Neuroengineering 2019-2020

Exam of 18 January 2021 – Part II

Solutions

Problem A

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

A study has the aim to investigate a short-term memory function. It is already known that:

1. the function involves 6 brain regions;
2. it is based on a specific activity in alpha and theta bands;
3. learning and habituation effects prevent from performing long recording sessions.

Question A1 *(2 points)*

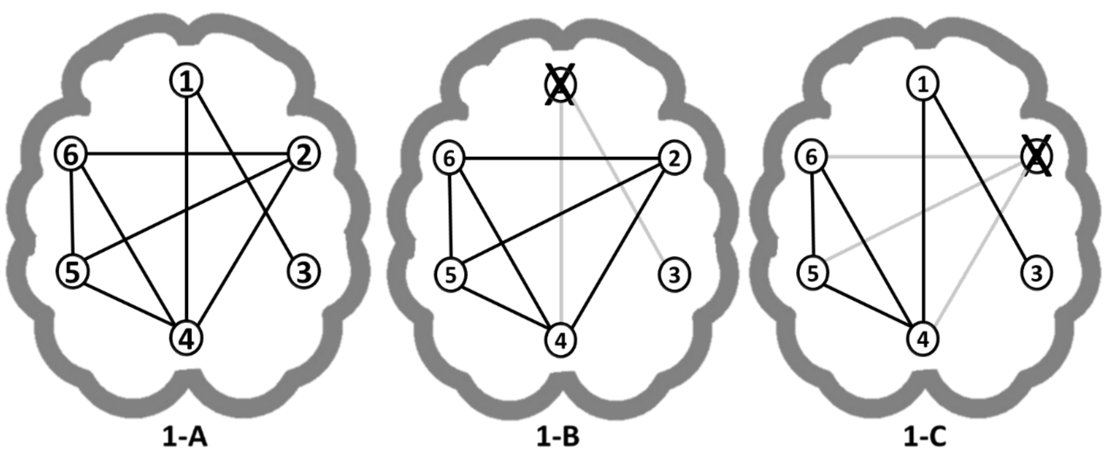
Indicate which method you would use to perform the functional connectivity analysis. Motivate your choice, based on the above-mentioned conditions.

SOLUTION:

Since the memory function is known to be based on the activity in specific frequency bands, I will prefer a spectral estimator, which restricts my decision to Ordinary Coherence or Partial Directed Coherence. Being a multivariate method, PDC requires long data segments to provide a reliable estimation. In this study, however, long recording sessions are not allowed by the learning and habituation effects. Thus, Ordinary Coherence is the best choice according to the study conditions.

Question A2 *(3.5 points)*

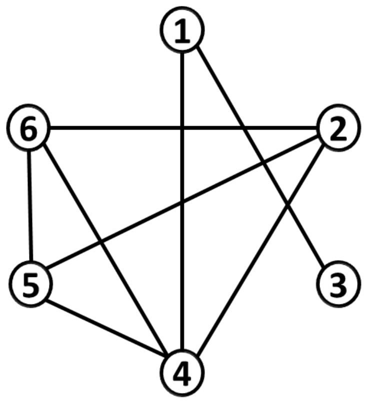
As a result of the study, we obtain the functional brain network reported in Fig. 1-A. Then, to investigate the role of specific regions in the network, we examine the same network after the removal of node 1 (Fig. 1-B) and node 2 (Fig. 1-C).



A2.1: Compute the Global Efficiency for each of the three graphs *(2 points)*

SOLUTION:

1-A



Distance matrix:

D=

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

$N = 6$

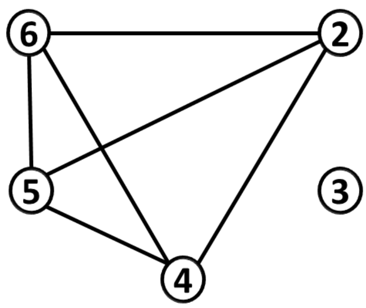
$L = 8$

$L_{max} = \frac{N(N-1)}{2} = 15$

Global Efficiency for undirected graphs:

$$E_g = \frac{2}{N(N-1)} \sum_{i,j=1,i\neq j}^{N} \frac{1}{d_{ij}} = \frac{2}{6(6-1)}\left(8 + \frac{4}{2} + \frac{3}{3}\right) = 0{,}73$$

1-B



Distance matrix:

D=

-	∞	1	1	1
∞	-	∞	∞	∞
1	∞	-	1	1
1	∞	1	-	1
1	∞	1	1	-

$N = 5$

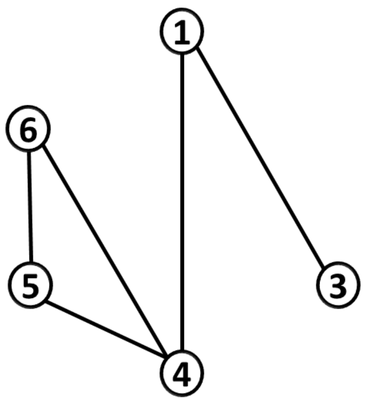
$L = 6$

$L_{max} = \frac{N(N-1)}{2} = 10$

Global Efficiency for undirected graphs:

$$E_g = \frac{2}{N(N-1)} \sum_{i,j=1,i\neq j}^{N} \frac{1}{d_{ij}} = \frac{2}{5(5-1)}(6) = 0{,}6$$

