What is EEG?

Electroencephalography or EEG is a non-invasive method to record electrical activity in the brain, which is generated by ionic currents that flow within and across neuron cells. When a large population of thousands or millions of neurons with a similar orientation in a specific region in the brain together synchronize their electrical activity, the produced electrical field is large enough to be observable on the scalp. By attaching an array of electrodes to the scalp, these electrical fields can be recorded by measuring the electrical potential (typically 10-100 microVolt) between pairs of electrodes in the array.

EEG has the advantage that it is non-invasive (no surgery required) while it also does not require expensive and bulky machines in shielded rooms (like for MRI, MEG, …), thereby allowing bed-side monitoring in the clinic. As opposed to indirect measurements of brain activity through slowly-varying blood oxygenation levels (as in fMRI and fNIRS), EEG directly measures the ionic currents produced in the brain, thereby allowing it to measure fast neural oscillations and responses with a high temporal resolution. This makes it very useful for specific clinical applications (e.g., epileptic seizures) and for brain computer interfaces that rely on fast neural responses to sensory stimuli such as auditory, visual, and somatosensory. While the temporal resolution is high in EEG, the spatial resolution is rather low due to spatial smoothing by the skull and due to volume conduction within the brain itself. As a result, each neural source is generally observed at multiple electrodes, and vice-versa, each electrode captures multiple neural sources.

While EEG is currently mostly used in a hospital or research lab environment, current research efforts in the field of EEG systems design are towards wearable, wireless, and concealable EEG systems that can be worn 24/7 in daily life, and their integration in wearable medical devices or consumer devices like hearing aids, ear phones, etc.

Recording EEG

Most EEG systems have 20 up to 256 electrodes (systems with >50 electrodes are typically referred to as high-density EEG). Mostly wet electrodes are used, which require to connect the electrodes to the scalp using a conductive gel to make a good low-impedance contact between the scalp and the electrode. Recently, also systems with dry electrodes have been developed, which do not require such gel, but which typically record with a poorer SNR and lower quality in general. The positions of the electrodes are standardized according to the international 10-20 system (see Figure 1).

An EEG signal is an electrical potential that is measured between 2 positions (electrodes) on the scalp (an EEG channel is defined by an electrode pair, not a single electrode!). In a 'common reference montage', each EEG channel is recorded as the potential difference between an electrode and a common 'reference electrode', which is the same for all channels (in practice often the electrode at the 'Cz' position is chosen as the reference, i.e., the middle point on top of the head). The scalp potential between any arbitrary pair of electrodes can then be computed by subtracting the 'common reference montage' channels corresponding to these electrodes from each other, thereby canceling the effect of the common reference electrode. Therefore, N electrodes allow to define different EEG signals (although with a lot of redundancy, i.e., all channels are linear combinations of the same set of N-1 linearly independent channels).

