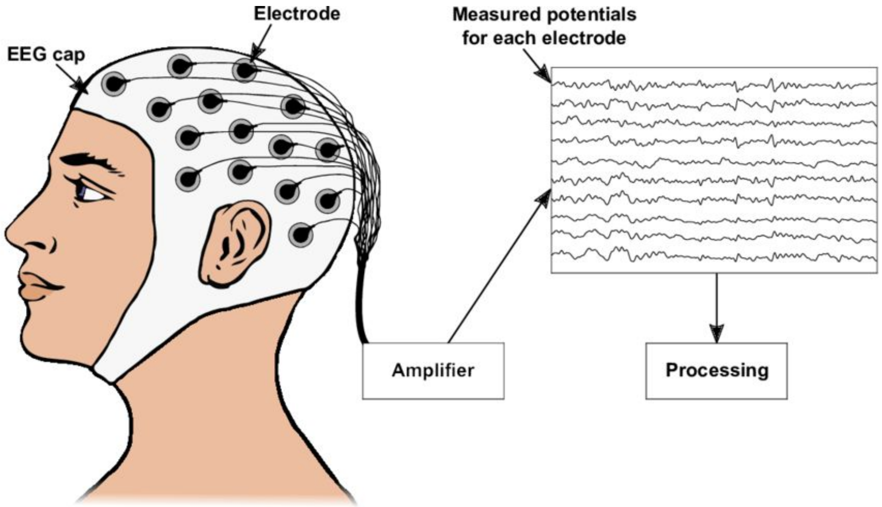
BCI – fields of use

- communication and control of assistive devices (e.g., wheelchairs or robots) for people with paralysis or other neurological disorders
- rehabilitation for people after stroke
- gaming and VR
- monitoring brain states

→ monitoring workload in tasks could help adapting it to improve user performance

EEG - What is an electroencephalogram and how does it work

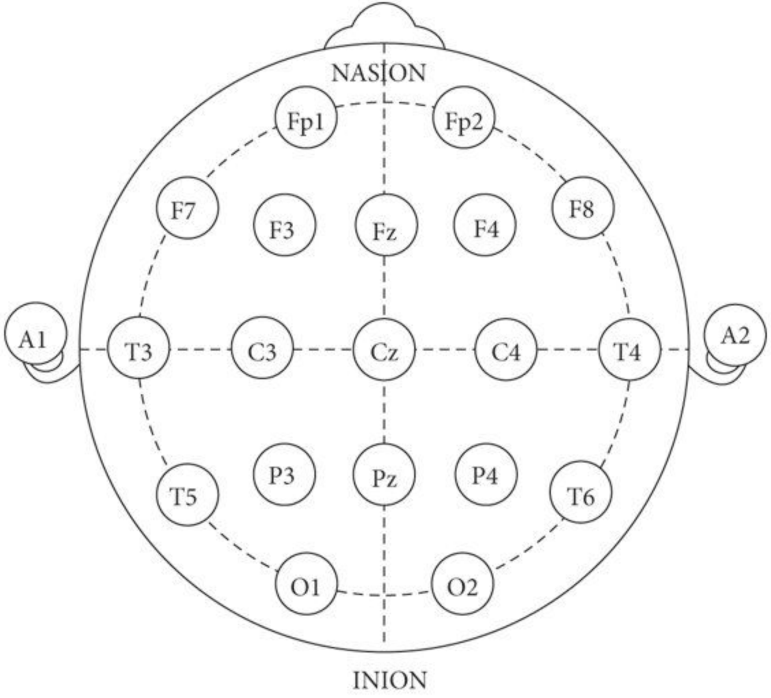
- a non-invasive method to measure brain activity
- recording of electrical currents (potential changes) of the cortex
- brain waves represent the aggregated electrical activity of the nerve cells
- signal always relative
  - differential amplifier
    - records the difference



Nagel (2019).

EEG – setup

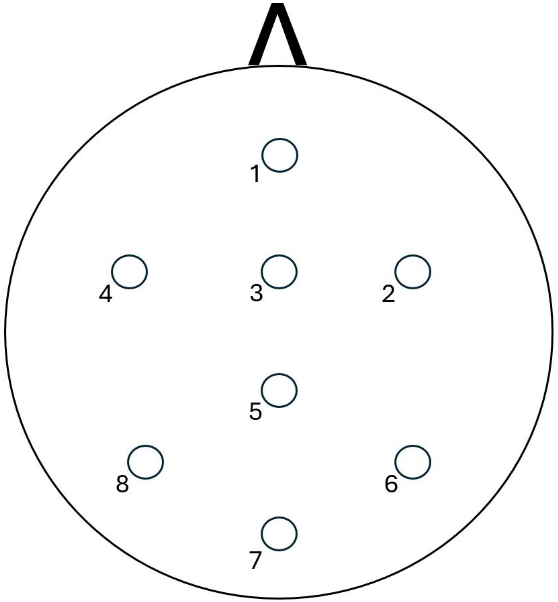
- measure center of head
- 10-20 system
- central, frontal, parietal, occipital, temporal
- odd numbers left, even numbers right
- signal display
  - bipolar montage
    - compare to each other in chains
  - common average reference montage
- grounding to subtract baseline / reduce interference



Suhaimi et. al. (2020).