1-C



Distance matrix:

D=

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

$N = 5$

$L = 6$

$L_{max} = \frac{N(N-1)}{2} = 10$

Global Efficiency for undirected graphs:

$$E_g = \frac{2}{N(N-1)} \sum_{i,j=1,i\neq j}^{N} \frac{1}{d_{ij}} = \frac{2}{5(5-1)}\left(5 + \frac{3}{2} + \frac{2}{3}\right) = 0{,}72$$

A2.2: Indicate which, among the two removed nodes, has the more important role in the efficiency of communications in the network. Motivate your choice. *(1.5 points)*

SOLUTION:

Comparison between the three networks:

	Global Efficiency
Complete network	0.73
Removal of region 1	0.6
Removal of region 2	0.72

The removal of region 1 significantly reduces the Global Efficiency of the network, while the removal of region 2 leaves it basically unmodified with respect to the original network. This means that region 1 has a more important role in the efficiency of communications in the brain network during the short memory task.

Problem B

A somatosensory evoked potential (SEP) is recorded by delivering electrical stimulations to the peripheral nerve to the most distant segment of the subject's limb. The procedure is repeated twice, once per experimental condition (conditions "red" and "black"), in each of which 100 single trials are collected. Following synchronized averaging of the raw EEG trials, the waveforms of the averaged potentials are plotted in *Figure B1*.

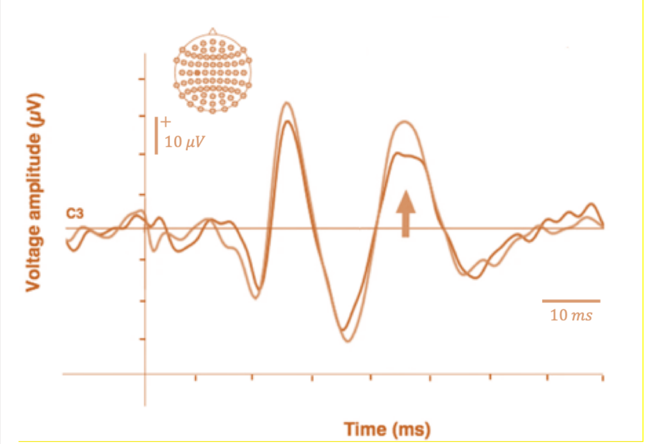


Figure B1. Example of normal Somatosensory Evoked Potential acquired in two experimental conditions (red, black). The vertical axis corresponds to the stimulation time.

Questions:

B1. Make an informed guess on the names of the peaks (EP components) visible in the "red" condition. Briefly explain your reasoning.
Justify in max 5 lines..

Answer B1

Components: N20, P25, N35, P45, and N55 ([1])

Justification:

Scale with positive up → top peaks have positive polarity (P), bottom troughs have negative polarity (N). Latencies are ~20 ms (N20), 25-30 ms (P30), ~35 ms (N35), 45-50 ms (P45) , ~55 ms (N55)

B2. Make a broad visual estimate of the amplitude of the noise affecting the waveform. (*Hint: check the baseline period*). Assuming this ERP was obtained from the average of 100 single trial, estimate the amplitude of the subject's spontaneous EEG. Explain your reasoning.
Justify in max 10 lines.

Answer B2

Noise amplitude: ~10μV

Spontaneous EEG amplitude: ~100μV

Justification:

In the latency interval before the stimulus (and up to +15 ms) the average amplitude of the signal is ~10μV. Since we expect no ERP up to this time, we can assume this equals to the amplitude of noise.

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[1] See also https://www.nature.com/articles/s41598-018-27698-2

In the averaging process, the amplitude of the uncorrelated signal (spontaneous EEG) is attenuated by a factor $\sqrt{N}$, where N is the number of trials. From $X \cdot / \sqrt{100} = 10\mu V$ we obtain $X = 100\mu V$

B3. Assuming the conduction velocity is about 60 m/s, is it more likely that the stimulation was delivered to the upper or to the lower limb (i.e. arm or leg)? Was it delivered to the right or the left limb?. max 5 lines.

Answer B3

Limb: upper right

Justification:

It takes 20 ms for the peripheral stimulus to reach the contralateral brain hemisphere. The distance travelled is $D = 60\frac{m}{s} \cdot 20\, ms = (60 \cdot 0.02)\, m = 1.2\, m$. The "*most distant segment of the subject's limb*" can be either the hand fingers or the foot toes. Given the distance D, the former (hand, thus upper limb) is the correct answer for a person of average height. ([2])

The primary somatosensory area which processes the sensory input is contralateral to the side of the body receiving the stimulus. Since the N20 is visible on channel C3 (which is on the left side of the head), the stimulus must have been delivered to the right hand.

[2] Moreover, a lower limb SEP would have been analyzed on an electrode closer to the midline (Cz).