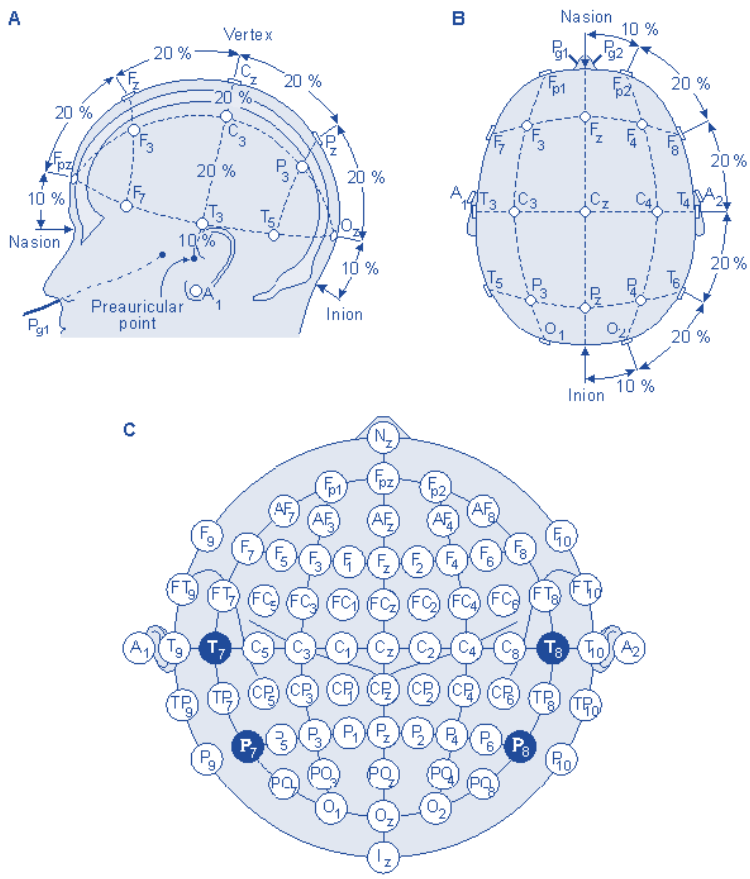


Figure 1 The original 10-20 system for 19 electrodes (A and B) and the extension to 70 electrodes (C)

The voltages that are measured through EEG have very small amplitudes (10-100μV) and therefore require very sensitive amplifiers. This makes EEG prone to electro-magnetic artifacts due to powerline noise, movement of the wires, etc. On top of that, also physiological artifacts can be picked up, the most notorious being eye blinking and eye movement artifacts which mostly appear in the frontal channels near the eyes. Another common type of artifacts are electromyographic activity, i.e., electrical activity of face or neck muscles that is picked up by the EEG electrodes.

Most of the energy in an EEG signal is found between 0-40Hz (frequencies >40Hz are often ignored due to extremely poor SNRs). EEG signals are often divided in different frequency bands which are associated to different brain states. The most prominent ones are alpha waves (high-amplitude oscillations with a resonance frequency of 8-12Hz), which typically appear in the occipital channels in awake state when the subject closes the eyes, and the delta waves (<4Hz) which are dominant when the subject is in deep sleep.

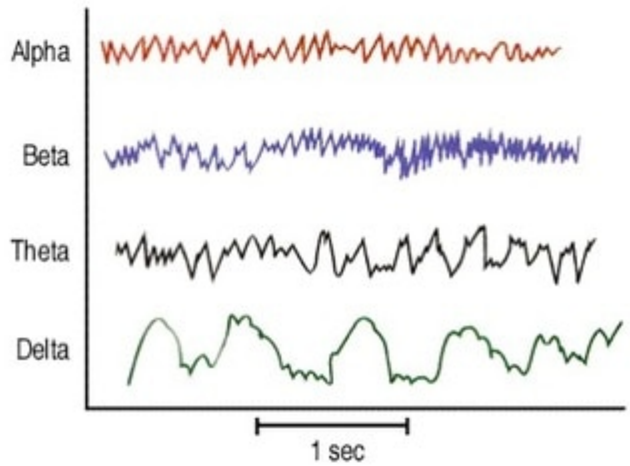


Figure 2: Different brain waves observable in EEG

EEG Recording Setups

In this project, you will work with EEG data from two different EEG recording devices with a different number of channels, and with a different reference electrode. To make the data from both systems compatible (i.e., if you aim to train/test a decoder on data from both systems), one has to make sure that the following settings match:

1) The sampling rate must be the same
2) The number of channels and the electrode lay-out (scalp positions and ordering of channels in the data matrix) should be the same. This requires to discard channels if one system has more channels than the other.
3) The reference electrode should be the same. If this is not the case, re-reference the data: choose a reference electrode that exists in both systems (e.g. Cz). Then subtract the channel corresponding to this reference electrode from all other channels within the same recording.
4) Pay special attention that the time synchronization between the audio stimulus and the EEG signals remains the same (filtering operations during resampling can introduce delays to the signals)

Biosemi ActiveTwo system

The Biosemi ActiveTwo system records 64-channel EEG data at a sampling rate of 8192 Hz. The 64 channels measure EEG recorded by electrodes placed according to international 10-20 standards and referenced to the CMS electrode. The 64 electrode layout of the Biosemi system is provided in fig 1 in Annex I. The electrical ground of the system is realized as a combination of CMS and DRL electrodes with the DRL electrode placed as shown in the figure.

