Neuroengineering 2023-2024

July 3rd 2024

Part II – Odd (solutions)

Carefully read the following scenario and answer the questions listed below.

Electroencephalography (EEG)-based Brain–Computer Interfaces (BCIs) have been successfully employed to address upper limb motor rehabilitation after stroke. These systems allow for a real-time monitoring/reinforcement of the modulation of brain activity induced by the kinesthetic Motor Imagery (MI) practice. The latter induces changes in sensorimotor oscillatory activity (i.e. sensorimotor rhythms, SMRs, oscillations of the EEG potential in the alpha and beta frequency bands). Briefly, these changes include a desynchronization which occurs before and during the MI task and reflects activation mainly on the scalp sensorimotor areas contralateral to the imagined limb.
The EEG features fed into the BCI classifier consist of the PSD estimate performed on each relevant channel (i.e. those acquired over the brain sensorimotor areas), limited to the relevant spectral bin (i.e. those included in the alpha and beta bands). PSD estimation is performed using the Welch's method, using a Hamming window and 50% overlap between segments, yielding a spectral resolution of 2 Hz. The classifier is trained to detect MI using a calibration dataset and then used to provide real time feedback to the patient and to the therapist on the correct execution of the rehabilitative MI exercise.

Experimental subjects
Thirteen subacute stroke participants with (i) a history of first-ever unilateral stroke, (ii) hemiplegia/hemiparesis caused the stroke and (iii) age between 18 and 80 years performed a calibration session (recording of EEG signals under controlled conditions) before undergoing one month of BCI-supported MI training.

Calibration Dataset
To select the BCI control features and train the classifier's weights, we used the EEG data collected during a calibration session. Scalp EEG potentials were collected by means of an electrode cap (61 electrodes; linked ears reference, mastoid ground) and bandpass filtered between 0.1 and 70 Hz. All signals were digitalized at 200 Hz and amplified/digitized by a commercial EEG system (BrainAmp; Brain Products, Gilching, Germany). Participants were instructed to perform a visually cued kinesthetic MI of the (i) grasping or (ii) finger extension movements with their affected upper limb (experimental task). The calibration session comprised four runs (two for each MI task, grasping and finger extension) Recording runs comprised 30 trials ([1]): 15 ± 1 experimental task trials and 15 ± 1 rest trials, randomly intermingled. The trial duration was 7 s with an inter-trial interval of 1.5 s. Participants were instructed to rest for the first 3 s of each trial and then either to perform the task (MI) for 4 s (experimental task trials) or to keep resting until the end of the trial (rest trials). Visual cues displayed on a monitor provided the participants with timing and information about the type of the current trial. For each experimental task, the time interval subjected to the analysis was of 3 s: from 4 to 7 s with respect to the trial start, for the MI task; from 0 to 3 s, for the rest (no MI) task.

[1] During the exam it was clarified that this sentence should be interpreted as: "<u>Each</u> recording run comprised 30 trials"

Questions

Note that the comments below each answer are longer that the allowed number of characters for didactic purposes. They can be easily summarized to fit the limits.

Q1. (2 points) Assuming that experimental subjects were given 5 minutes breaks between runs, how long did the recording session last?
Justify in max 200 characters.

Answer: 1914 s (almost 32 minutes).

The session is composed by 4 runs separated by breaks.

$$T_{sess} = 4 \cdot T_{run} + (4-1) \cdot T_{break}$$

Each run is composed by 30 trials separated by inter-trial intervals ([2])

$$\begin{aligned} T_{run} &= 30 \cdot T_{trial} + (30-1) \cdot ITI \\ &= 30 \cdot 7s \ + \ 29 \cdot 1.5s \\ &= 253.5s \\ &= 4'14" \end{aligned}$$

Thus:

$$\begin{aligned} T_{sess} &= 4 \cdot 253.5s \ + (4-1) \cdot 300s \\ &= 1014s + 900s \\ &= 1914s \\ &= 31'54" \end{aligned}$$

Q2. (2 points) If it was found advantageous, could the dataset be re-referenced to the CAR?
Justify in max 200 characters.

Answer: Yes.

The necessary condition to apply the Common Average Reference is that potentials are acquired with a monopolar montage, which is the case (we can infer it from the use of the linked ears reference).
Moreover, the relatively high number of electrodes used is in line with the appropriate estimation of the spatial distribution of the scalp potential, which justifies the approximation between the CAR-referenced potential and the "ideal" potential (with reference at infinite distance)

Note:

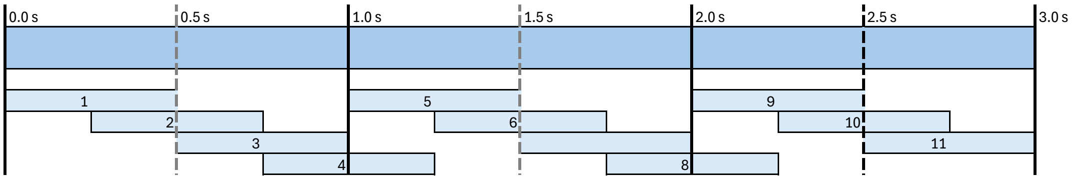
the assignment did not specify whether the re-referencing was to be performed off- or on-line. It is worth noting that being the CAR an instantaneous computation, the procedure can also be implemented online.

