Neuroengineering 2019-2020

Exam of 17 September 2020 – Part II

Solutions

Problem A

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

A novel approach for the cognitive rehabilitation of short-term memory functions is tested in a group of post-stroke patients. The duration of the rehabilitative intervention is 4 weeks.

Before and after the intervention, the patients are subjected to a neurophysiological assessment, with the aim to evaluate the changes in the connectivity occurred as a result of the rehabilitation.

EEG recordings (64 electrodes) are performed in two sessions: one immediately before (PRE) and one immediately after (session POST) the rehabilitative intervention (Fig. A1). During the screening, the patients perform a cognitive task based on short-term memory.

The neurophysiological assessment includes the following steps:

1- The pre-processing of the EEG traces

2- The analysis of brain functional networks during the task, by means of the Ordinary Coherence

3- The extraction of a subnetwork associated with short-term memory, including 6 electrodes (Fig. A2)

4- The computation of local and global indices (Degree of each electrode, Density, Global Efficiency) for the PRE and POST sessions (Fig. A3) and their comparison.

Questions

A1. For a specific subject, the graphs obtained for the PRE and POST sessions are reported in Fig. A3. *(write the answers on paper)*

A1.1. Extract the corresponding **adjacency matrices** *(0.5 points)*
A1.2. Compute the **degree** for each node *(0.5 points)*
A1.3. Compute the **Density** for each graph *(0.5 points)*
A1.4. Compute the **Global Efficiency** for each graph *(2 points)*

A2. Are there **any changes** (POST vs PRE) in these indices after the intervention? (Max 5 lines) *(write the answers in the exam.net editor) (0.5 points)*

A3. Indicate **which connectivity estimator** you would use to improve the **network analysis**. **Motivate your choice**, indicating the advantages of the method selected with respect to the one used in the proposed scenario. (Max 5 lines). *(write the answers in the exam.net editor) (1.5 points)*

Fig. A1 – Temporal organization of the study

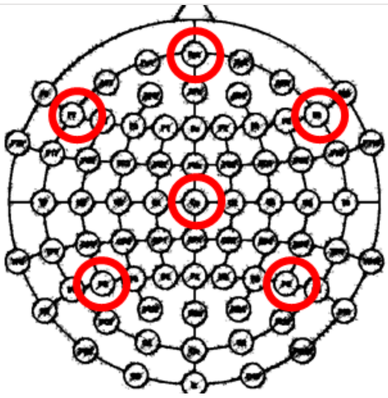

Fig. A2- The electrodes selected for the study (circled)

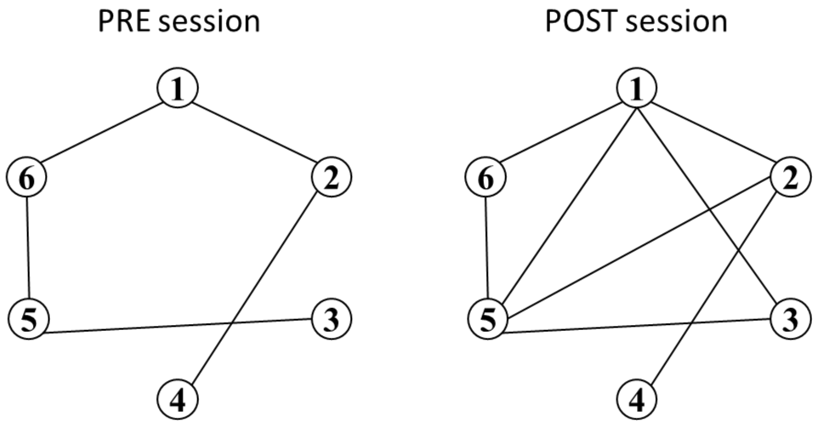

Fig. A3- Graphs obtained for a specific patient

Solutions

A1.1. Adjacency matrices:

A_{PRE}=

-	1	0	0	0	1
	-	0	1	0	0
		-	0	1	0
			-	0	0
				-	1
					-

A_{POST}=

-	1	1	0	1	1
	-	0	1	1	0
		-	0	1	0
			-	0	0
				-	1
					-

A.1.2. Degree

A_{PRE}=

						Degree
-	1	0	0	0	1	2
1	-	0	1	0	0	2
0	0	-	0	1	0	1
0	1	0	-	0	0	1
0	0	1	0	-	1	2
1	0	0	0	1	-	2

A_{POST}=

						Degree
-	1	1	0	1	1	4
1	-	0	1	1	0	3
1	0	-	0	1	0	2
0	1	0	-	0	0	1
1	1	1	0	-	1	4
1	0	0	0	1	-	2