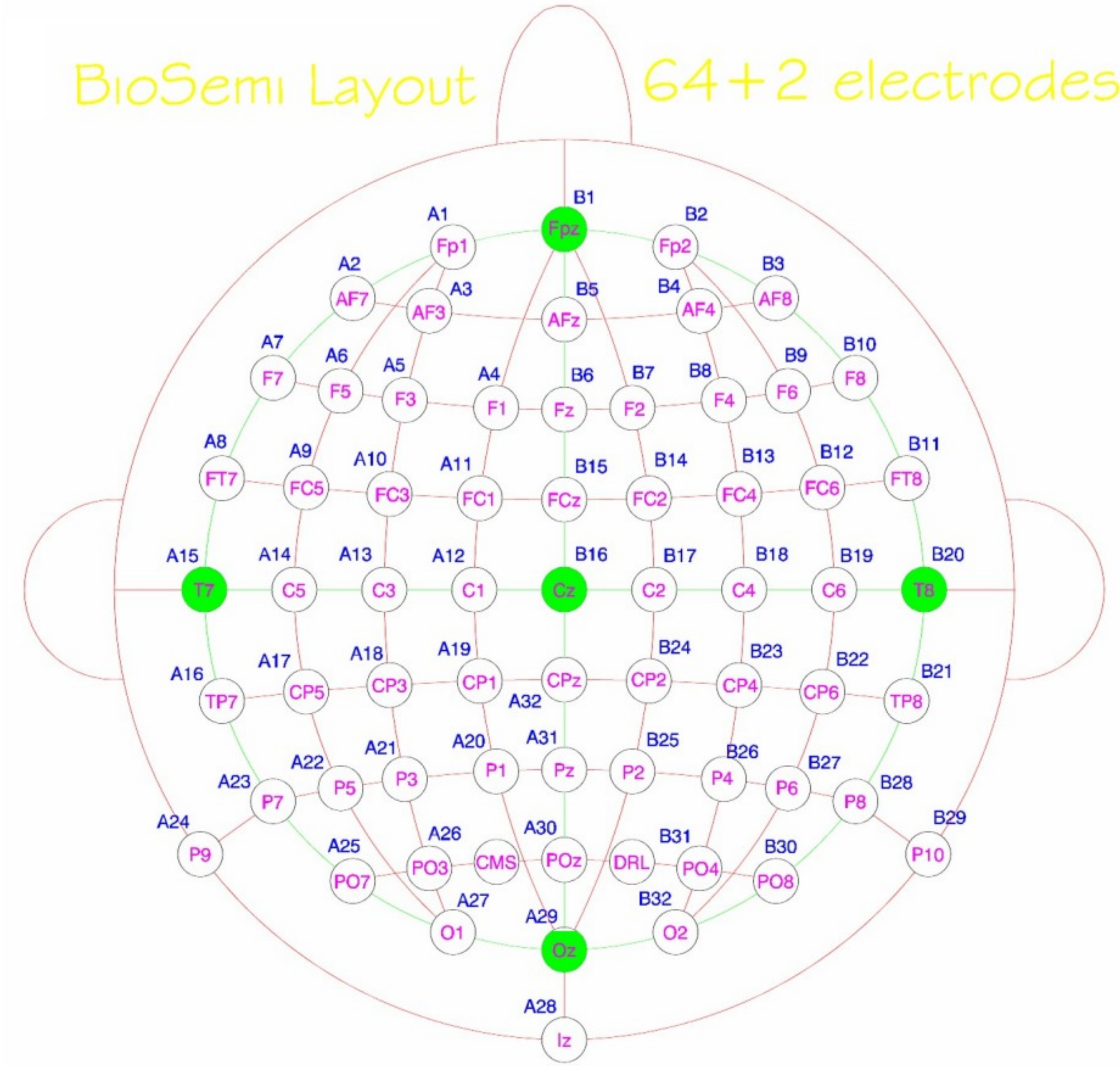
The EEG data that you will receive from these Biosemi ActiveTwo recordings have already been pre-processed according to the pre-processing pipeline described in a separate document.

Smarting mobile EEG system

This Smarting mobile EEG system is a wireless 24-channel EEG system connected to a laptop via Bluetooth. The system contains a small 24-channel amplifier with similar characteristics to a stationary laboratory amplifier (< 1V peak to peak noise). The EEG is sampled at 500 Hz using 24 Ag/AgCl passive scalp electrodes placed according to the 10–20 standard system, the layout of which can be found in Annex II. The electrodes record EEG with respect to the reference electrode CMS, which is placed at position FCz. The electrical ground of the system is realized as a combination of CMS and DRL with the DRL electrode corresponding to the AFz location on the scalp.

