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EEG recording, data pre-processing and ERP potentials. An adaptation of local resources to the highest standards.

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INFORMACION

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ABSTRACT

Electroencephalography (EEG) recording constitutes a relatively inexpensive and non-invasive method to study the electrophysiological activity underlying several cognitive processes. Nonetheless, from a closer look, EEG recording and analysis has several critical steps and conditions that must be achieved in order to be able to understand the underlying cerebral activity. The aim of the present article is to offer a detailed explanation of the different requirements that need to be fulfilled in order to correctly analyze EEG activity. The next stage is to acquire the event-related potentials (ERP) based on the average of the preprocessed EEG signals. ERP activity is usually time locked to a particular event. To exemplify pre-processing of EEG data and ERP components, we use the example of a classical P300 task. Details associated with different parameters (filters, baseline, epochs, etc.) will be discussed.

Palabras Clave
ERP
EEG
Psicofisioloogía
Neurociencia

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RESUMEN

El registro de electroencefalografía (EEG) constituye un método relativamente económico y no invasivo para estudiar la actividad electrofisiológica subyacente a varios procesos cognitivos. No obstante, desde una mirada más cercana, el registro y análisis de EEG tiene varios pasos y condiciones críticos que deben lograrse para poder comprender la actividad cerebral subyacente. El objetivo del presente artículo es ofrecer una explicación detallada de los diferentes requisitos que se deben cumplir para analizar correctamente la actividad de EEG. La etapa siguiente es adquirir los potenciales relacionados con eventos (ERP) basándose en el promedio de las señales de EEG preprocesadas. La actividad de ERP suele estar limitada en el tiempo a un evento en particular. Para ejemplificar el preprocesamiento de datos EEG y componentes ERP, utilizamos el ejemplo de una tarea P300 clásica. Se discutirán los detalles asociados con diferentes parámetros (filtros, línea de base, épocas, etc.).

1.1 Electrophysiological activity and Brain dynamics

Electroencephalography (EEG) is the continuous recording of electrical fields through electrodes located on the scalp. These electric fields were observed as oscillating waves that provided very valuable clinical information for various neurological studies (e.g., epileptic disorders and sleep disturbances) and some scientific studies, such as research related to brain rhythms. Its ability to directly demonstrate the electrophysiological activity caused by discrete experimental events, its high temporal resolution, and its low cost position it as the best technique for studying the temporal course of various cognitive processes (Dhond et al., 2005).

Within the EEG signals, lies the neural responses associated with specific cognitive events. It is possible to extract those responses from the total EEG signal simply by using the averaging method. The specific responses that arise from the averaging of EEG waves are called "event-related potentials" (ERP) to denote the fact that they are electrical potentials that are related to point events (Luck, 2014). Although the ERP uses the same electrical information as the EEG, they can show us activity related to cognitive functions (Bressler, 2002). In such a way that the presentation of a specific event will produce particular waves that, after being averaged, will be analyzed. These potentials are taken as indicators of the activity of a group of neurons that underlie the recording electrodes (Handy, 2005).

Usually, the cognitive activity associated with a task is observed during the period of time from the moment a stimulus is presented until approximately one second after its disappearance. The ERP technique also allows, although in a less precise way than other neuroimaging techniques, to observe the topographic distribution of brain electrical activity along the scalp (Wilding, 2000). This allows discriminating in a very general way the location of different components present in cognitive tasks. The recording and analysis of ERP is currently one of the procedures most used by researchers in cognitive neurosciences (Rugg & Curran, 2007).

1.2 The EEG Apparatus

We use an apparatus developed by AKONIC.S.A. This is a local company with high quality standards. It was originally developed for medical purposes. Therefore, there is one minor disadvantage from the point of view of research: There is no unique software which synchronizes a particular cognitive task with the EEG recordings simultaneously. We will discuss later how to solve this.

