BITalino (r)evolution ~~Lab~~ Home Guide

EXPERIMENTAL GUIDES TO MEET & LEARN YOUR BIOSIGNALS

ATTENTION

The present document includes experimental protocols to be shared with customers who have PLUX products.

This document should not be distributed through alternative routes unless the customer chose to acquire our biosignals acquisition systems.

The information contained in this manual has been carefully checked and were made every effort to ensure its quality. PLUX reserves the right to make changes and improvements to this manual, especially during the initial phases of the creation of this document.

PLUX – Wireless Biosignals, S.A.
Av. 5 de Outubro, n. 70 – 2.
1050-059 Lisbon, Portugal
BITalino@plux.info
http://BITalino.com/

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HOME-GUIDE #3

ELECTROENCEPHALOGRAPHY (EEG)

Exploring Brain Signals

1. GOALS

After this lesson you will be able to understand the basic principle of Electroencephalography (EEG), how a brain signal is triggered, acquired with the given system, and explore different signals in various brain areas.

In this Home-Guide you will explore the EEG signals in detail. The main goals of this lesson will be the following:

- Perform a set of EEG acquisitions in real-time.
- Test different electrode positions to examine different brain areas.
- Understand the change of signal triggered by changes of neuronal activity.
- Getting familiar with the frequencies of interest.

2. REVIEW HOME-GUIDE #2 & INTRODUCTION

All information of Home-Guide #2 can be found here: HOMEGUIDE#2. Complementary information can be found at bitalino.com

In the Home-Guide #2 we learned how to acquire cardiac signals using an ECG sensor. In this Home-Guide we will get to know brain signals with an EEG sensor.

Electrical activity of the brain can be recorded with an EEG sensor by placing specific electrodes on the scalp. The acquired signals reflect the neuronal activity of these specific brain areas above which the electrodes are positioned. Each electrode records an area specific signal from which the magnitude of associated frequency bands can be extracted to evaluate the influence of specific tasks on the brain activity.

3. MATERIALS

OpenSingals (r)evolution software is available on: https://bitalino.com/en/software

- OpenSignals (r)evolution software
- 1 x BITalino (r)evolution Assembled Core BT
- 1 x Assembled Electroencephalography (EEG) Sensor
- 1-lead electrode cable (e.g., usually placed on a bone to be used as an internal reference)
- 3 x Gelled Self-adhesive Disposable Ag/AgCl- Electrodes
- 1 x Bluetooth dongle

(a) (b) (c) (d) (e) (f)

Figure 1: BITalino (r)evolution Assembled Core BT - Front View (a) and Back View (b); Assembled Electromyography (EEG) Sensor (c); 1-Lead Electrode Cable (d), Gelled Self-adhesive Disposable Ag/AgCl electrodes (e), and Bluetooth dongle (f).

**for each experiment you must use 2 gelled electrodes for the EEG sensor and 1 gelled electrode for the reference cable. Each time you want to repeat your experiment, or each time you see the electrodes are not in a good condition it is recommended to change them for new ones. Also make sure that you clean the skin area with alcohol before adjusting the electrodes to remove skin particles and improve the skin conductivity.*

4. RELATED DOCUMENTATION

BITalino (r)evolution Quick Start Guide

BITalino Assembled Core BT Datasheet

Assembled EEG datasheet

EEG sensor datasheet

5. INTRODUCTION TO ELECTROENCEPHALOGRAPHY (EEG)

5.1. EEG Basics

The human brain has around 85 billion neurons that are responsible for most of the communication through the synapses which are positioned at the end of the axons. The fired information also release neurotransmitter causing the change of voltage throughout the cell membrane. An electrical field of only a few hundred milliseconds is generated (postsynaptic potential). The most important cell type to measure electrical fields from the scalp is the pyramidal neuron whose activity is strong enough to go through the different layers. This is due to the specific orientation which is perpendicular to the cortical surface.[1] [2]

Figure 2: Artistic illustration of a neuron of the human brain.

Let's have a deeper look into the different brain areas and tasks that can be performed to trigger such areas as well as specific frequency bands.