A.1.3. Density

$k_{PRE} = {}^{L}/{}_{L_{tot}} = {}^{5}/{}_{15} = 0{,}33$

$k_{POST} = {}^{L}/{}_{L_{tot}} = {}^{8}/{}_{15} = 0{,}53$

A.1.4. Global Efficiency

D_{PRE}=

-	1	3	2	2	1
	-	4	1	3	2
		-	5	1	2
			-	4	3
				-	1
					-

$$E_{gPRE} = \frac{2}{N(N-1)} \sum_{i,j=1,i\neq j}^{N} \frac{1}{d_{ij}} = \frac{1}{15}(5 + \frac{4}{2} + \frac{3}{3} + \frac{2}{4} + \frac{1}{5}) = 0.58$$

D_{POST}=

-	1	1	2	1	1
	-	2	1	1	2
		-	3	1	2
			-	2	3
				-	1
					-

$$E_{gPOST} = \frac{2}{N(N-1)} \sum_{i,j=1,i\neq j}^{N} \frac{1}{d_{ij}} = \frac{1}{15}(8 + \frac{5}{2} + \frac{2}{3}) = 0.75$$

A.2. After the intervention there is an increase of the network density and global efficiency. The nodes become more connected and their average degree is increased. While in the PRE condition no node has a prevalent role in the network, in the POST condition nodes 1 and 5 become central.

A.3. Ordinary Coherence estimates correlation, but not causality. A **correct solution** can be **either** of the following:

- to indicate the **Granger Test** as a possible method;
- to justify the choice with the **advantages** of **directionality** and **robustness to data paucity**

OR

- to indicate **PDC** as a possible method;
- to justify the choice with the **advantages** of **directionality** and **accuracy**.

Problem B

A single-board computer is used to perform automatic diagnosis of visual evoked potentials (VEPs) by analyzing the amplitude of the P100 potential. An example of a normal VEP is shown in *Figure B1*.
The input EEG signal is filtered to attenuate all artifacts, thus its range is $\pm 100\mu V$. The signal is then amplified; the gain is set to a value such that the range of the amplified signal matches the input range of the ADC. The board features a low quality 8-bit ADC.
The P100 potential is relevant for the diagnosis and must be acquired with a specified Signal to Noise Ratio.

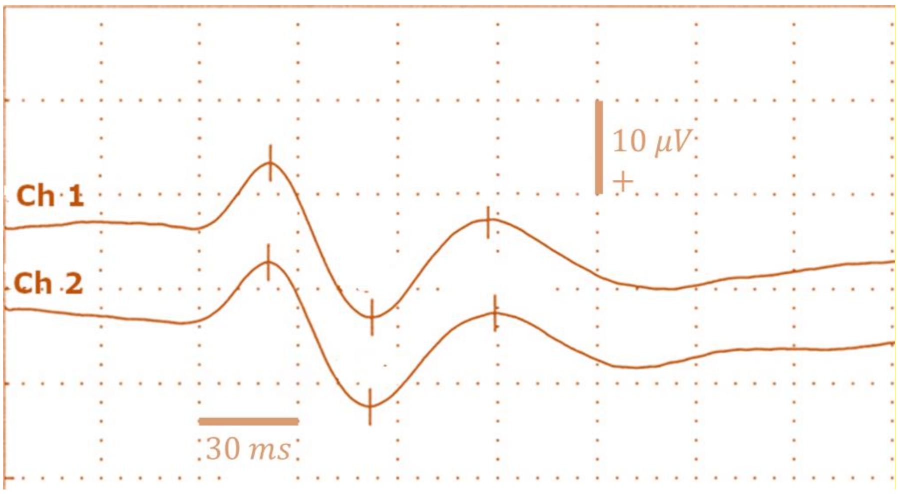

Figure B1. Example of normal Visual Evoked Potential acquired from two unspecified channels. The left margin of the figure corresponds to the stimulation time. Note on the vertical axis, positive potentials appear downwards.

Questions:

B1. Concerning the quantization noise, what is the SNR of the raw, unprocessed EEG? What would the SNR be if a more expensive SBC with a 10-bit ADC was used?
Explain why.
Justify in max 10 lines.

Answer B1

$$SNR\,|_{dB} \cong \begin{cases} 48\ dB, & NBIT = 8 \\ 60\ dB, & NBIT = 10 \end{cases}$$

The Signal to Noise Ratio is given by:

$$SNR_{dB} = 20\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right)$$

A_{signal}: Since "*the gain is set to a value such that the range of the amplified signal matches the input range of the ADC*", the range of the unprocessed EEG signal is:

$$EEG_{pp} = \Delta V_{in}$$

where V_{in} is the input range of the amplifier+ADC system.