This EEG apparatus comprises two parts: 1) the amplifier (header) 2) the base-BIO-PC (analog-to-digital converter). It runs with a software called EEG11. To conduct an EEG experiment, two extra components are necessary: 3) the EEG Cap (manufactured by Electro-Cap International Inc. from Ohio) which has 20 cap-mounted tin electrodes which follow the extended international 10/20 system (Figure 1.1) and finally 4) the computer running the cognitive task (COM1) and 5) the recording PC (COM2) and (figure 1.2). Our EEG apparatus has a high-pass filter of 0.1Hz and a low-pass filter of 100Hz. Besides the 20 electrodes embedded in the cap, three additional electrodes are attached, two for measuring vertical and horizontal eye movements and one for reference, fixed with tape to the side of the right eye and down the left eye and clipped to the left ear lobe respectively. These electrodes make contact with the skin through conductive gel (AG1000 Neurotronic ®). In addition, the apparatus has the possibility to register cardiac activity (ECD). Detection of the eye movement and heart activity could be important for later analysis when we need to decompose all the recorded activity and decide which ones belong to actual brain activity and which ones belong to different sources (being the most important the eye movements and blinks).

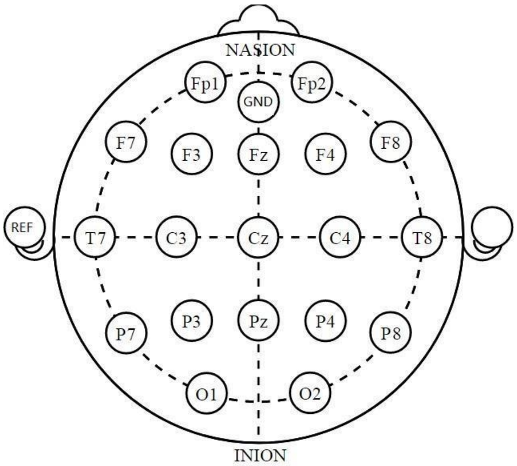

Figure 1.1. The disposition of the 20 electrodes mounted in the EEG cap. Notice that the ground electrode is also embedded in the cap with the 19 active electrodes.

2. Coupling the cognitive task with the EEG data

As mentioned before, a possible disadvantage of this device is that the software recording the EEG data is independent of the task that subjects perform. Therefore, we must synchronize the EEG activity with the cognitive task's events. This can be achieved by connecting a USB cable from the computer which runs the cognitive task (COM1) to the Base Bio-PC and then to the computer which registers the EEG activity (COM2) Figure 1.2. Usually, the cognitive tasks consist in showing visual stimuli at the computer screen and asking subjects to perform a motor response (e.g., press a key on the keyboard). In the software psychopy (Pierce et al., 2019), we can program the signal that indicates the presence of a stimulus on the screen with a couple of line codes (figure 1.3).

Therefore, COM1 sends an electrical signal to the Base Bio-PC (with clear and uniform frequency and amplitude) through the USB port when the stimulus is presented on the screen through one specific channel called external (EXT) that information is then sent to COM2 (EXT1). The same can be achieved when the subject makes a response (EXT2) Figure 1.2. These two time points of information are enough to lock the EEG activity to the stimulus or to the response. Later, a matlab script will extract that information from the EEG signal (Box 1). For example, in case the EXT1 signal corresponds to the channel 21 (out of 23 = 19 active electrodes +2 oculars +2 externals).

The script retrieves all the numbers corresponding to the external channels and we will know that some of them belonged to the time in which the stimulus was presented on the screen (EXT1) and others belonged to the time in which the subject gave a response (EXT2). This coupling can be achieved through a simple Matlab (MathWorks Inc.) script (Box 1). We will be able to align (time lock) the EEG activity with the event codes (Figure 1.4) and later average it.