5.1.1. How does the Brain work? A Physiological Overview

The cerebrum consists of four main surface lobes or function areas which are the frontal (orange), temporal (green), parietal (blue), and occipital (yellow) lobes as illustrated in Figure 3 with their respective functions. The occipital lobe is located at the back of the skull and is responsible for visual processing. The temporal lobe is responsible for sensory processing, long-term memory, visual memories as well as emotion and language. The parietal lobe is responsible for merging information's from sources from the surroundings such as the environment and its relation to our body (e.g. Coordination of hands when grasping an object). The frontal lobe is responsible for voluntary movements, decisions, thoughts, cognitive processing such as planning and attention and is known as our personality center.[2] [3]

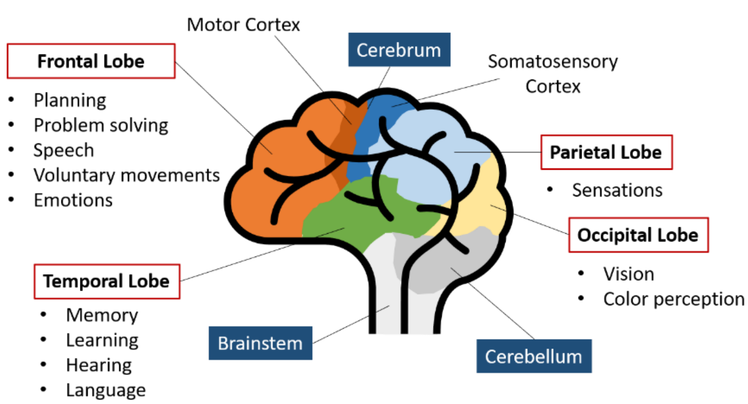


Figure 3: The cerebrum and its surface lobes with their respective functions (marked in red).

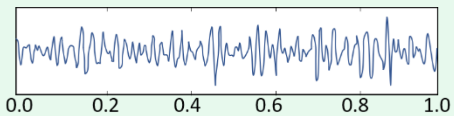
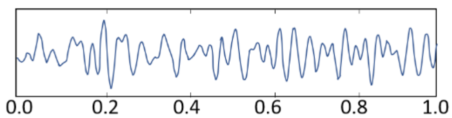
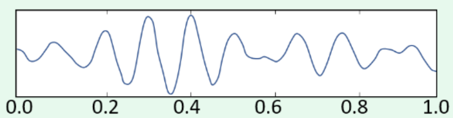
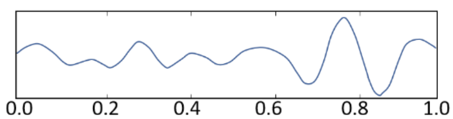
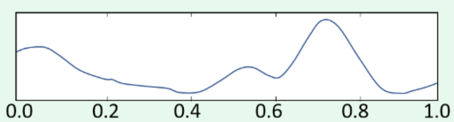
[1] *Herculano-Houzel, Suzana. "The human brain in numbers: a linearly scaled-up primate brain." Frontiers in human neuroscience 3 (2009): 31.*

[2] *Farnsworth, B. "EEG (Electroencephalography): The Complete Pocket Guide." (2019).*

[3] *Bansal, Dipali, and Rashima Mahajan. EEG-Based Brain-Computer Interfaces: Cognitive Analysis and Control Applications. Academic Press, 2019.*

Five frequency sub-bands define the EEG signal frequencies that can be measured from the cerebrum, with gamma being the fastest and delta being the slowest frequencies, see Table 1.[4]

Table 1: EEG frequency bands, occurrence, and tasks to trigger the band power.

Wave Type	Signal Example	Frequency [Hz]	Occurrences	Tasks / Studies
Gamma		**> 25**	Problem solving, concentration	Micro saccade studies
Beta		**12 – 25**	Busy, active mind	Motor control / stimulant-induced alertness
Alpha		**8 – 12**	Reflective, restful	Meditation / biofeedback training / attention
Theta		**4 – 8**	Drowsiness	N-back test / spatial navigation
Delta		**0 – 4**	Sleep, dreaming	Sleeping studies

Delta band oscillations range in frequencies of 0-4 Hz and are present in different sleeping phases (e.g. the power of the delta band correlates to the deepness of sleep).