This is the system you will use for your own recordings, which means you have to do the pre-processing yourself on the raw EEG data.

Annex I


BioSemi Layout
64+2 electrodes
B1
Fpz
A1
Fp1
B2
Fp2
A2
AF7
A3
AF3
B5
AFz
B4
AF4
B3
AF8
A7
F7
A6
F5
A5
F3
A4
F1
B6
Fz
B7
F2
B8
F4
B9
F6
B10
F8
A8
FT7
A9
FC5
A10
FC3
A11
FC1
B15
FCz
B14
FC2
B13
FC4
B12
FC6
B11
FT8
A15
T7
A14
C5
A13
C3
A12
C1
B16
Cz
B17
C2
B18
C4
B19
C6
B20
T8
A16
TP7
A17
CP5
A18
CP3
A19
CP1
CPz
A32
B24
CP2
B23
CP4
B22
CP6
B21
TP8
A24
P9
A23
P7
A22
P5
A21
P3
A20
P1
A31
Pz
B25
P2
B26
P4
B27
P6
B28
P8
B29
P10
A25
PO7
A26
PO3
CMS
A30
POz
DRL
B31
PO4
B30
PO8
A27
O1
A29
Oz
B32
O2
A28
Iz

Annex II

Smarting layout

Linear EEG

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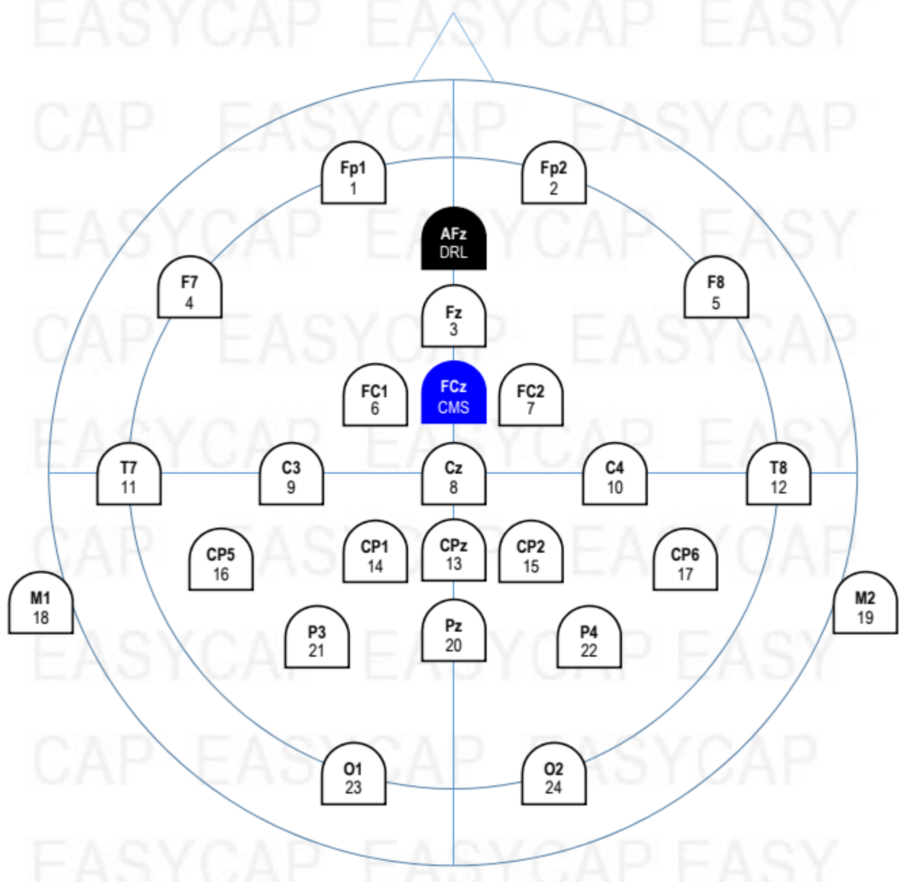
Cap for Real-Behavior-EEG, 24Ch Motor Area Emphasized Layout, for Smarting



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