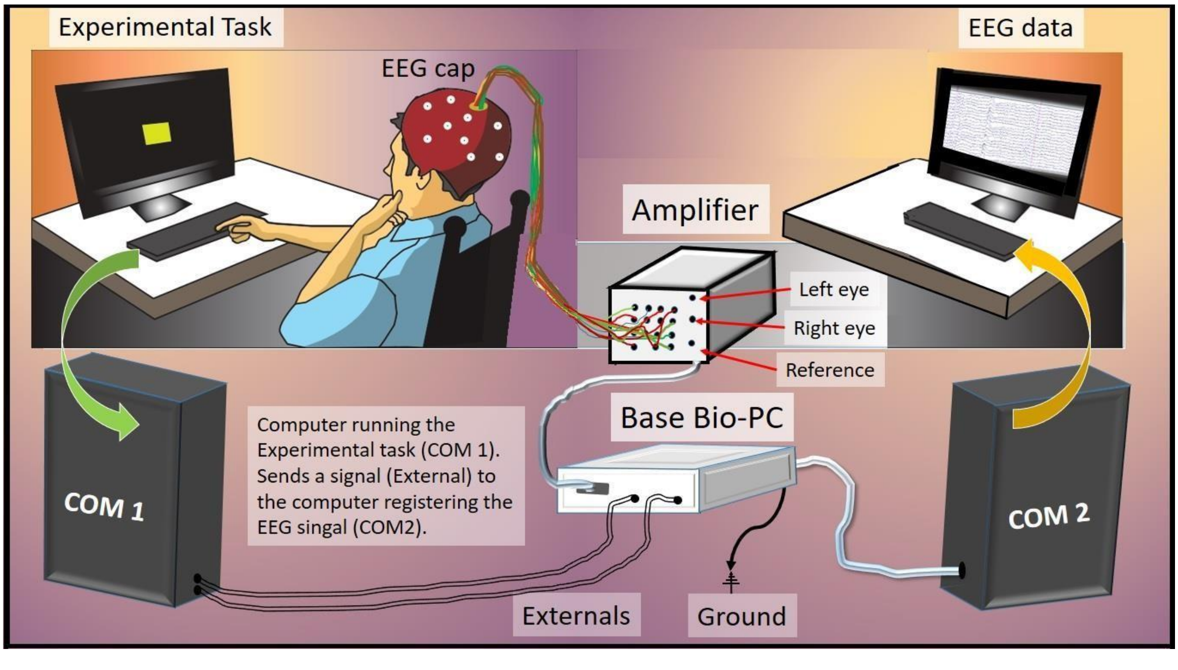

Figure 1.2 AKONIC S.A. device for EEG recordings

3. Preprocessing the EEG data using EEGLAB

EEGLAB is an open source signal processing environment for electrophysiological signals running on Matlab (Delorme & Makeig, 2004). It allows the user to analyze EEG, and other electrophysiological data. Once we paired the EEG data (txt file) with the conditions , we are ready to start the data preprocessing (Box 2 and 3). The steps in the preprocessing are:

1- Filter. We apply a hig-pass filter of 0.1Hz and a low-pass filter of 30Hz

2- Add the epochs (limits of each trial). For example, in our experiments we usually create an epoch of minus 200ms pre stimulus and 800ms post stimulus (Figure 1.5).

3- Run the Independent Components Analysis (ICA, see Sun et al., 2005; Figure 1.6).