Theta frequencies range in frequencies of 4-8Hz and originate from the thalamus and are stronger on the right side of the brain. Theta waves are associated with the frontal area of the brain and correlate to metal tasks and indicate a higher band power with higher task difficulty, though can be measured in all cortex areas and relates to brain region carrier. A typical test is the N-back test in which a subject receives visual stimuli on a screen such as letters and has to simultaneously remember one specific stimuli letter and when this stimuli letter appeared N-steps before, the subject needs to respond. Another task is the navigation in a virtual reality.

Alpha-band oscillations range in frequencies of 8-12Hz and reflect functions correlated to memory, motor, and sensory. An increase of alpha band power can be triggered by wakeful relaxation when the eyes are closed for example in meditation. In comparison, alpha waves are suppressed when opening the eyes and physical or mental activity. Besides meditation other typical studies on alpha waves are for example attention and biofeedback training.

Beta waves oscillate in between 12 to 25 Hz and are generated in the posterior and frontal regions. They correlate to active thinking and concentration. With higher concentration, the beta oscillations fire in a faster frequency. Typical studies include tasks about motor control in which an object must be grasped (i.e. with Parkinson's patients) and stimuli-induced alertness (light/sound stimuli).

[4] *Abhang, Priyanka A., Bharti W. Gawali, and Suresh C. Mehrotra." Chapter 2 - Technological Basics of EEG Recording and Operation of Apparatus", Introduction to EEG-and speech-based emotion recognition. Academic Press, p.19-50, 2016.*

The final band is the **gamma band** with frequencies above 25 Hz. The origin and the reflection of these oscillations are not noticeably clear and different research studies argue various information such as the reflection of eye movements and therefore tested in microsaccade studies. [1-4]

5.1.2. How to acquire an EEG?

An internationally recognized method on how to describe the electrode positions on the scalp is the ***international 10-20 system***, see Figure 4. The total distance between front (nasion)-to back (inion) as well as right to left is defined by 100%, hence the 10 and the 20 describe the distances between each adjacent electrode in percent. Each position contains a letter as well as a number, describing the location on the lobe (**F**rontal, **T**emporal, **C**entral, **P**arietal, and **O**ccipital) and the hemisphere, respectively. Notice, that uneven numbers refer to the left (in red) and even numbers to the right hemisphere (in blue). The midline is defined by the letter 'z' for zero (in black).[4,5]