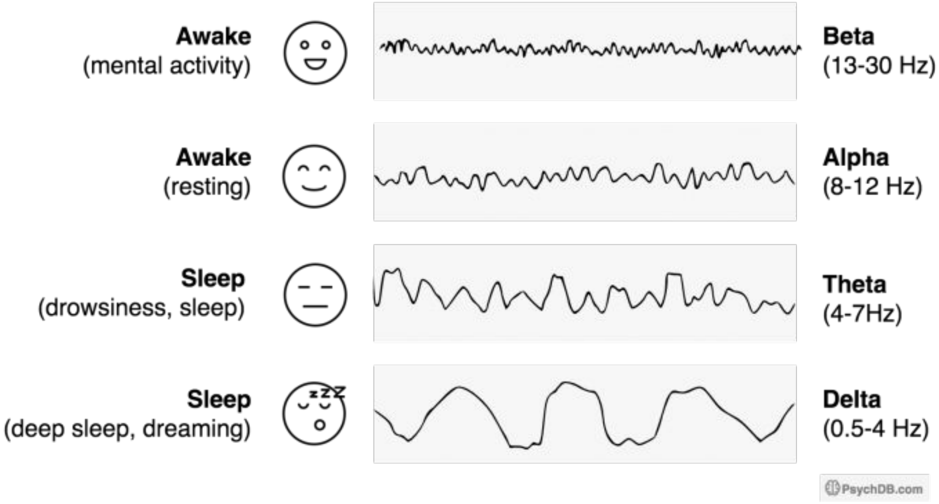
EEG – our system

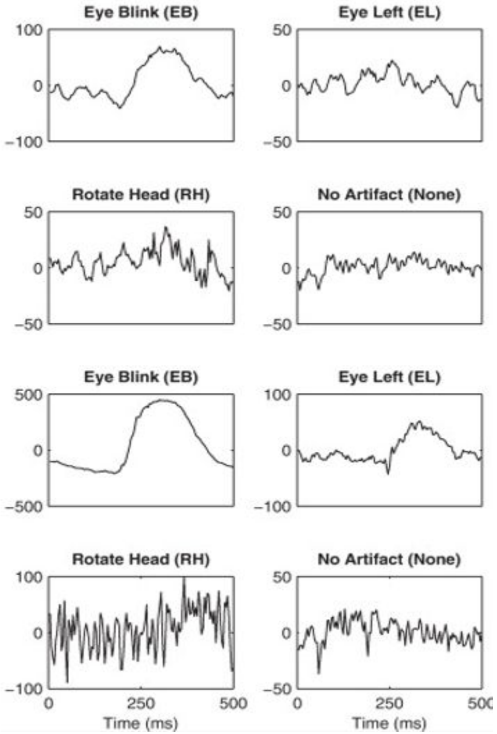
- Unicorn Suite Hybrid Black
    - https://github.com/unicorn-bi/Unicorn-Suite-Hybrid-Black
- 8 electrode system
- portable → recording in lab vs. busy environment



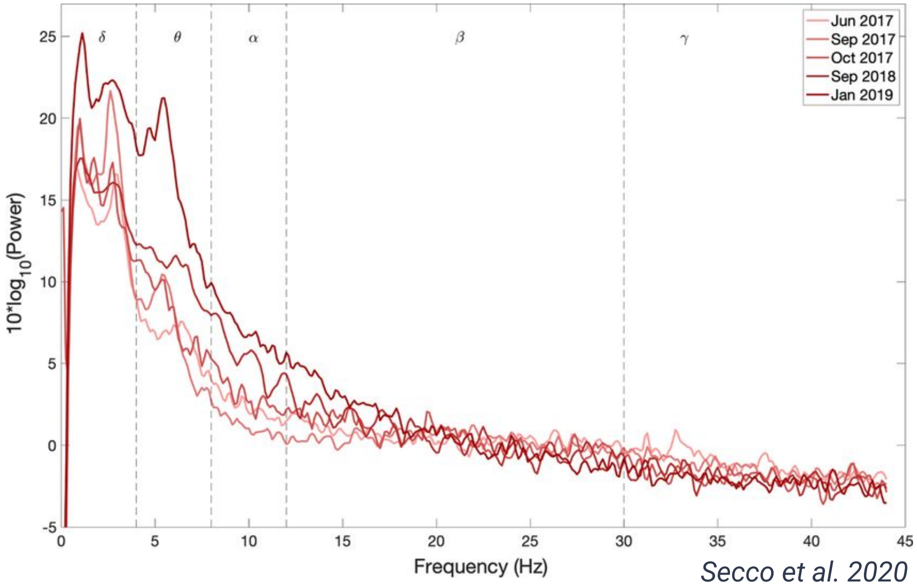
EEG – Typical signal

- Ongoing oscillations (beta/alpha/theta/delta), transient responses
- Common artifacts
  - Muscle movement
  - Eye blinking





EEG – Power Spectral Density



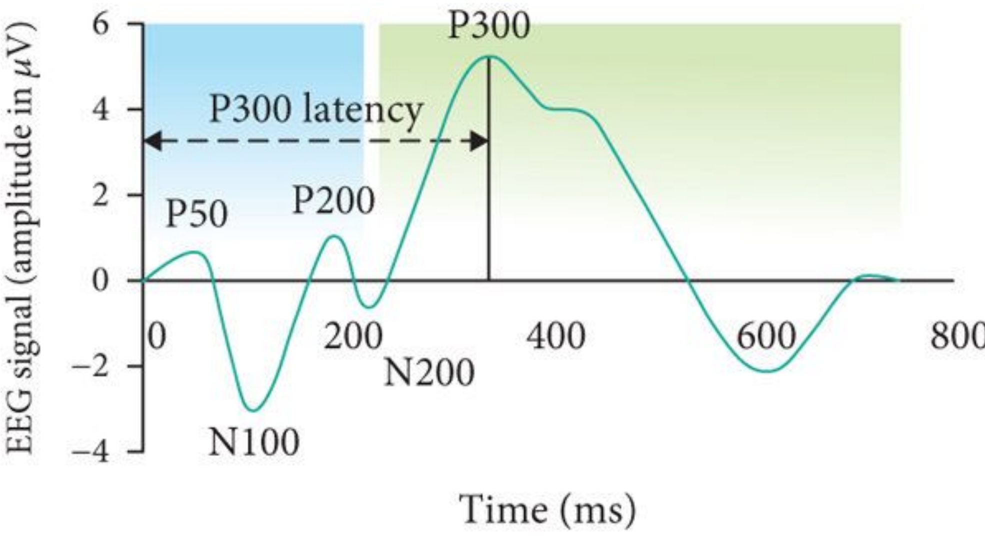
Secco et al. 2020

- Alpha frequency bands:
    - Decreased ⇒ increased arousal
    - Most present in parietal areas
- Theta frequency bands:
    - Increased ⇒ increased task demand
    - Most present in frontal areas *(Brouwer et al. 2012)*

EEG – Event Related Potentials (ERPs)

- ERPs = Time-locked averaged responses to sensory, motor or cognitive events

- Changes to P300 for attention and working memory *(Brouwer et al. 2012)*
    - ⇒ Decreased P300
    - ⇒ Increased workload/ memory demand