A_{noise}: The range of the quantization noise (peak to peak value, $QNoise_{pp}$) equals the quantization interval. Given the number of bits $NBITS$ of the ADC, the quantization noise is given by:

$$QNoise_{pp} = \frac{\Delta V_{in}}{2^{NBITS} - 1} \cong \frac{\Delta V_{in}}{2^{NBITS}}$$

Taking the peak-to-peak value as a proxy of the amplitude ([1]), we obtain:

$$\frac{A_{signal}}{A_{noise}} = \frac{EEG_{pp}}{QNoise_{pp}} = \frac{\Delta V_{in}}{\frac{\Delta V_{in}}{2^{NBITS}}} = 2^{NBITS} \Rightarrow$$

$$SNR_{dB} = 20\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right) = 20\log_{10}(2^{NBITS})$$

Thus, in the given conditions (the signal fills the input range) the SNR is independent of the actual amplitude values, and only depends on the number of bits.

$$SNR\,|_{dB} = 20\log_{10}(2^{NBIT}) \cong \begin{cases} 48\ dB, & NBIT = 8 \\ 60\ dB, & NBIT = 10 \end{cases}$$

B2. Considering all contributing noises, how many trials must be acquired so that the SNR of the VEP is greater than 10dB? Would this number change using a 10-bit ADC?
Explain why.
Justify in max 10 lines.

[1] Using the RMS values would yield similar results.

Answer B2

$N_{Trials} = 252$, and it is practically independent of the resolution of the ADC.

In this case the contribution of the quantization noise is marginal, since the “noise” that most contaminates the VEP is the ongoing EEG which is several orders of magnitude greater ([2]). Using again the peak values of both signal and noise, for the un-averaged single trial, the signal to noise ratio is:

$$\frac{A_{signal}}{A_{noise}} = \frac{V_{P100}}{V_{EEG} + \cancel{QNoise}} = \frac{V_{P100}}{EEG_{pp}/2}$$

When N_{Trials} are averaged:

$$\frac{A_{signal}}{A_{noise}} = \frac{V_{P100}}{V_{EEG}/\sqrt{N_{Trials}}} = 2\sqrt{N_{Trials}}\,\frac{V_{P100}}{EEG_{pp}}$$

We see from Figure B-1that the peak value of the P100 potential is approximately $10\ \mu V$, thus

$$\frac{A_{signal}}{A_{noise}} = 2\sqrt{N_{Trials}}\,\frac{10\ \mu V}{100\ \mu V} = 0.2\ N_{Trials}$$

To achieve the minimum required SNR:

$$SNR\,|_{dB} = 20\log_{10}\left(0.2\sqrt{NTrials}\right) \;= -14 + 10\log_{10}(NTrials)$$
$$SNR\,|_{dB} \geq 10\ dB \quad \Rightarrow NTrials > 10^{24/10} \;= 251.2$$

B3. Name the three EP components marked in *Figure B1*.
max 2 lines.

Answer B3

Using only the information available from the text, thus estimating polarities and latencies from the figure the names N80, P110, and N150 fulfill the nomenclature introduced in the course ([3]).

Note from the figure’s legend that “*The left margin of the figure corresponds to the stimulation time*”, thus there is no reason to assume that the stimulus occurs on the second grid line (which would lead to estimate latencies of ~25, ~60 and ~90 ms).

[2] In fact $QNoise_{pp} = \frac{\Delta V_{in}}{2^{NBITS}} = \begin{cases} 100\ \mu V/256 = 0.39\ \mu V, & NBIT = 8 \\ 100\ \mu V/1024 = 98\ nV, & NBIT = 10’ \end{cases}$
while the ongoing EEG has an amplitude $EEG_{pp} = 100\ \mu V \gg\ QNoise_{pp}$

[3] In fact, the traces are an individual variation of the standardized N75, P100, and N135 peaks (source):

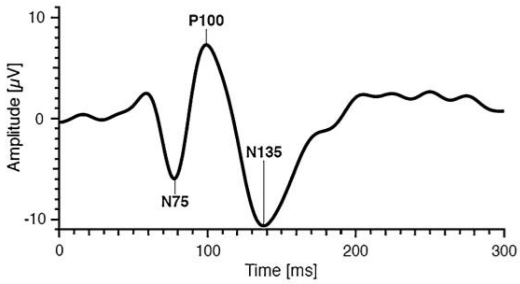

Fig. 2 A typical pattern-reversal VEP

Note from the figure's legend that "*positive potentials appear downwards*", thus the sequence of polarities is N, P, N.