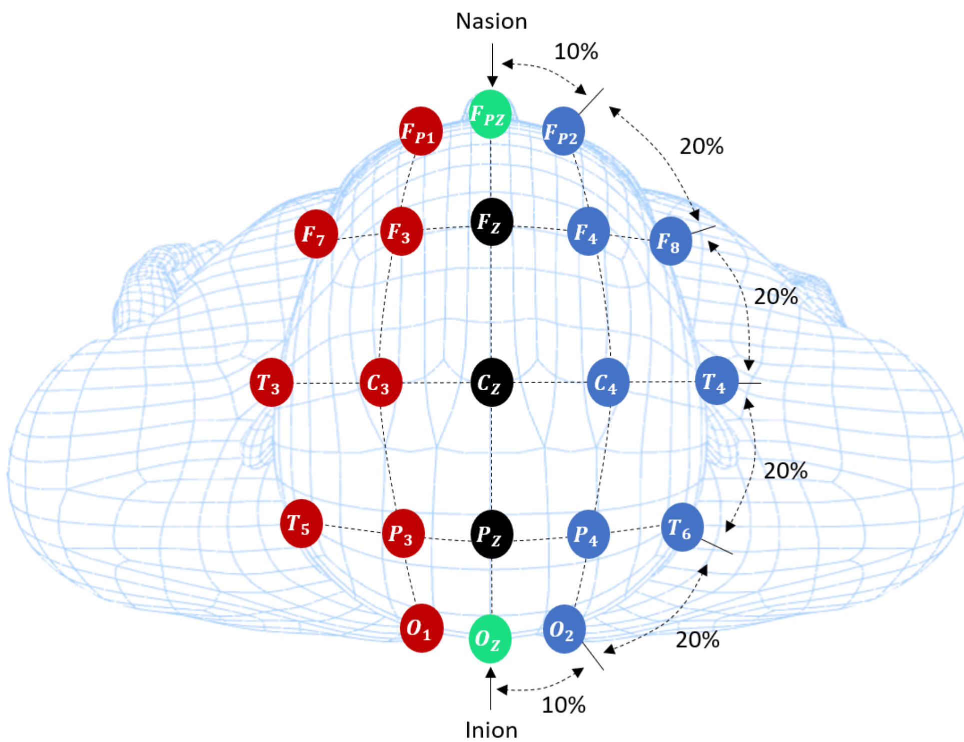


Figure 4: Top view of a head with electrode positioning according to the international 10-20 system.

Try to find the anion and inion region of your head from which the 10-20 system builds up from, see *Figure 5* for additional help). As a hint: You will notice a depression when running your finger up your neck, just above is the inion which protrudes. The nasion is the bridge of your nose.[4]

[5] *Sazgar, Mona, and Michael G. Young. "Overview of EEG, electrode placement, and montages." Absolute Epilepsy and EEG Rotation Review. Springer, Cham, 2019. 117-125.*

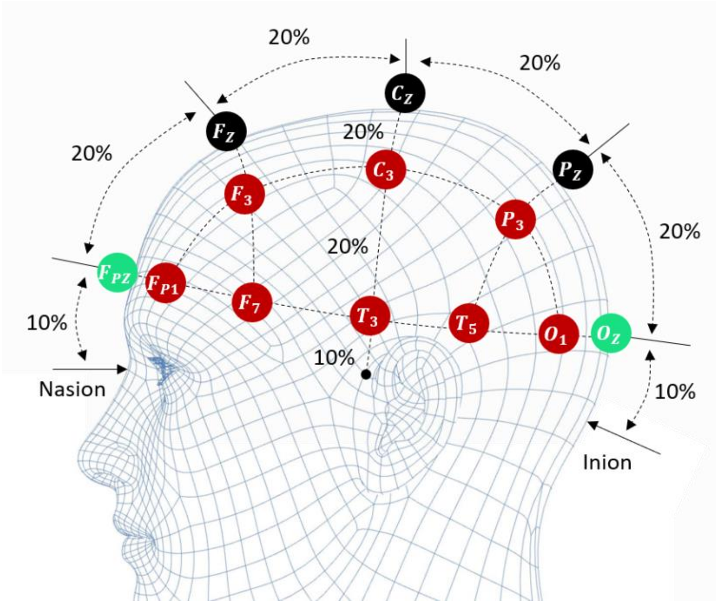


Figure 5: Side view of a head with electrode positioning according to the international 10-20 system.

To get the positioning right, pre-assembled electrode caps are available for optimal positioning of the electrodes. These might be very practical when EEG signals need to be acquired from the whole brain. Though it is very time intensive to prepare and adjust the cap and each electrode onto the scalp (unipolar measuring of signals and fixation of electrodes on the scalp with a conductive paste). Hence, when knowing which brain area to observe, it is easier to use single sensors (sets of two measuring pins plus one reference) which use a bipolar configuration and measures the potential differences in between two adjacent electrodes. One of those devices is your assembled BITalino EEG sensor. Furthermore, it is more convenient to adjust this sensor to pre-gelled electrodes to avoid using the conductive paste. You have already got to know the pre-gelled electrodes in detail in our EMG Home-Guide #1.

5.1.3. How to acquire an EEG with BITalino?

To measure brain activity from the scalp, two possible electrode measuring techniques are possible. One is monopolar (one electrode per brain area and a reference electrode) and the other one is the bipolar setup. Lets have a look at your asembled EEG from the inside, see Figure 6, which is a bipolar measuring setup that contains two measuring electrodes (IN + and IN-). With this setup an additional reference electrode has to be connected and placed in a bony area.