(Olichney et al., 2022)

paradigm – workload

Goal:

Acquire EEG Data in different environments (quite/loud) during a task with increasing workload to later create a passive BCI with it

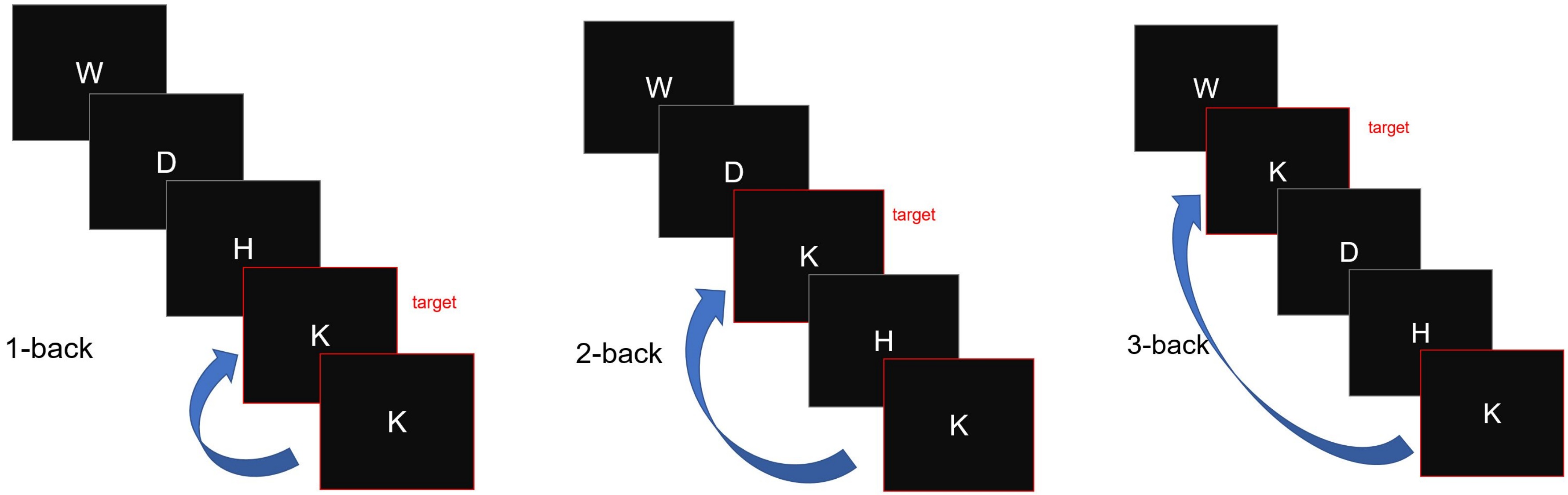
- get a good classification → better working BCIs

Workload:

Ratio between persons capacity and task demands

High workload → task demands are almost exceeding the persons capacity

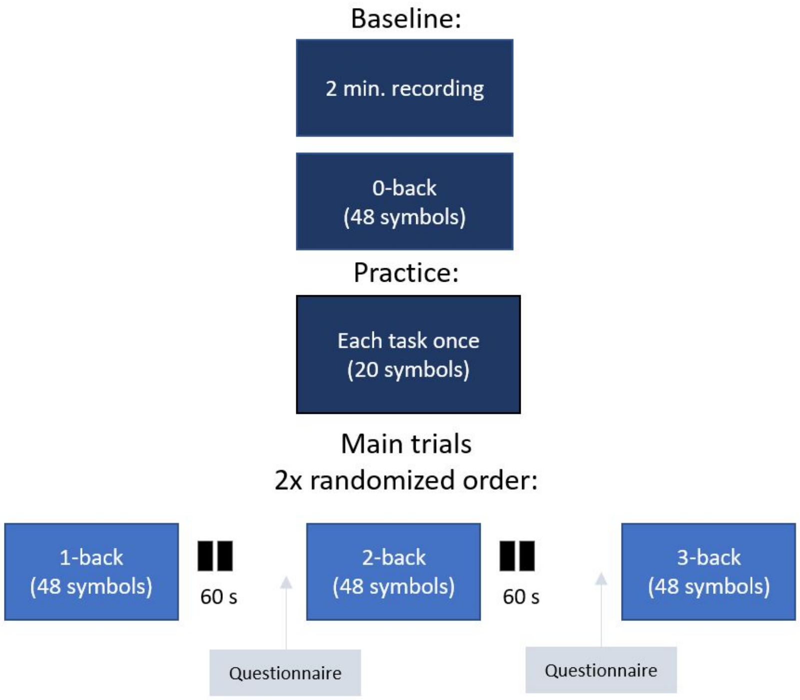
paradigm – general n-back task



paradigm – experimental setup

Two sessions:

- One at the lab/ one at GW2 (loud environment)
- 6 blocks per session
  - 2x each n-back task
- Go/ No-Go task
  - Press spacebar if target appears
- ⅓ target symbols per block
- Step-by-Step Guide:
  https://docs.google.com/document/d/1E3_jmILFGUS1C916i9WX3Garhy0jKLwKlvqqUx2H48E/edit?pli=1&tab=t.0#heading=h.61wt626xvadr