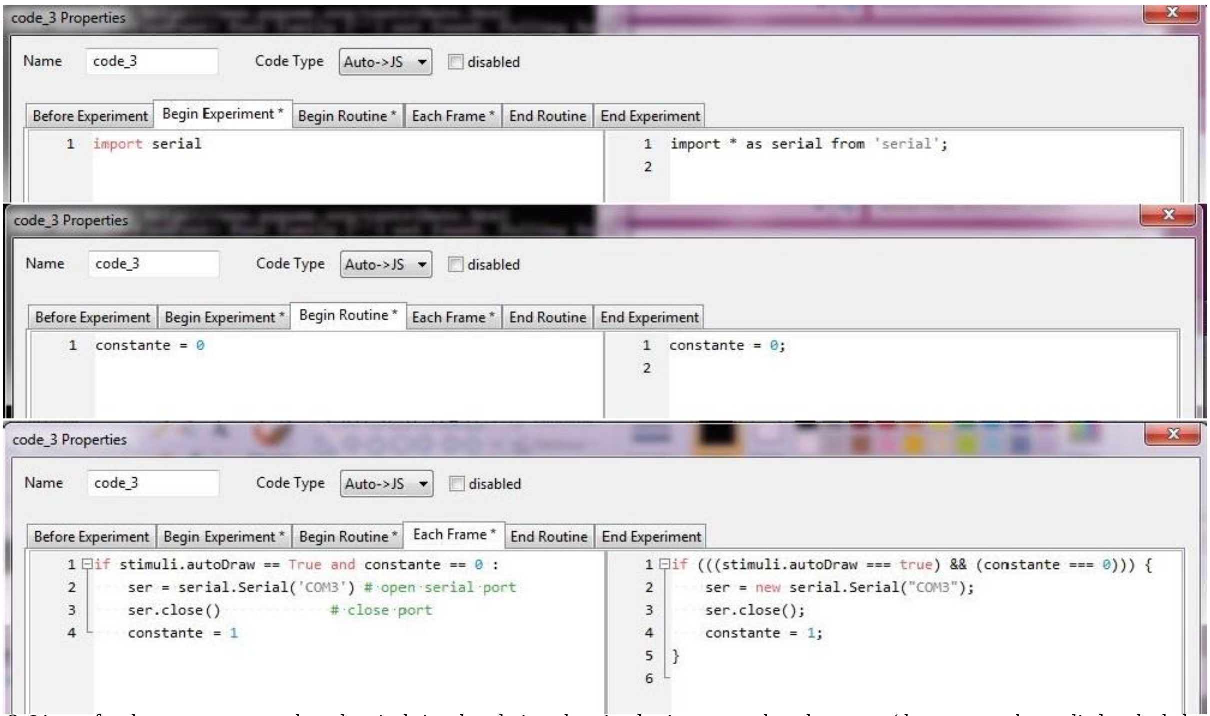

Figure 1.3. Lines of code necessary to send an electrical signal each time the stimulus is presented on the screen (the same can be applied to the behavioral responses for another external signal).

```
subject = {'S100'};
path = 'C:\Program Files\MATLAB\R2023a\Tutorials\'
subjectnum = subject
    subjectpath = strcat(path, subjectnum, '\')
    pat = strcat(subjectpath, '*xlsx');
    file = dir(char(pat));
    excel_file_with_conditions = strcat(subjectpath, file.name)
      data23channels = strcat(subjectpath, 'FileEEGLAB23Channels.txt')
      latenciesmodpath = strcat(subjectpath, 'LatenciesExt1MOD.txt')
      latenciespath = strcat(subjectpath, 'LatenciesExt1.txt')

A=load('S100.txt');
Datafinal23Channels=A([1:23], :);
dlmwrite ('FileEEGLAB23Channels.txt', Datafinal23Channels, ' ');
Ext1=Datafinal23Channels(21, :);
N=length(Ext1);
k=1;
for i=2:N
   if Ext1(i)>=-65 && Ext1(i-1)<-65
Indices(k)=i;
k=k+1;
   end
end
IndicesLenght=length(Indices);
Latencies=Indices/256;
Latencies=Latencies';
dlmwrite ('LatenciesExt1.txt', Latencies, 'delimiter', ' ', 'precision', '%.6f')
      lats = load(char(latenciespath));
      [a t]= xlsread(char(excel_file_with_conditions), 'B11:B130');%first 10 trials are practice trials
      conds = t;
      lats = lats(11:130);
      c={lats conds};
      fileID = fopen(char(latenciesmodpath),'w');
      formatSpec = '%f %s\n';
      fprintf(fileID,'latency type\n');
      for row = 1:120
         fprintf(fileID,formatSpec, lats(row), conds{row});
      end
```

Box 1. Script for coupling the latencies from EXT1 with the task events (oddball and standard) from the excel file and naming them "latency and type" respectively.

```
EEG.etc.eeglabvers = '2019.0' %EEGLAB version
EEG =
pop_importdata('dataformat','ascii','nbchan',0,'data','C:\\ProgramFiles\\MATLAB\\R2023\\Tutorial\\S1\\S1.TXT','srate',256,'pnts',0,'xmin',0,'chanlocs','C:\\Pro gra m Files\\MATLAB\\R2023\\Tutorial\\S1\\Map23canales_external_eog_aligned.ced'); % import subject 1 and set the sampling rate (256hz) and add the information about the electrodes corresponding with the channel
EEG.setname='S1';
EEG = pop_importevent( EEG, 'event','C:\\Program Files\\MATLAB\\R2023\\Tutorial\\S1\\LatenciesExt1MOD.txt','fields',{'latency' 'type'},'skipline',1,'timeunit',1);%add the events to the eeg data
EEG = pop_eegfilt( EEG, 0.1, 30, [], [0], 0, 0, 'fir1', 0); %filter the data (low and high-pass)
EEG = pop_epoch( EEG, { 'oddball' 'standard' }, [-0.2 0.8], 'newname', 'S1 epochs', 'epochinfo', 'yes'); %set the epoch for the events (conditions)
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended',1,'interrupt','on'); %run ICA with the ocular electrodes
EEG = pop_saveset( EEG, 'filename','S1_ICA.set','filepath','C:\\Program Files\\MATLAB\\R2023\\Tutorial\\S1\\');
```

Box 2. Preprocessing up to ICA analysis

At this step we visually inspect the ICA decomposition analysis and reject components not related to the brain activity. Then we follow with the preprocessing:

4- Run a second ICA
5-Remove Baseline (e.g. from 0 to 200ms)
6-Extract the epochs in separate files

```
[ALLEEG EEG CURRENTSET ALLCOM] = eeglab;
EEG = pop_loadset('filename','SX_ICA_prunned.set','filepath','C:\\Program Files\\MATLAB\\R2023\\Tutorial\\S1\\');
[ALLEEG, EEG, CURRENTSET] = eeg_store( ALLEEG, EEG, 0 );
EEG = pop_select( EEG, 'nochannel',{'EOG1' 'EOG2'});%we run ICA without the ocular electrodes
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG, 1,'overwrite','on','gui','off');
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended',1,'interrupt','on');
[ALLEEG EEG] = eeg_store(ALLEEG, EEG, CURRENTSET);
EEG = pop_rmbase( EEG, [-199 0] ,[]);%remove baseline
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG, 1,'savenew','C:\\Program Files\\MATLAB\\R2023\\Tutorial\\S1\\S1_Final.set','overwrite','on','gui','off');
%save the data as S1_Final.set
eeglab redraw;
—--------------------
%Extract epochs as separate ".set" files
—--------------------
cd 'C:\Program Files\MATLAB\R2023\Tutorial\S1' ;
EEG = pop_loadset( 'filename', 'S1_Final.set');
EEG = pop_epoch( EEG, { 'standard' }, [-0.2 0.8], 'newname', 'S1standard', 'epochinfo', 'yes');
EEG = eeg_checkset( EEG );
EEG = pop_saveset( EEG, 'filename', 'S1standard.set');

EEG = pop_loadset( 'filename', 'S1_Final.set');
EEG = pop_epoch( EEG, { 'oddball' }, [-0.2 0.8], 'newname', 'S1oddball', 'epochinfo', 'yes');
EEG = eeg_checkset( EEG );
EEG = pop_saveset( EEG, 'filename', 'S1oddball.set');
```

Box 3. Matlab code for continuation of the preprocessing up to the epochs extraction.

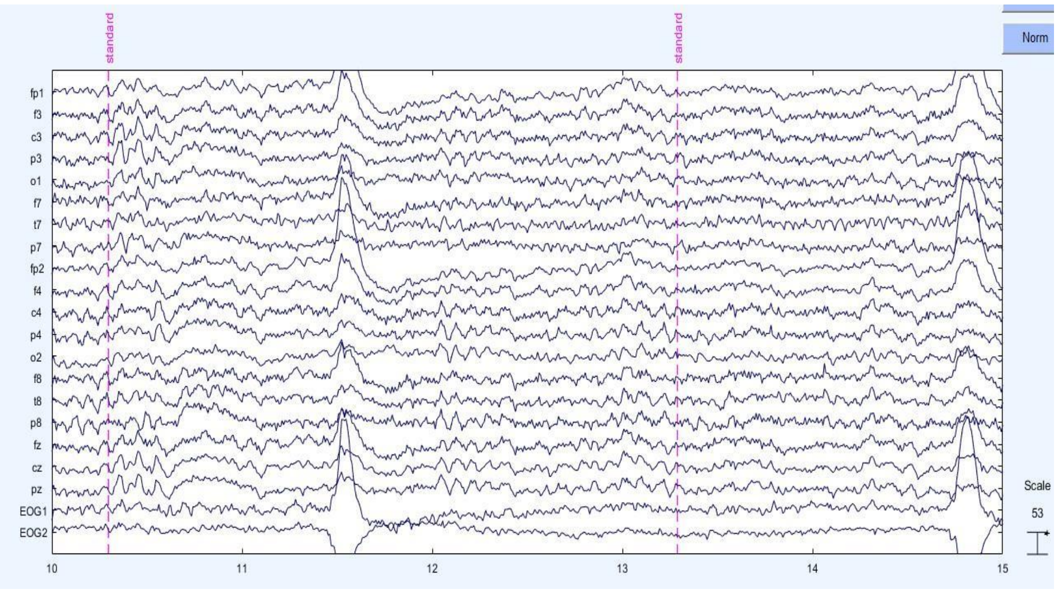

Figure 1.4 EEG data paired with the event codes.