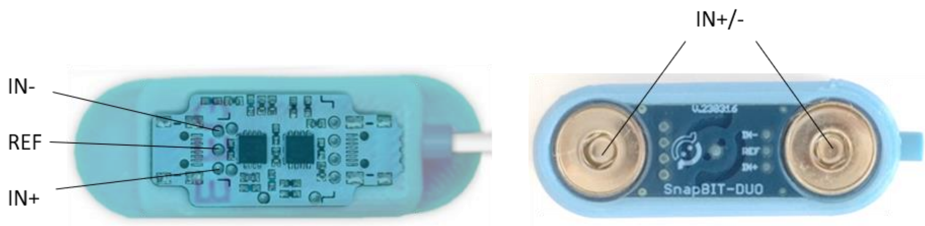


Figure 6: Assembled EEG sensor form the inside and pins for electrode connections. Top (left), bottom view (right).

Let's have a look at some important aspects when working with the EEG sensor:

- The measured signal is the amplified difference between the two measuring signals which is bandpass filtered by 0.8-48Hz to eliminate the common unwanted signals (see EEG datasheet).
- The high amplification (gain=40000) makes it very sensitive to surrounding artefacts such as light, movements and power supplies (50/60 Hz line noise).
- It is important to establish an appropriate environment to ensure optimal performance of the sensor.
- The test subject should suppress any muscular activation while the acquisition is performed especially in the facial area (eye movements and eye blinking) as well as neck and jaw movements (clenching/ chewing).
- This can be done by placing a big cross in front of the subject to focus their eyes on while performing the task (if the task is not visually displayed).
- To record some artefacts, it is recommended to acquire such data using EOG (Electrooculography), EMG (Electromyography), and ECG (Electrocardiography) if available.
- Movement artefacts can also be recorded with a video camera or written down for each time segment.
- The skin should be properly prepared before sticking the electrodes onto it.
- Disinfection of the skin to remove old skin particles and if needed removal of hair should be considered.

In the bipolar set-up two measuring electrodes (IN+/-) are placed above the electrode position for example FP1 (international 10-20 system, see Figure 4 and Figure 5) with a distance between the electrodes that is pre-defined by the assembled EEG sensor snaps, see Figure 6 (bottom) and Figure 7 (left). The reference electrode is placed in a neutral region such as on a bone behind the ear, see Figure 7 (right).