paradigm – procedure

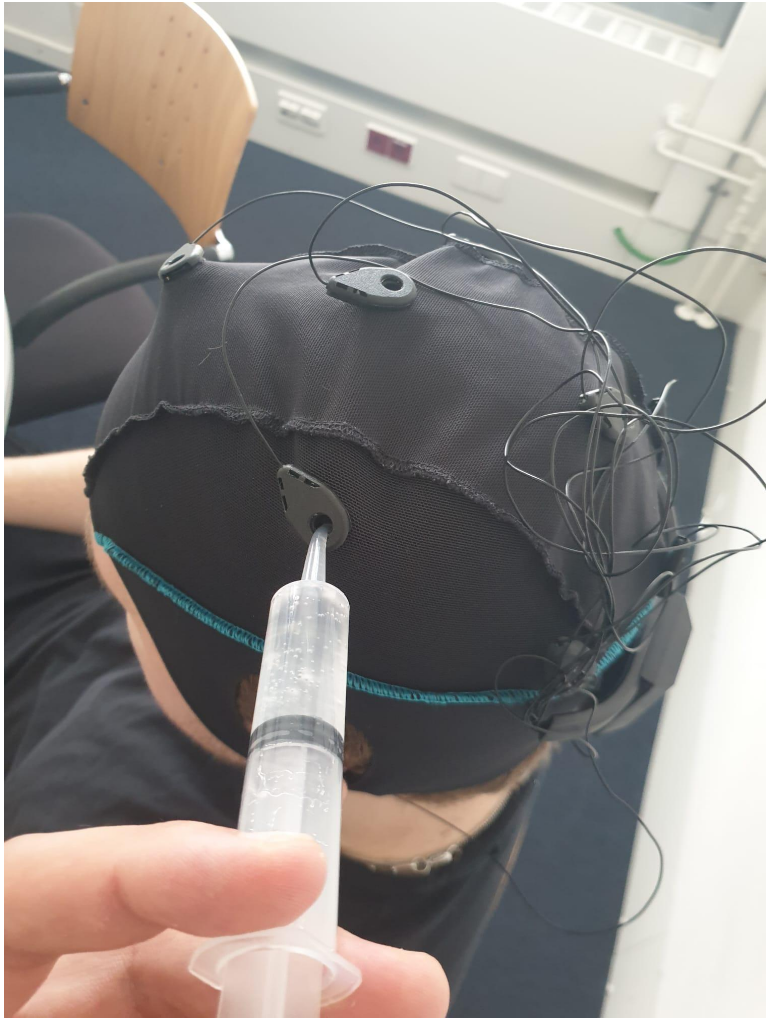
- preparation is key!
  - prepare eeg cap in advance
  - informe participant about everything
  - start with questionnaire
  - after each session again a questionnaire
- During EEG preparation:
  - avoid bridging effects → interference between electrodes
  - reach a good impedance → the lower the impedance, the better the signal
- Familiarise participant with EEG stream:
  - impact of movements (e.g., blinking)

  → Details in the live test recording

Hardware Setup:

EEG-cap

- Connect electrodes to the same positions on the cap
- Do not forget reference electrodes on the mastoid process
- Distribute the gel with the tip of the syringe and watch contacts go green in Unicorn Recorder



Live Demonstration

Data Structure

Dictionary with 3 keys:

- Timestamps
- Time series
- Info [name, type, channel, nominal_srate...]

EEG Stream

- 8 EEG channels (microvolts)
- Ch. 9 - 11 (Accelerometer)
- Ch. 12 - 14 (Gyroscope)
- Ch. 15 - Counter
- Ch. 16 - Battery

EEG Shape: [~411k rows, 18 columns]

1	time	ch0	ch1	ch2	ch3	ch4	ch5	ch6	ch7	ch8	ch9	ch10	ch11	ch12	ch13	ch14	ch15	ch16
2	424264.462	207969.4	214526.16	262586.44	205574.28	233423.56	221402	250628.25	232598.25	0.1362305	0.9812012	0.2294922	1.3732909	-0.610352	-0.396729	86.66667	160998	1
3	424264.466	207962.61	214518.9	262583.66	205569.1	233417.31	221397.61	250623.86	232593.34	0.1340332	0.9819336	0.2319336	1.4038085	-0.549316	-0.518799	86.66667	160999	1
4	424264.470	207975.22	214530.53	262595.28	205583.12	233431.08	221411.56	250639.33	232607.55	0.1354981	0.9821777	0.230957	1.3732909	-0.579834	-0.396729	86.66667	161000	1
5	424264.473	207993.28	214549.39	262599.4	205602	233447.27	221423.98	250653.9	232626.5	0.1359863	0.9807129	0.2290039	1.3122557	-0.671387	-0.335693	86.66667	161001	1
6	424264.477	207972.08	214526.69	262570.34	205579.55	233422.86	221396.36	250626.38	232600.4	0.1350098	0.9799805	0.2294922	1.434326	-0.701904	-0.305176	86.66667	161002	1
7	424264.481	207968.6	214525.61	262561.3	205574.45	233421.16	221402.44	250625.73	232594.77	0.1352539	0.9812012	0.2275391	1.434326	-0.701904	-0.335693	86.66667	161003	1
8	424264.485	207960.38	214520.97	262565.7	205565.88	233415.61	221401.38	250621.36	232585.64	0.1362305	0.9807129	0.2287598	1.3427733	-0.854492	-0.244141	86.66667	161004	1
9	424264.489	207964.58	214524.72	262580.97	205569.55	233419.19	221402.98	250625.83	232591.45	0.1369629	0.9792481	0.2260742	1.3732909	-0.793457	-0.152588	86.66667	161005	1
10	424264.493	207966.62	214523.47	262576.5	205568.73	233419.38	221400.03	250627.27	232593.97	0.1379395	0.9777832	0.2290039	1.3732909	-0.762939	-0.305176	86.66667	161006	1
11	424264.497	207966.1	214526.23	262564.44	205571.06	233422.4	221402	250630.48	232597.53	0.1374512	0.9765625	0.2272949	1.434326	-0.793457	-0.244141	86.66667	161007	1
12	424264.501	207965.83	214530.36	262559.78	205574.9	233424.64	221405.66	250630.3	232598.61	0.138916	0.9780273	0.2265625	1.3732909	-0.701904	-0.244141	86.66667	161008	1
13	424264.505	207973.34	214538.84	262573.1	205579.2	233429.73	221410.22	250632.89	232599.95	0.1394043	0.9782715	0.2265625	1.4038085	-0.640869	0	86.66667	161009	1
14	424264.509	207981.2	214546.98	262583.75	205583.05	233437.52	221420.33	250641.48	232605.23	0.1391602	0.9802246	0.223877	1.3122557	-0.579834	-0.091553	86.66667	161010	1
15	424264.513	207976.64	214542.69	262581.16	205587.42	233438.69	221414.69	250642.55	232609.52	0.1413574	0.9821777	0.2297363	1.3732909	-0.427246	-0.030518	86.66667	161011	1
16	424264.517	207967.25	214533.84	262566.94	205582.42	233434.3	221408.7	250637.1	232603.08	0.1428223	0.9838867	0.2277832	1.4038085	-0.457764	-0.152588	86.66667	161012	1
17	424264.521	207952.23	214518.28	262546.9	205566.23	233424.11	221403.25	250630.48	232593.69	0.1442871	0.9833984	0.2285156	1.2817382	-0.457764	-0.061035	86.66667	161013	1
18	424264.525	207951.44	214515.42	262550.84	205563.02	233420.17	221398.33	250627.89	232591.02	0.1430664	0.986084	0.2290039	1.1901854	-0.396729	-0.091553	86.66667	161014	1
19	424264.529	207955	214515.61	262557.56	205563.28	233419.1	221396.55	250628.16	232590.12	0.1437988	0.9868164	0.2292481	1.0986327	-0.244141	0.0305176	86.66667	161015	1
20	424264.533	207956.44	214519.1	262550.3	205564.44	233421.16	221399.05	250628.33	232590.39	0.145752	0.9875488	0.2282715	1.0375975	-0.183105	0.0610352	86.66667	161016	1
21	424264.537	207965.83	214530.8	262556.84	205578.3	233436.98	221411.39	250642.11	232605.94	0.1447754	0.9868164	0.2275391	0.8239746	-0.091553	0.1525879	86.66667	161017	1
22	424264.541	207968.42	214536.61	262556.38	205582.86	233444.4	221420.23	250649.88	232611.22	0.142334	0.987793	0.2282715	0.7019042	0.0305176	0.1220703	86.66667	161018	1
23	424264.545	207956.8	214523.83	262552.53	205571.16	233429.83	221401.9	250636.47	232599.42	0.1420898	0.9875488	0.2299805	0.6713867	0.1220703	0.1525879	86.66667	161019	1
24	424264.549	207949.11	214520.52	262559.34	205567.75	233427.06	221402.8	250636.92	232599.33	0.1435547	0.987793	0.2282715	0.5187988	0.213623	0.0610352	86.66667	161020	1
25	424264.553	207950.45	214523.38	262561.12	205570.7	233432.06	221408.08	250644.7	232607.83	0.1420898	0.9897461	0.2304688	0.4272461	0.3051758	0.0915527	86.66667	161021	1
26	424264.557	207955.19	214530.8	262559.78	205575.08	233438.33	221413.34	250648.72	232611.58	0.1408691	0.9882813	0.2307129	0.2441406	0.3356933	0.213623	86.66667	161022	1
27	424264.561	207951.34	214526.69	262552.47	205569.1	233431.89	221409.78	250640.94	232601.92	0.1398926	0.9863281	0.230957	0.0915527	0.3051758	0.1220703	86.66667	161023	1
28	424264.565	207940.17	214515.06	262557.38	205555.5	233418.11	221398.88	250628.42	232585.2	0.1386719	0.9853516	0.2292481	-0.061035	0.213623	0.0610352	86.66667	161024	1
29	424264.569	207957.25	214529.11	262585.53	205568.2	233428.58	221404.77	250636.38	232592.08	0.1384277	0.9819336	0.230957	-0.030518	0.1220703	-0.061035	86.66667	161025	1

