Neuroengineering 2020-2021

Exam of 21 Jult 2021 – Part II

Solutions

Problem

(The following text is a modified version of the Methods section of a scientific paper [1])

During the planning and execution of a motor task, a characteristic EEG response (ERP) is produced, known as the motor-related cortical potential (MRCP). The early components of the MRCP are associated with preparation for movement execution.

Motor task.
A motor target task was displayed on a PC that required an accurate 14-cm linear movement in the horizontal plane, from the center of the workspace to a target placed in a direction directly away from the subject, and was accomplished using shoulder flexion and elbow extension of the right arm.
Five runs of task containing 30 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 *(International 10–20 System [2])*. Impedance at lower than 10000 Ω was obtained prior to data collection. The active electrodes were referenced to the common linked left and right mastoid surface electrodes. EEG signals were amplified (×75 000), low-pass filtered (0–100 Hz), and digitized (500 sample/s).
In addition to dataset acquire for the experimental (motor) task, one run of rest with open eyes (1 minute), one run of rest with closed eyes (1 minute) were acquired.

Motor-Related Cortical Potential (MRCP)
Raw signal recordings were visually inspected to detect artifacts induced by eye blinks, facial muscle contractions, or head movements and removed either manually or with software filters; otherwise, the trials were discarded if noise or artifacts were not correctable. Trials containing noise from EMG signals were discarded.
MRCP was derived from movement onset trigger-averaged EEG signals (50 trials). The EEG signal included an 8-s window (4 s before and 4 s after the onset event). The mean MRCP start time and amplitude were calculated for each electrode. We defined cognitive effort level as MRCP amplitude (µV; *Figure 1*) and cognitive planning time as the duration of time between MRCP onset and EMG onset (*Figure 1*).

EMG data acquisition
The EMG signal was acquired using bipolar electrodes (8-mm recording area) applied on the anterior deltoid and triceps, agonist muscles. EMG onset time was defined as: 2 standard deviations (SD) increase in amplitude above the resting baseline that was maintained for at least 100 ms. The EMG signal was amplified (×1000), filtered 10–2000 Hz, digitized (2000 samples/s), and synchronized with EEG.

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[1] See https://ieeexplore.ieee.org/document/1642760

[2] Due to an oversight in the preparation of the exam, the text in parentheses was skipped. For this reason, twice the points associated to Q1 and at least half of the points associated to Q2 were attributed, independently of the answer, for the unintended increased difficulty of the test.

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*.

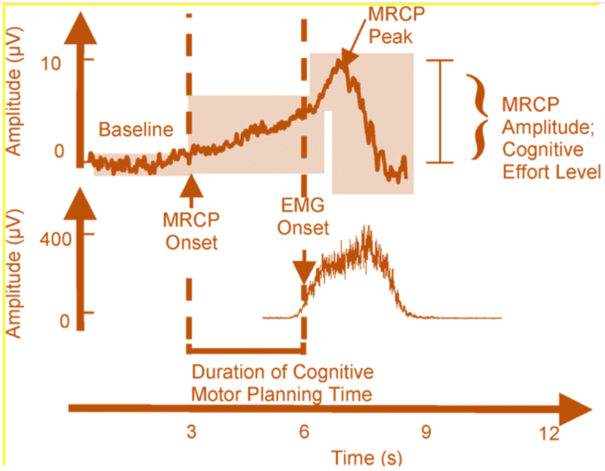

Figure 1. Top graph shows schematic of MRCP, characteristic EEG signal present prior to and during performance of motor task. Vertical axis shows amplitude of signal and horizontal axis represents time (in seconds). First 3 s shows baseline EEG signal. MRCP onset is labeled at 3 s with upward vertical arrow. Vertical distance from baseline to MRCP peak is labeled as "MRCP amplitude" or "cognitive effort level." bottom graph shows schematic of EMG signal, and EMG onset is labeled at 6 s with downward vertical arrow and associated vertical line (vertical dotted line on right). MRCP onset is indicated across both top and bottom graphs with vertical dotted line on left at 3 s. Duration of cognitive planning time is horizontal solid line between MRCP onset (3 s) and EMG onset (6 s).

Questions:

Q1. Regarding the acquired EEG channels:

a. Following the experiment's description from the paper, how many EEG channels were acquired?
b. How many electrodes had to be mounted on the subject's head?
c. If only the following six bipolar channels were acquired in the experiment, how many electrodes should have been mounted on the subject's head?
   C3-P3, P3-O1, Cz-Pz, Pz-Oz, C4-P4, P4-O2
   Justify each answer in max 10 lines total.