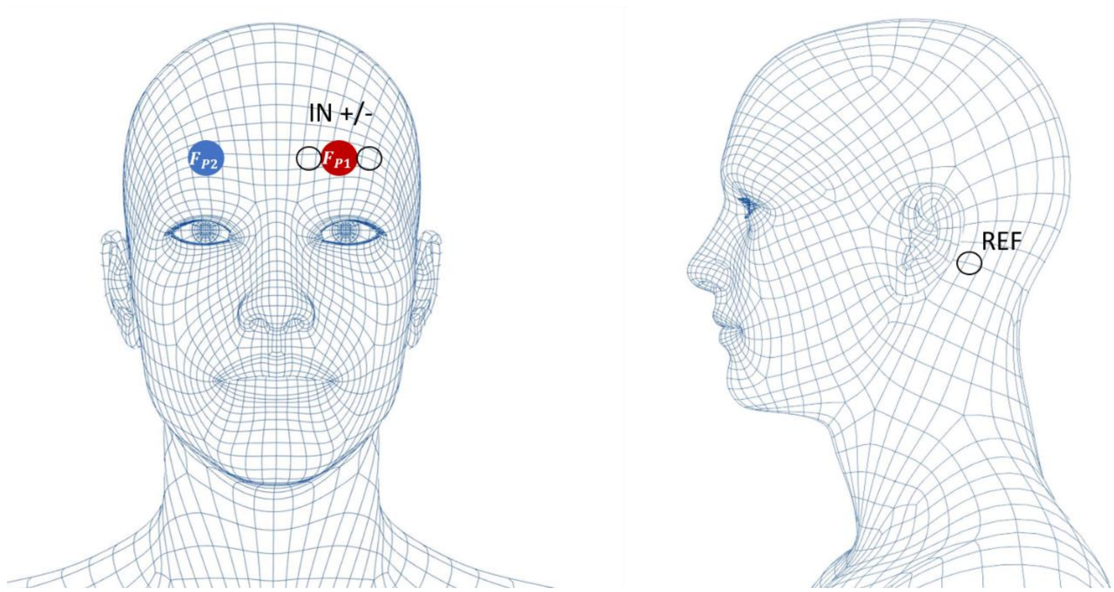


Figure 7: Electrode positioning to measure EEG at position FP1: Measuring pins IN+/- (left) and reference (right).

IMPORTANT NOTES:

✓ In the case of EEG recording very small muscular activations such as eye or jaw movements can cause artefacts in the signal. Therefore, we need to make sure that all muscles are relaxed.

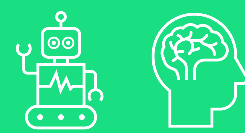
5.2. Applications – What is EEG used for?

Now that we know how an EEG sensor works, let´s have a look at some applications in which EEG signals are used.

In medical applications, EEG is typically used for the diagnosis of disorders or diseases in the brain that cause abnormalities which can be seen in the EEG signal such as in the case of epilepsy or sleep disorder. EEG can also be helpful when used with a brain-computer interface (BCI) for example for patients with a spinal cord injury, brainstem stroke, or amyotrophic lateral sclerosis (ALS) which are “locked in” their bodies without being able to communicate. Such patients with severe motor disabilities need alternative communication methods. The BCI extracts “features” from the brain signals and can trigger external device such as a switch, prostheses, or computers. [6]

Did you know?

➔ ***That you can control a robot with your mind?***



If you are interested in BCIs and want to learn more about this topic, check out this review: *Comprehensive review on brain-controlled mobile robots and robotic arms based on electroencephalography signals*

A simple example of a “feature” is the extraction of the alpha band power which represents the magnitude of alpha frequencies from the brain signal. In the case of eyes closed the alpha waves can be distinguished clearly, see Figure 8 (zoom in red).

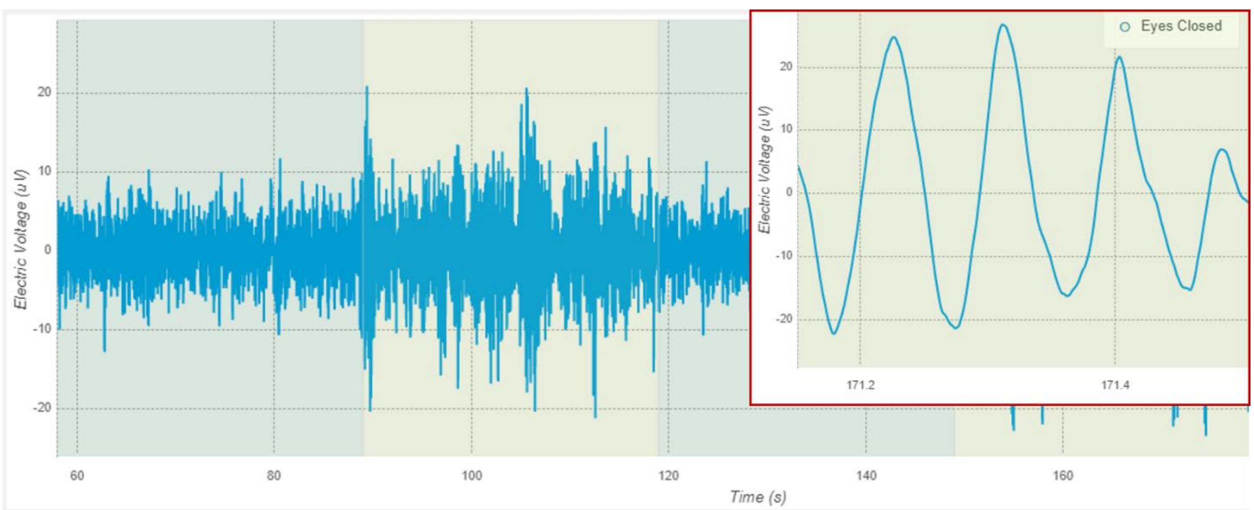


Figure 8: EEG signal acquired with a PLUX sensor while eyes open and eyes closed: Alpha waves appearing when eyes closed (zoom in red).