Data Structure (Markers)

NBack Marker Stream:

- baseline_start (2 minutes)
- baseline_end
- main_block_{block_n}_start
- sequence_U,E,B,K…
- targets_12,17,20,22
- main_{block_n}_{trial_n}_on
- resp_False
- corr_True
- rt_0.651
- {trial_n}_end
- main_{block_n}_end
- main_{block_n}_accuracy_0.98
- question_{question_description}_resp_{key_press}

Marker Shape: [1498 rows x 2 columns]

Data Structure (Mic Stream)

Audio dB dynamic range: 50.367637634277344

	# time	# decibels
0	0.027119077744014842	-64.526985
1	0.027119077744014842	-60.563847
2	0.027119077744014842	-59.785492
3	0.027119077744014842	-60.410515
4	0.027119077744014842	-57.80225
5	0.027119077744014842	-61.00383
6	0.027119077744014842	-60.65604
7	0.027119077744014842	-58.939053
8	0.027119077744014842	-60.06972
9	0.027119077744014842	-60.881214

Shape: [40-70k rows, 2 columns]

Preprocessing

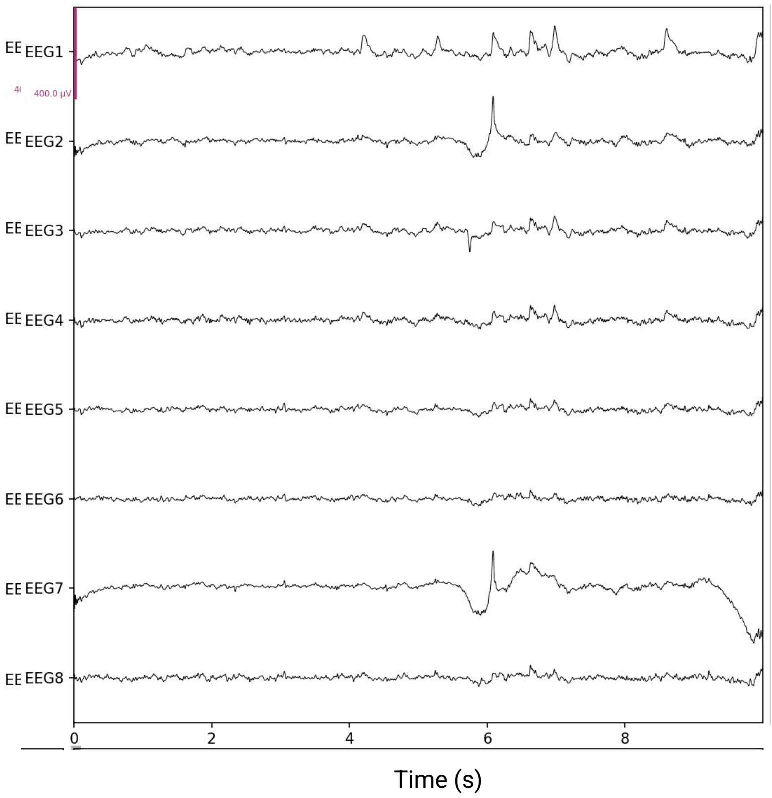
Data Selection, Filtering and Re-Referencing,
Artifact Handling and Feature Extraction

Preprocessing - Data Selection

Channel Selection

Relevant EEG-Channels
(All or just a subset?)