[2] Note that here the less frequent definition of ITI was used, but it should be obvious from the context because otherwise the ITI should be greater than the trial duration.

Q3. (2 points) When estimating the PSD, how many segments were extracted from each trial for the MI task?
Justify in max 200 characters.

Answer: 11 segments

The spectral resolution of the spectral analysis is $\Delta f = 2Hz$, thus the length of the segments used in the Welch's algorithm is $T_{win} = 0.5s$.
The analysis interval is $3s$ long (latency range: $[4s, 7s]$). ([3])
Since the segments were overlapped by 50% of their length ($0.25s$), the number of windows can be easily counted graphically ([4]):



Q4. (2 points) Which of the following artifacts would require rejecting the trial (or part of it) and which could be tolerated because they happen in a disjoint frequency band?
Type 'reject' or 'tolerate' on the same line as the artifact name

1. EMG
2. EOG
3. sweating
4. powerline
5. movement

Justify in max 400 characters.

EMG: **reject**
EOG: **tolerate (*)**
Sweating: **tolerate**
Powerline: **tolerate**
Movement: **tolerate**

The frequency range of interest in this analysis includes the alpha and beta bands (8-30 Hz).

EMG artifacts have a wide frequency spectrum from tens of Hz to a few kHz, thereby in the same frequency range as beta- and gamma-band signals. It partially overlaps with the frequency content of SMR.

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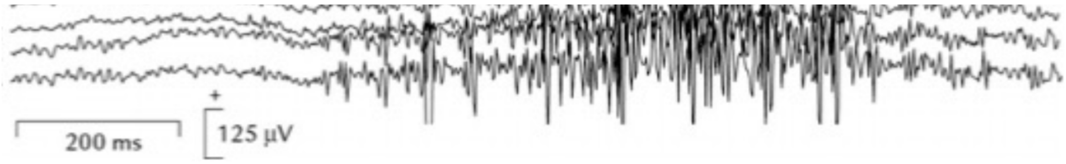
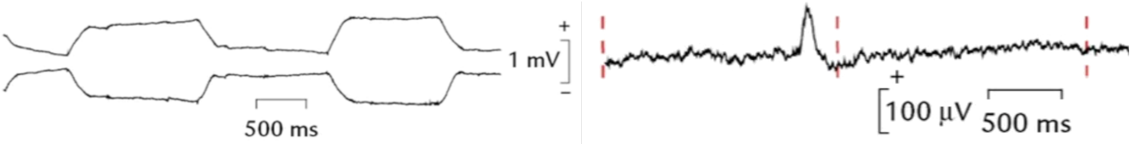
[3] Note that the interval taken into account for the offline analysis is different from the interval in which the subject was asked to perform the MI task while acquiring data.
[4] Or algebraically:

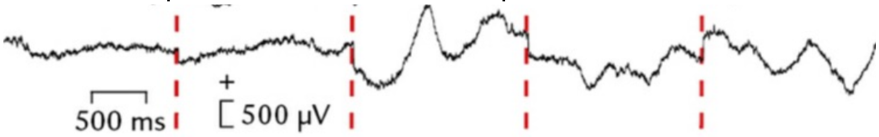
$$T_{shift} = (1 - \%ovl) \cdot T_{win} = 50\% \cdot 0.5s = 0.25s$$
$$N_{win} = 1 + \left\lfloor \frac{T - T_{win}}{T_{shift}} \right\rfloor = 1 + \left\lfloor \frac{3s - 0.5s}{0.25s} \right\rfloor = 1 + \left\lfloor \frac{2.5}{0.25} \right\rfloor = 11$$



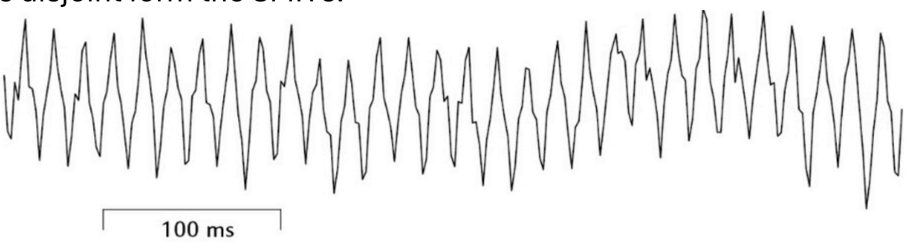
EOG artifacts (due to eye movements) are relatively slow (transitions are in the order of hundreds of milliseconds, thus frequency content is well below 10 Hz). Its spectral content does not overlap significantly with SMR.
(*) Particularly fast eye movements and blinks may have non-negligible power in the lower alpha band, and thus be harder to filter out.



Sweating artifacts are relatively slow potentials, with changes taking place in hundreds of milliseconds. Its frequency components are usually below 0.5 Hz, thus well below the alpha band and its spectrum does not overlap with SMR's.



Powerline artifact has a spectrum composed of spectral lines, the lowest of which (fundamental) is at 50 Hz (or 60 Hz). Since this frequency is above the beta band, its spectrum is disjoint form the SMR's.



Movement artifacts are mostly produced by movements of the subject's head and their timecourse is as slow as the movement itself. Their spectrum is well below the alpha band, this not overlapping with the SMR's spectrum.