Answer Q1

a) number of channels: 19 (see footnote 2)
b) number of channels: 22 (see footnote 2)
c) number of channels: 10
Justification:
a) EEG collection according to the International 10-20 System, which specifies the position of 19 electrodes (the recording was monopolar, being later specified what -common- reference was used).
b) 19 active electrodes, + 2 reference electrodes ("common linked left and right mastoid") + 1 ground electrode
c) 9 active/reference electrodes (C3, P3, O1, Cz, Pz, Oz, C4, P4, O2) + 1 ground

Q2. Is there any inconsistency or mistake in the description of EEG signals Analog-to-Digital conversion? What about the EMG signal?
Justify in max 5 lines.

Answer Q2
Mistakes: Yes, only in the EMG conversion.
Justification:
No obvious mistakes for the EEG conversion.

The sampling frequency of the EMG signal should be at least twice, for the antialiasing filter used "The EMG signal was … filtered 10–2000 Hz, digitized (2000 samples/s)"

Remarks:
- Amplification can theoretically be swapped with analog filtering, being both linear operations. Nevertheless, amplification is usually the first operation in the chain, so that electronic noise introduced by filtering is not further amplified. The amplification factor is appropriate to bring the output in the range of Volts, which is the required input range for digital circuits in the ADC.
- The sampling frequency must be *greater than* twice the maximum frequency of components in the analog signal, not *equal to*
- When signals with different bandwidths must be acquired, it is acceptable to do so with different sampling frequencies, so that disk space is not wasted to sample the EEG with the high sampling frequency appropriate for the EMG. If the sampling frequencies are in an integer ratio (e.g. 2000/500 = 4), it is easy to keep the signal synchronized in the digital processing pipeline.

Q3. Assuming the amplitude (RMS) of the raw EEG on channel is 15µV, compute the expected noise on the ERP due to spontaneous EEG activity.
Justify in max 5 lines.

Answer Q3
Noise amplitude: $1.25\ \mu V$ (or $2.12\ \mu V$, see below)
Justification:
The task was composed of "*Five runs of task containing 30 trials*", i.e. $N = 150$ trials. The amplitude of the residual spontaneous EEG in the average of N trials is $\sigma_{avg} = \sigma_{raw}/\sqrt{N} = 15/12.25\ \mu V = 1.25\ \mu V$

Elsewhere in the text a conflicting information is given: "*MRCP was derived from movement onset trigger-averaged EEG signals (50 trials)*". Thus $\sigma_{avg} = \sigma_{raw}/\sqrt{50} = 15/12.25\ \mu V = 2.12\ \mu V$ is also considered a correct answer.

Q4. Analyzing *Figure 1*, and considering the EMG onset as the relevant event (zerotime), what is the latency of the MRCP onset? What is the latency of the MRCP peak?
Justify in max 5 lines.

Answer Q4
MRCP onset latency: $-3\ s$ (or $-3000\ ms$)
MRCP onset latency: $+1\ s$ (or $+1000\ ms$)
Justification:
The MRCP onset takes place 3 s before the EMG onset. The MRCP peak takes place 1 s after the EMG onset.

Q5. Is the EMG represented in *Figure 1* the raw signal or was it processed? If so, what processing steps were presumably done to obtain the graph?
Justify in max 5 lines.

Answer Q5

Is EMG raw?: no

Justification:

Had the EMG been raw, we would expect the mean to be zero. Since we aim to detect the onset, the typical processing pipeline yielding to this waveform include bandpass filtering (unspecified), squaring, synchronized averaging (for display purposes). Squaring is critical so that the mean and the RMS of the average do not tend to zero, $N_{trials} \rightarrow \infty$.

Q6. The technician misnamed the files with the rest EEG runs, and now he is not sure which was acquired with the subject's eyes open and which with the eyes closed. Would you be able to tell them apart? If so, would visual inspection sufficient or would you need to process the data?
Justify in max 5 lines.

Answer Q6

Are data runs identifiable? : Yes

Justification:

In most subjects, one can observe the increased amplitude of the alpha rhythm in the eyes-closed condition with respect to the eyes-open condition, by visual inspection of the raw EEG. The parieto-occipital and occipital channels show the synchronization most clearly (see slides about the alpha blocking phenomenon).

Alternatively, one could seek blink artifacts on prefrontal and frontal channels, which would indicate an eyes-open condition.

Q7. Which EEG channel was likely represented in Figure1? Indicate a channel name or a set of possible channels.
Justify in max 5 lines.

Answer Q7

Displayed channel (or reasonable set): C3 or CP3 (or electrodes nearby)

Justification:

We can expect that a motor related potential is maximally visible on the sensorimotor area of the contralateral hemisphere. Since the motor task was "shoulder flexion and elbow extension of the right arm", we can thus speculate that the authors used a central (or centroparietal) channel of the left hemisphere, near the cortical representation of the arm, thus in the neighborhood of C3 or CP3.