Frontal theta ↑, parietal alpha ↓ with increased workload (Gorji, 2023)

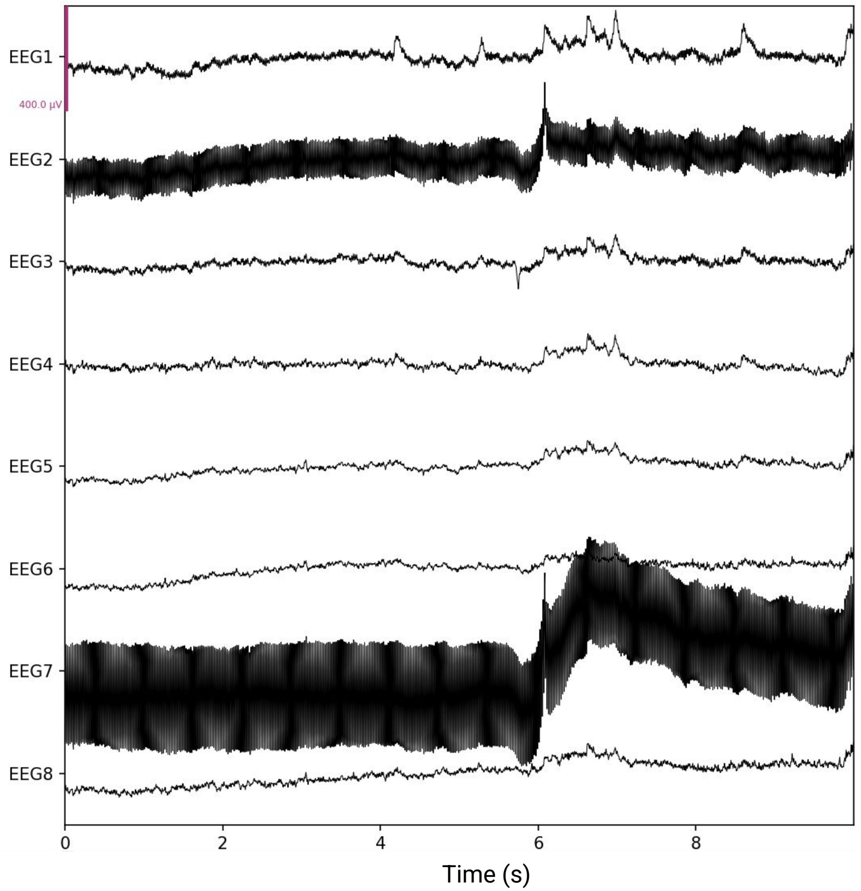


Preprocessing - Filtering

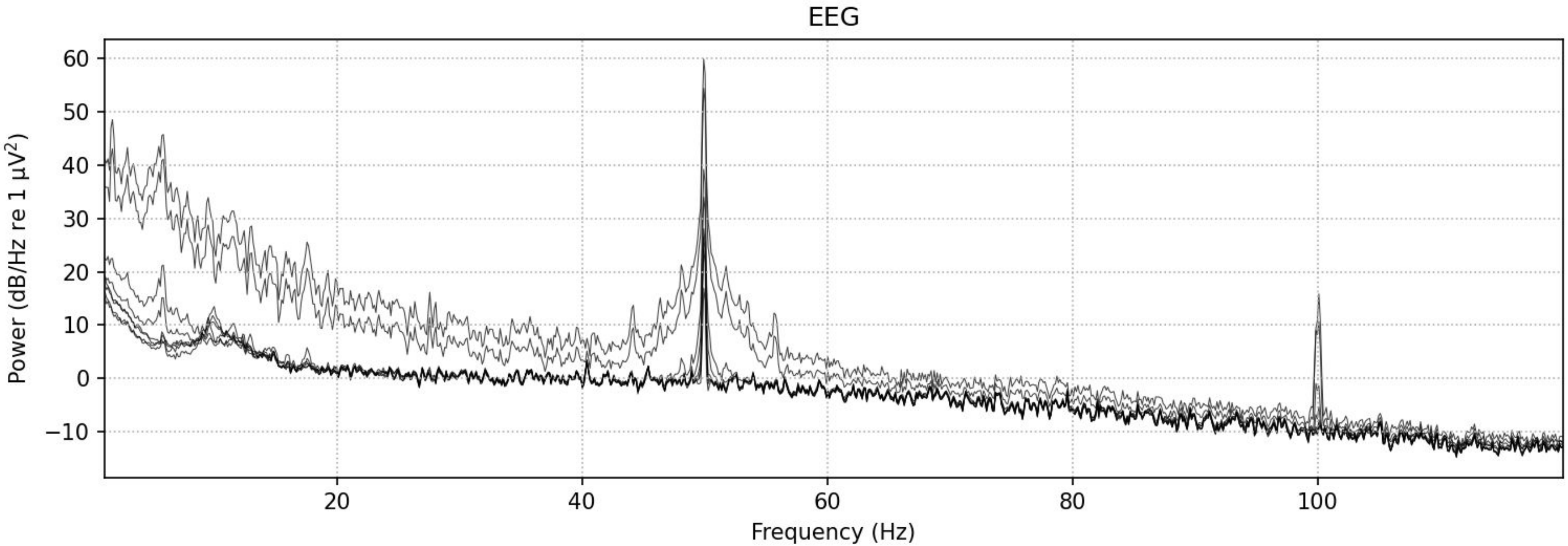
Notch Filter
50 Hz Noise (where does it come from?)

