

Neuroengineering 2024-2025
Exam 5 June 2025
Part II

How to submit your answers.

The answers can be typed in the provided text file, following the template. Do not modify or move the lines containing the headers.

Keep your answers tidy. Messy, hard-to-read answers may penalize your mark.

The maximum total score for part II is **8**.

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

A start-up is developing a low-cost, non-invasive Brain-Computer Interface (BCI) for severely paralyzed individuals, allowing them to issue *Yes*, *No*, or *No answer* commands. The BCI operates by modulating Sensorimotor Rhythms (SMRs) through motor imagery: *Yes* corresponds to imagined right-hand movement, and *No* to imagined left-hand movement. A *No answer* command is issued when neither distinct motor imagery pattern is detected.

Hardware specifications

The analog subsystem includes a 2-channel instrumentation amplifier (differential gain $G_d = 10^4$, $CMRR = 90$ dB) and a custom bank of analog filters.

An ADC with a maximum sampling frequency of 100 Hz is used to convert analog signals to digital. It has a resolution of 8 bits and an input voltage range of $V_R = \pm 2.5$ V.

Signal processing is handled by a microcontroller. Although low-power, it can perform digital filtering, FFT, and basic mathematical operations using specialized libraries.

User interface

A binary (yes/no) question is displayed on a screen for 4 seconds (a *trial*), cueing the user to imagine moving the hand corresponding to their desired answer. A short break follows each trial. If a "*No answer*" is detected, the same question is repeated in the next trial.

To help users improve their SMR modulation, real-time feedback is provided during each trial as a cursor that moves in the direction of the detected motor imagery. The cursor position is updated every 100 ms. See also [Figure 1](#).

Neurophysiological specifications

Sensorimotor rhythms modulated by motor imagery span the alpha and beta bands. However, the exact frequencies modulated vary between individuals. Therefore, spectral analysis must identify components no wider than $\Delta f = 2$ Hz.

Signal processing

Power Spectral Density (PSD) is computed for each 4-second trial using the Welch method. To save computational resources, the EEG window length is chosen as the shortest possible while still satisfying the required spectral resolution.

Each periodogram (from each window) is used to update the cursor position. The window overlap is chosen so that a new window starts exactly one update period (i.e. 100 ms) after the previous one.

Classification

PSD values from both channels are concatenated into a feature vector and fed into a linear classifier. Two types of classification occur at different rates:

- At each update interval, the feature vector contains the most recent periodogram values, which are used to adjust the cursor position.
- At the end of each trial, the feature vector contains the full Welch PSD estimate and is used to predict the user's answer.

The features for each channel are the PSD values at each frequency bin across the alpha and beta bands.

Questions

Write all your answers in the provided text file, following the template

Q1. (2 points) Electrode Placement

- a. Identify the two optimal 10–20 system electrode locations for capturing SMR changes associated with left- and right-hand motor imagery.
- b. Are other electrodes necessary to feed all required potentials to the instrumentation amplifier?

Justify (max 300 characters).

Q2. (2 points) ADC Parameters

- a. What is the Nyquist frequency?
- b. What cut-off frequency would you choose for the anti-alias filter? (*)
- c. What is the quantization step size (V_{LSB})?

Justify (max 300 characters).

(*) In your answer take into account the effect of a non-infinite roll-off.

Q3. (3 points) PSD Calculation

- a. What should be the window length? Express the length both in milliseconds and in samples.
- b. What is the time interval between the beginning of a window and the beginning of the following one? What is the percent overlap between windows?
- c. How many periodograms are used in the PSD computation at the end of the trial?

Justify (max 400 characters).

Q4. (1 point) Final PSD and feature vector

- a. What is the total length of the feature vector that would be passed to the classifier?

Justify (max 100 characters).

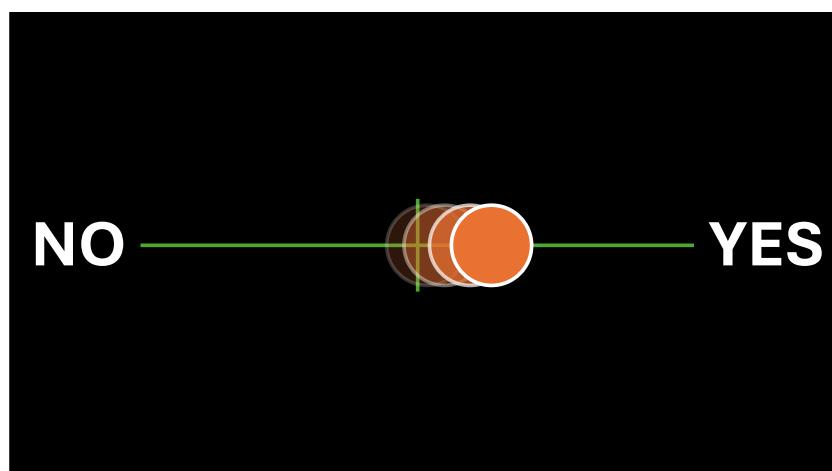


Figure 1. The user interface.

The orange cursor moves on the horizontal green line and its position is updated every 100 ms.

A classification is attempted after 4 s, then the cursor is reset in the center.

(End of the test)