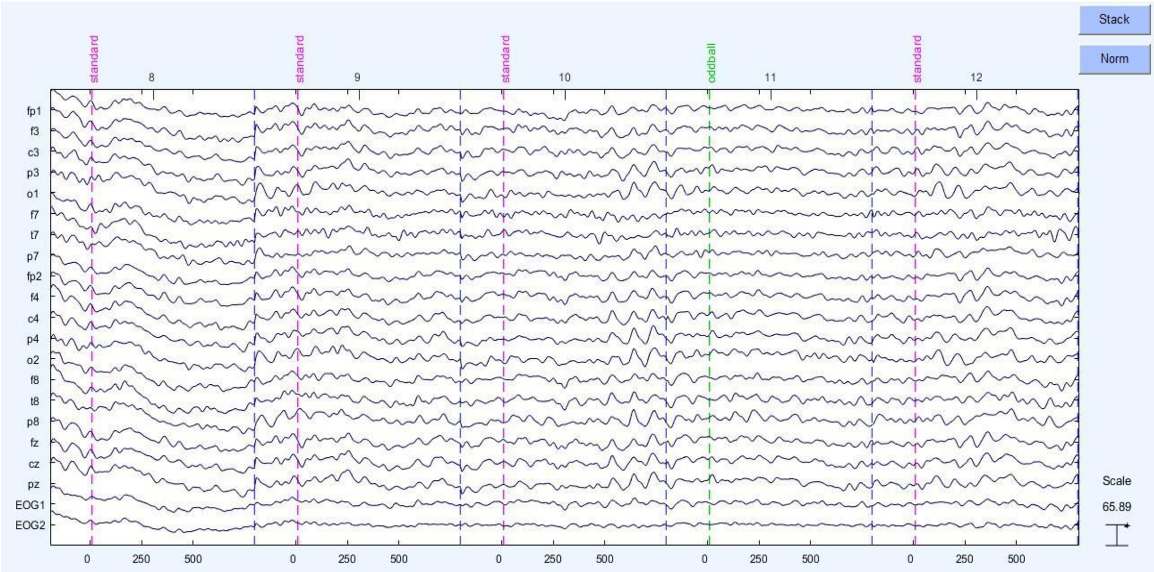

Figure 1.5 EEG data divided in epochs.