Bandpass filter
Specific frequencies are relevant others sensitive to artifacts/noise

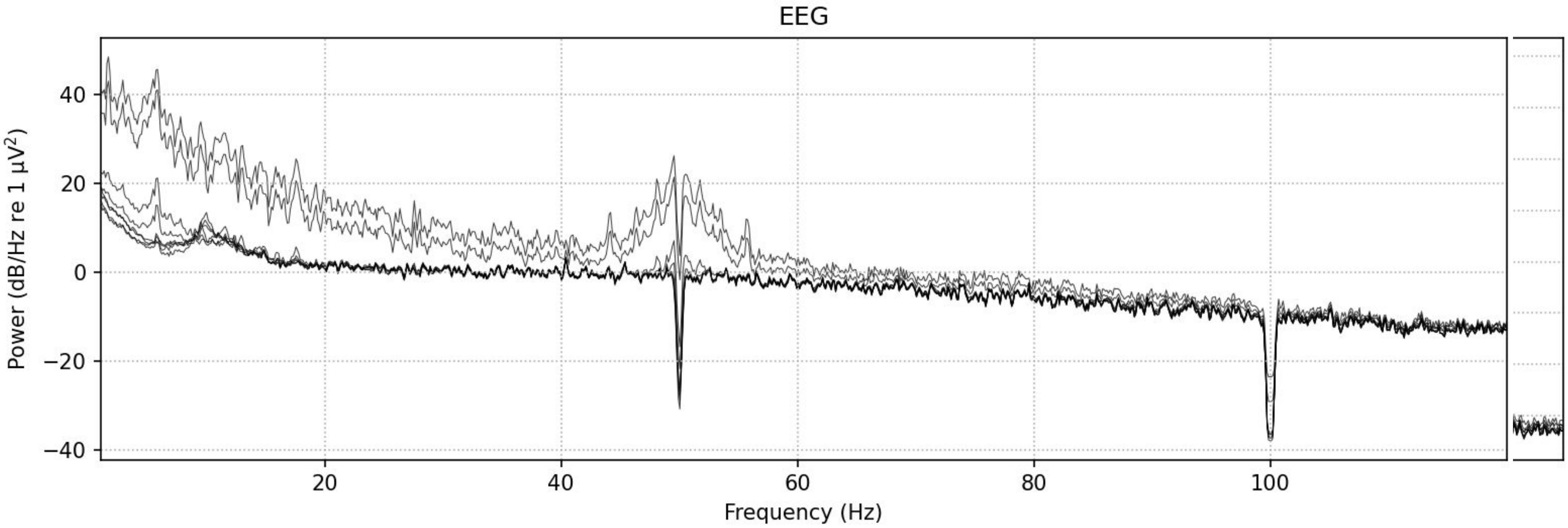
TIP OF THE DAY
Always make sure electrodes are connected well - double check if needed.



