Neuroengineering 2023-2024

June 4th 2024

Part II – Odd (solutions)

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

During the planning and execution of a motor task, the amplitude of sensorimotor rhythms is modulated. Event-related Desynchronization/Synchronization (ERD/S) can be used as an index to quantify the modulation induced by the motor task.

Motor task.
At the beginning of each trial, the subject is promted with one of three possible cues: “Right hand”, “Left hand”, “Feet”. The subject can wait a self-decided interval of time in the range between 3 and 6 serconds since the appearance of the cue, and then perform a brisk extension of the wrist/ankle, in agreement with the cue they received.
Four runs of this task containing 20 trials each were interleaved with 2 minutes of rest.

EEG Data acquisition.
Simultaneous data was obtained for EEG, EMG, and movement onset (the latter via a custom movement detection device). A commercial system and software were used to acquire and process surface EEG signals. Electrodes were placed on the scalp over the sensorimotor brain areas. The experimenter mounted the EEG electrodes according to the 10-10 system (see endnote a) , specifically only the five rows whose electrodes have labels starting with the following letters:

F, FC (or FT), C (or T), CP (or TP), and P.

Impedance at lower than 5 kΩ was obtained prior to data collection. The recording electrodes were referenced to the linked ears. EEG signals were amplified (×50 000), band-pass filtered (0.1–70 Hz), and digitized (500 sample/s).
In addition to the dataset acquired for the experimental (motor) task, one run of rest with open eyes (1 minute) and one run of rest with closed eyes (1 minute) were acquired.

EEG Data processing.
For each of the runs associated with the motor task, EEG trials were segmented from -5 s to +5 s with respect to the onset of the EMG signal recorded on the target limb.
EEG trials were visually inspected to detect artifacts produced by eye blinks, facial muscle contractions, or head movements and discarded if artifacts were found.
For the resting EEG runs, the artifact rejects was performed on the raw recording, marking as “invalid” those time intervals containing an artifact, thus preventing them from being considered for subsequent analysis.
Power Spectral Density was estimated for each of the three conditions (motor tasks). Results from electrodes C3, Cz and C4 are shown in *Figure 1*.
ERD/S in the beta band (26-30 Hz) was estimated according to the original algorithm proposed by Pfurtscheller et al. in 1999 ([1]) . The results of each step of the procedure is shown in *Figure 2*.
A periodogram was computed, after artifact removal, on the longest uninterrupted interval of EEG acquired in the open-eyes condition. Results from electrode Pz are shown in *Figure 3*

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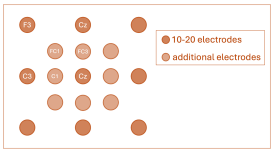
a) With respect to the 10-20 system, in the 10-10 system an extra electrode is placed between each original pair of electrodes, in the longitudinal, transverse and both diagonal directions. For instance, the following figure shows of the additional electrodes placed between Cz and its 10-20 neighbors.



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[1] Which is the algorithm that was presented in class.

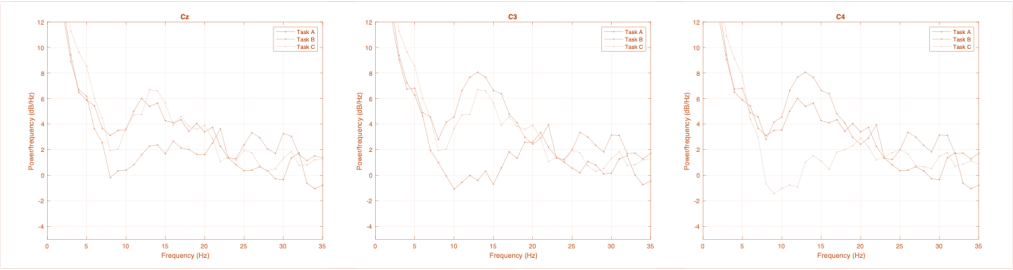


Figure 1. PSD (Welch)