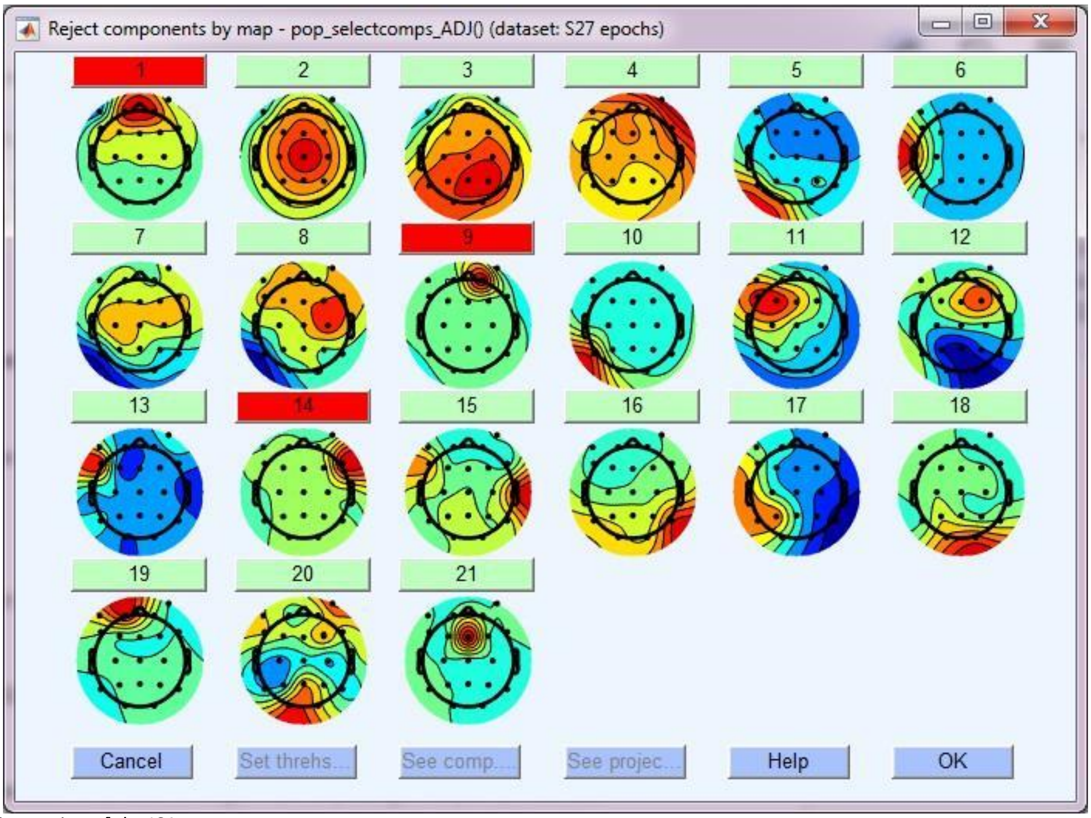

Figure 1.6 Visual inspection of the ICA

1. 4. Creating a .study file and analyzing the ERP data

We finally use the extracted epochs and create a .study file (Box. 4. We use 10 subjects for the example script below). Once we have the .study file, we are able to create an ERP image with both conditions for all subjects and all electrodes (Figure 1.7).

```
  subjects = {'S1','S2','S3','S4','S5','S6','S7','S8','S9','S10'}; %define the number of subjects (e.g. 10)
condiciones = {'oddball', 'standard'};
  name = '';
filename = '';
task = 'P300'

  path = 'C:\Program Files\MATLAB\R2023\Tutorials\Study P300\';
cd 'C:\Program Files\MATLAB\R2023\Tutorials\Study P300\';
  i = 1;
  subjects_and_conditions = {};
```

```
for subject = subjects
   subjects_and_conditions{i} = {'index' i 'load' char(strcat(path, subject, condiciones{1} , '.set' )) 'subject' char(subject) 'condition' condiciones{1} };
   subjects_and_conditions{i+1} = {'index' i+1 'load' char(strcat(path, subject, condiciones{2} , '.set' )) 'subject' char(subject) 'condition' condiciones{2} };
     i=i+2;
   end

subjects_and_conditions

[ALLEEG EEG CURRENTSET ALLCOM] = eeglab;
[STUDY ALLEEG] = std_editset( STUDY, ALLEEG, 'name', name, 'task',task, ...
   'filename', char(filename), 'filepath', char(path), ...
   'commands',subjects_and_conditions,'updatedat','on' );
[STUDY ALLEEG] = std_checkset(STUDY, ALLEEG);
CURRENTSTUDY = 1; EEG = ALLEEG; CURRENTSET = [1:length(EEG)];
eeglab redraw;
```

Box 4.Matlab script to create a .study file in EEGLAB

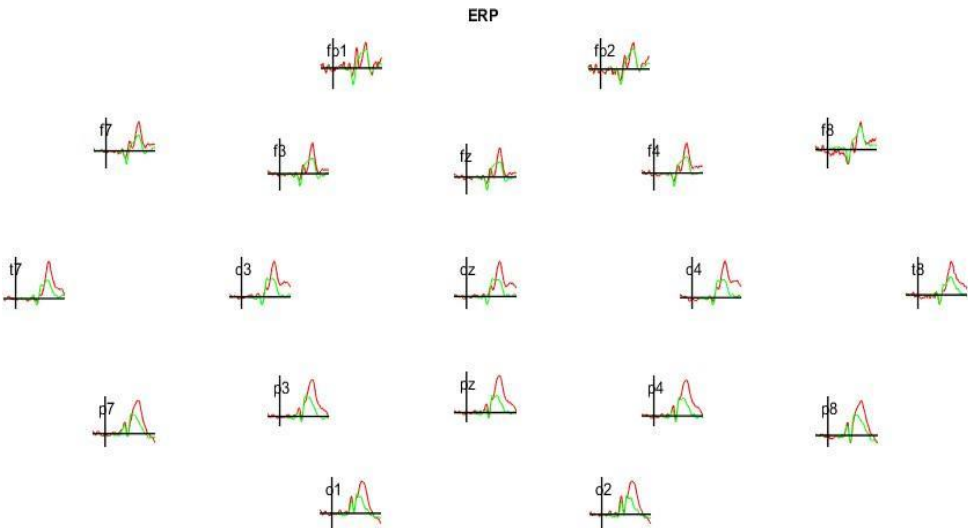

Figure 1.7 ERP plotting for all the subjects (n=10) and all the channels (19)

Conclusion

The present paper explains and shows the way in which EEG data can be acquired and processed with local resources by clearly defining each step and the programming code associated with it.

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