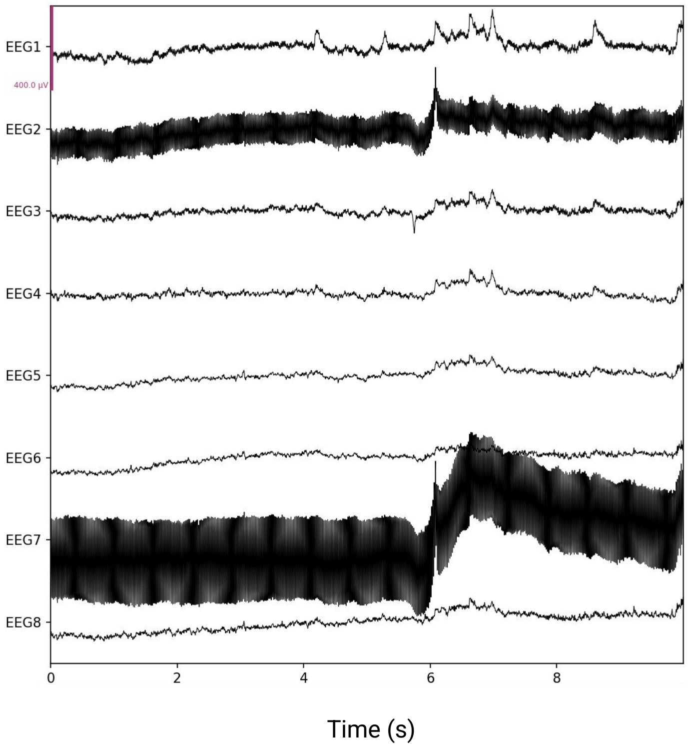
preprocessing – Power Spectral Density

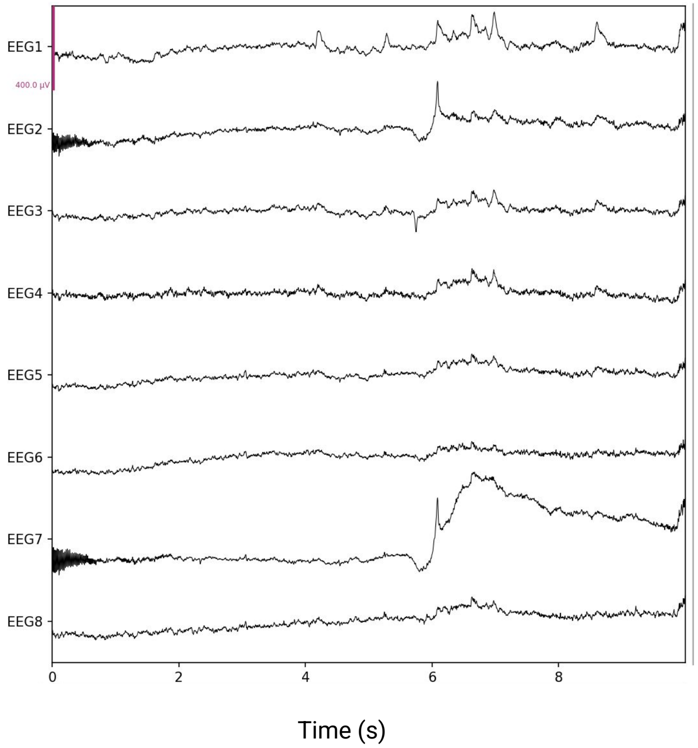


preprocessing – Power Spectral Density

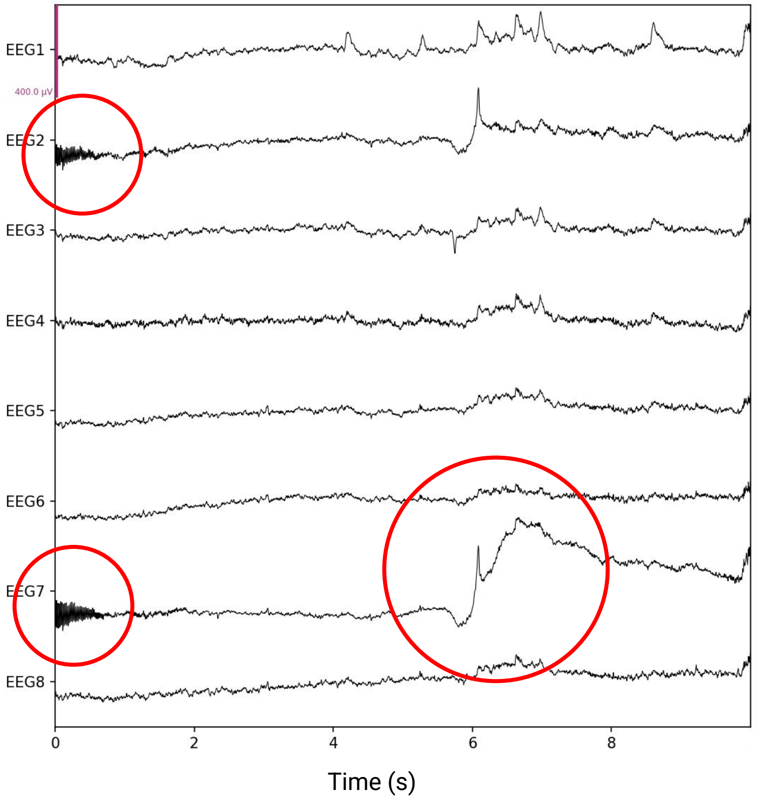


preprocessing - Notch Filter





preprocessing - Bandpass Filter

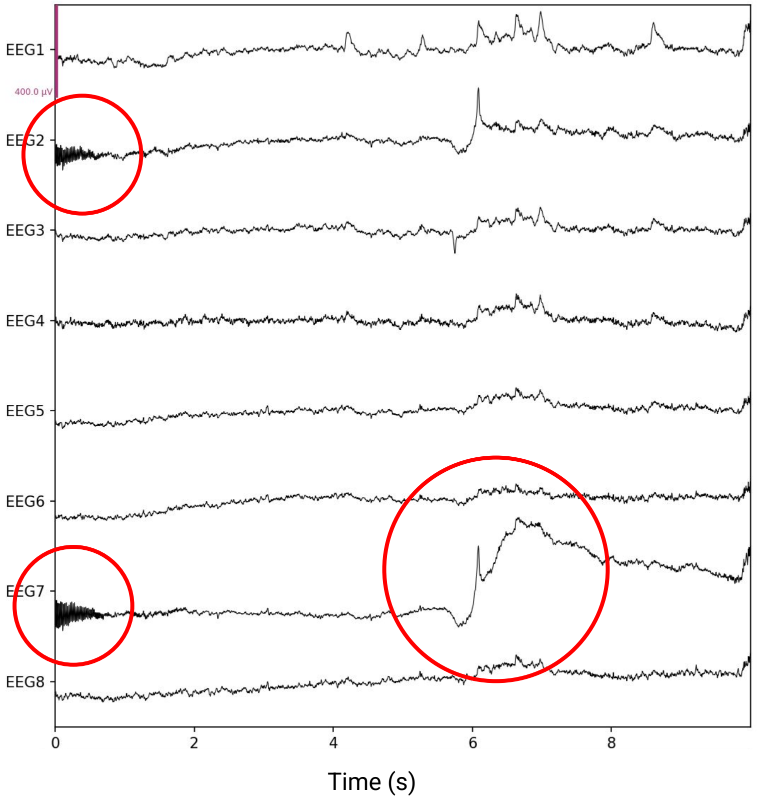


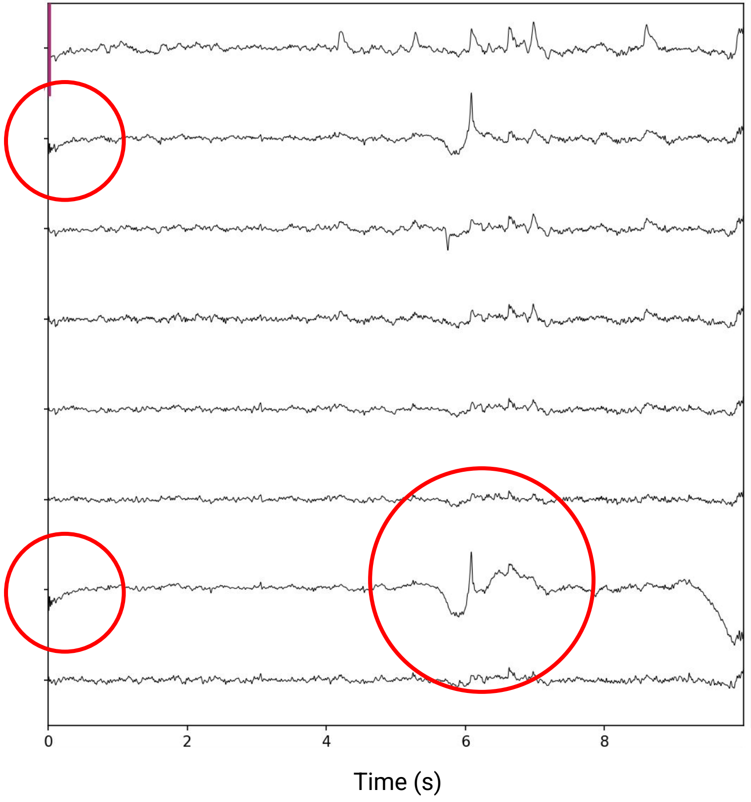
Restrict to a specific range of frequencies relevant to cognitive workload (e.g. theta, alpha, beta - check Literature).

Also removes frequency-ranges sensitive to artifacts e.g. <1 Hz from electrode drift or >50 Hz for muscle artifacts.

In this example: 1 - 40 Hz

preprocessing - Bandpass Filter





Preprocessing - Feature Extraction

1. **Slicing EEG-Data into Epochs**
   The different task blocks with different difficulties

2. **Labeling**
   Marking the blocks with the corresponding difficulty level

3. **Power Spectral Density**
   Compute mean power in relevant frequency bands e.g. theta or alpha

MNE

MEG + EEG ANALYSIS & VISUALIZATION

Open-source Python package for exploring, visualizing, and analyzing human neurophysiological data: MEG, EEG, sEEG, ECoG, NIRS, and more.

mne.tools/stable/auto_tutorials/preprocessing/

what’s next ?

- do your own recordings
- preprocessing of the EEG data
- analysis of metadata

References

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Thanks for your attention!