II. SIGNAL PRE-PROCESSING

EEG-TRAINING

OUTLINE

1. Sources of noise – recall
2. Filtering
    1. Filtering out artifacts
    2. Filter design
3. Data rejection
    1. Epoch rejection
    2. Channel rejection
    3. Channel interpolation
4. Referencing
5. Feature selection

1) SOURCES OF NOISE

In the previous session, we mentionned several types of common artifacts in EEG data:

- Eye movements (EOG) : low frequency step-like signals, in frontal channels mostly
- Sweat artifacts: low frequency, high amplitude drifts
- Muscle contractions: high frequency, high amplitude components
- Line noise: from the electricity running in the building: frequency 50Hz in Europe

2) FILTERING OUT ARTIFACTS

- The signals of interest are typically in the range 1-250Hz
- Unless using a particular setup (eg: Faraday cage), information can usually be extracted only up to ~80Hz
- High-pass filtering can get rid of sweat artifacts and some EOG
- Low-pass filtering can get rid of some artifacts
- Notch-filtering for getting rid of the line noise
- Recommandations: filter signal as much as necessary, ie if your applications focus on the alpha band only (8-13Hz), you can safely low-pass data with cut-off frequency 25Hz and high-pass with cut-off 5Hz. In that case a notch-filter is not necessary, and you get rid of a good part of the noise

2) FILTER DESIGN

When to apply filter?

You would want to filter the data before epoching. Indeed, filtering can introduce edge artifacts (that is, distortion of the signal at the beginning and at the end of the recording being filtered). By taking the raw data, you only have two edges instead of $n_{epochs} + 1$ after epoching

Building filters:

- Unless a specialist in filter design, using the pre-designed filters on MNE is safe and recommended
- The pre-designed filters still have to be parametrized

2) FILTER DESIGN

Selecting the right cut-off frequencies

- The cut-off frequency corresponds to the frequency beyond or beneath which the spectral components will be attenuated, respectively for low- and high-pass filters.
- The filters are not perfect, so there is a small frequency band within which frequencies are not fully attenuated, and also a small band in which the signal is attenuated although you don't necessarily want it to be
- Recommendation: visualize your filters before application: you can fine-tune the cut-off frequencies to your needs

2) FILTER DESIGN

Phase:

- Filtering can in certain instances introduce a phase bias. Ideally, we want as little bias as possible
- With the phase parameters, you can decide how the filter is applied
- This also has consequences on the **causality** of the filter

Causality:

- A filter is **causal** when the signal at time t_n depends on the signal at previous times
- This is a situation we usually want to avoid, as it introduces a bias.
- If a filter is **non-causal**, it means that the filtered signal at each time point does not depend on the signal at other time points

3) EPOCH REJECTION

- Once all the filtering done, you want to visualize the result of your hard work, which normally has helped in obtaining clean data
- However, it can be that on specific epochs the noise is so important that the relevant signal remains invisible
- In that case, it is best to get rid of the epochs

3) EPOCH REJECTION

- Manual rejection: you can pinpoint to the epochs you identifies as being bad, list them and remove them manually
- Automatic rejection: there are several statistical methods for epoch rejection that are not yet implemented on MNE.
- Alternatively you can also use thresholding for a more automated rejection method:
    - Epochs where one electrode was not working properly are recognisable because the signal at these channels is either completely flat or noisy with amplitudes that are beyond neurophysiological meaning

3) CHANNEL REJECTION

- Channel rejection is necessary if you notice that a set of electrodes is down for most of the epochs
- If when setting up the EEG cap you noticed that you could not bring the impedence of one of the electrodes to an acceptable value, you can reject it as the signal will be low quality compared to the other channels throughout the experiment. Make sure you visualize the data beforehand: sometimes the impedence gets better after a few minutes, and luckily your experiment has started after this waiting time
- Channel rejection is done through the same process as epoch rejection: manual, statistical or thresholding
- You would generally perform channel rejection before epoch rejection

3) CHANNEL INTERPOLATION

- For different participants you may reject different electrodes
- For the sake of comparison, you want to have the same set of electrodes in each place
- EEG: interdependence of the signals at all electrodes
- The signal at the rejected electrode can be interpolated from the signals at the neighboring electrodes
- Usual algorithm: square splines

4) REFERENCING

- EEG measures a difference of potential between a reference electrode (common reference to all electrodes) and a recording electrode
- You can keep this reference or change it:
  - Set another electrode as the reference
  - Set the average of all electrodes as the reference (common average re-referencing)

5) FEATURE SELECTION

- Heartbeat artifacts are usually difficult to filter out of the data
- EOG and blinks can remain after filtering
- ICA can help with that:
  - Extracts sources of the signal: solution to the « cocktail party » problem
  - Can separate what signal comes from eye movements, which from the heart beat, from the others relevant for EEG analysis
  - EOG and heartbeat signal produce very recognizable activation patterns

CONCLUSION

- Starting with clean data is key to a proper analysis and scientific investigation
- Many techniques for filtering (even more than these presented here!) and artifact rejection: pick the easiest and most suited method for your needs
- Excellent pre-processing will not compensate for poor acquisition: denoising starts before the experiment!
  - Good preparation of the setup, paradigm
  - Clear explanations to the participant to minimize movement and to fulfill the task required
- Next time: Time-series analysis