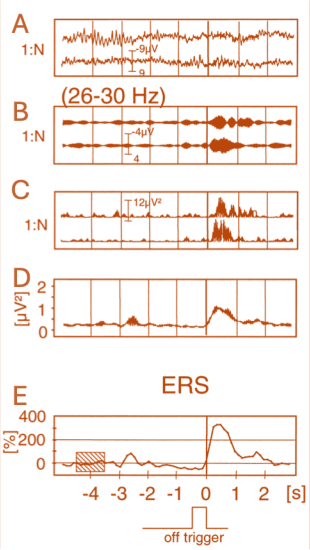


Figure 2. ERD/S estimation steps

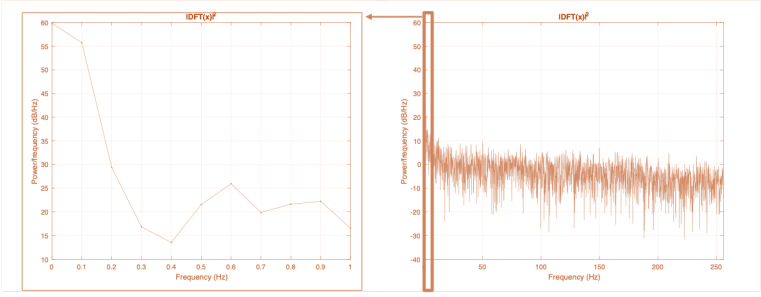
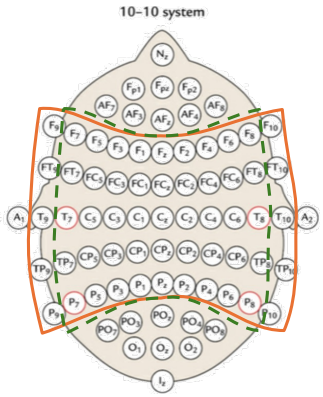


Figure 3. Right panel: Periodogram estimated on the run acquired while the subject was resting with open eyes. Left panel: Zoomed view of the same periodogram.

Questions

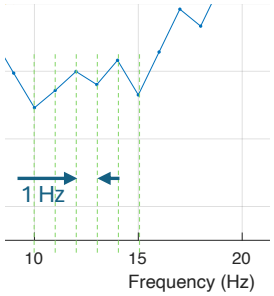
Q1. (1.5 points) How many EEG electrodes did the experimenter mount of the subject's head?
Justify in max 1 line.



58 electrodes (or 48, see below).
The number of electrodes equals: the number of monopolar channels + 2 electrodes for the reference (linked ears) + 1 electrode for the ground.
Each of the five rows of the montage contains 11 electrodes for a total of 55.

It is acceptable to omit the electrodes of the columns "9" and "10" (which are beyond the most lateral positions of the 10-20). In this case the number of electrodes per row is 9, yielding 45 monopolar electrodes, thus 48 total electrodes.

Q2. (1 point) How long (in samples) is the window that was used to estimate the spectra in Figure 1 using the Welch algorithm?
Justify in max 1 line.



500 samples.
The analysis of figure 1 shows that PSDs have a spectral resolution $\Delta f = 1\ Hz$. This means that windows used in the Welch algorithm were $T_{win} = 1/\Delta f = 1\ s$. The number of samples is $T_{win} \cdot f_s = 500$

Note that neither the width of the horizontal axis of the figure nor the duration of the segmented trials has any impact on the solution of this problem.

Q3. (2 points) Associate each of the spectra (A-C) in figure 1 to one of the motor tasks?
Justify in max 2 lines.
Task of spectrum A: **Right hand**
Task of spectrum B: **Feet**
Task of spectrum C: **Left hand**
In fact, only of the three spectra shows a desynchronization in each panel, showing the sensorimotor cortex below the corresponding electrode has been activated:

- The spectrum of Task A (blue line) desynchronizes on C3, over the cortical representation of the right hand
- Task B (red line) desynchronizes on Cz, representation of the feet
- Task C (yellow line) desynchronizes on C4, representation of the left hand

Q4. (2.5 points) Name the processing steps of the ERD/S computation, whose results are shown in panels (A-E) of Figure 2.

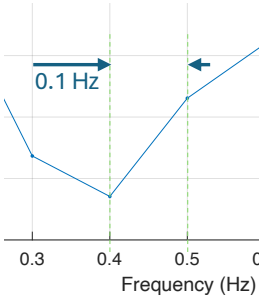
Step A: **segmentation** of raw EEG signals into trials/epochs [or just "raw EEG trials"]
Step B: bandpass-**filtering** in a subset of the beta band (26 – 30 Hz)
Step C: **squaring** the samples of each trial/epoch
Step D: **averaging** [or average over trials or group average, or synchronized average]
Step E: smoothing, resampling and **normalization** to percent changes

For further details, please refer to the lesson held on 27/03/2024 and to the Matlab notebook shown on 24/04/2024.

Q5. (1 point) What is the duration (in seconds) of the signal that was used to estimate the periodogram in Figure 3?
Justify in max 1 line.

10 seconds.

As for Q2, the answer must be based on the spectral resolution of the frequency domain representation. Since $\Delta f = 0.1\ Hz$, and since the transformation is a plain periodogram ($|DTF(signal)|^2$) with no windowing, the duration of the signal is the inverse of the frequency resolution: $T = 1/\Delta f = 10\ s$



Note that the signal used in this part of the problem did not undergo segmentation into trials, thus information about the trial length given in the assignment is irrelevant.