[6] *Machado, Sergio, et al. "EEG-based brain-computer interfaces: an overview of basic concepts and clinical applications in neurorehabilitation." Reviews in the Neurosciences 21.6 (2010): 451-468.*

6. PROTOCOL

6.1. Body Sensor Setup on the Forehead

An example of placing your assembled BITalino EEG sensor is the position FP2 on the forehead (above your right eye) according to the international 10-20 system, see Figure 7. Using this setup, you can measure the activity of for example beta waves (level of active thinking).

Figure 9: BITalino assembled EEG placement on the forehead (FP1 and FP2 acc. to int. 10-20 system) and reference electrode behind the ear.

6.2. Data Acquisition

Review: Follow the device setup (1-2) as already explained in Home-Guide #0 and continue with steps 3-12.

1. Connect your BITalino (r)evolution Core BT
2. Testing your set-up

Live Brain Activity with Electroencephalography (EEG):

3. Connect the Assembled EEG Sensor and the reference cable to two of the analog channels available.
4. Place the Gelled Electrodes on the two snaps of the assembled EEG sensor and onto the reference.
5. Place the Assembled EEG on the FP2 position according to the 10-20 system (as illustrated in Figure 9).
6. Place the reference on a bony region (behind your ear).
7. Start recording data on OpenSignals (r)evolution (if needed, check [Home-Guide #0](#) Section 2 to recall how this is done). Set your sampling frequency to a value that is appropriate to the sensor's bandwidth according to the Nyquist Shannon sampling theorem (min. 2 x max. Frequency of the frequency band of interest).

8. Start recording a signal baseline with low noise and no movements (normal breathing, no eye movements/ eyes closed) for 30 seconds.
9. Repeat a cycle of EYES OPEN EYES CLOSED five times, maintaining both phases for five seconds.
10. Record another baseline phase of 30 seconds.
11. Perform a set of complex calculations mentally (12) that your partner reads out loud for you, focus your eyes on a specific point to avoid artefacts.
12. Stop the recording and save your data.

6.3. Repeat Activities for different Locations.

Preform an acquisition using different electrode locations:

1. Frontal FP2
2. Frontal FP1
3. Occipital O2

For additional information review the last Home-Guide which is available here:

HOMEGUIDE#2 and the documentation available on the previous section "RELATED DOCUMENTATION"

6.4. Elaborate your Report and answer the Quiz.

Write a report on the performed acquisitions of each brain area, following the acquisition steps mentioned in section 2. Finally, fill out the quiz and check out the additional documents for help.

IMPORTANT NOTES:

- ✓ Check out the "PsychoPy" tool to visualize your stimuli for your own experiments.
- ✓ Check out "PhysioNet" from which you can access EEG data from other studies.

7. QUIZ

In this section you can find some questions for you to work on during your Home Session and to explore the EEG sensor.

Q1. Which are the significant frequencies for EEG acquisitions? Are they the same in all brain areas?

Q2. Which kind of filter is essential when working with EEG signals? Why do we need to apply such a filter?

Q3. Can you influence the EEG signal by your thoughts? What action can you do to trigger one frequency band of choice? Were you able to visualize the change in the signal?

Q4. Show a screenshot of a relevant portion of EEG data within the experiment proposed. Does this signal correspond to what you expected? Why?

Q5. Is there any difference in the signal between the two locations FP1 and FP2?

Q6. Which frequencies are supposed to change in the given tasks? Can you see the specific changes in the RAW signal? Describe what you see.

Q7. To the best of your knowledge, does the EEG amplitude equal to the level of focus you have applied?