Research Use of Emotiv EPOC

P300 and Emotiv EPOC: Does Emotiv EPOC capture real EEG?

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Introduction

The Emotiv EPOC headset (http://emotiv.com/) has become one of the leading BCI equipment available today as a result of its low-cost (consumer edition for $300-400, research edition for $500) and features (14 EEG channels plus two references, inertial sensors, wireless connectivity, etc.). Although it has been integrated in a vast number of BCI applications, yet, its use for research purposes is being questioned by many researchers. As a response to such concerns, this article has been published (originally on 25-12-2010) by including the results of an empirical evaluation of the Emotiv EPOC headset based on an oddball paradigm and the procedure for repeating the experiment for interested individuals.

Background

Event-related potentials and P300

As far as 1929, Burger has demonstrated the possibility of recording electrical activity of the brain by placing electrodes on the scalp surface of the brain (Fabiani, Gratton, & Federmeier, 2007). Although Burger and his followers had been mainly focused on spontaneous rhythmic oscillations in scalp voltages (called electroencephalogram, or EEG), more recent research has shifted its focus towards time-locked electrical potentials to sensory, motor, or cognitive events called event-related brain potentials, or ERPs (ibid.). ERPs reflect brain activity from a pooled synchronous activity of a large population of neurons that occurs in preparation for or in response to discrete events which can be internal or external to a subject. ERPs can be categorized into two types: exogenous and endogenous (ibid.). The exogenous (or sensory) ERPs are elicited within the first 100 milliseconds from the stimulus and its characteristics are largely depend on the physical properties of the external stimulus. In contrast, the endogenous (or cognitive) ERPs are elicited in the latter part and its characteristics are determined by the information processing activities required of the subject. Figure 1 represents the components of a typical ERP waveform.

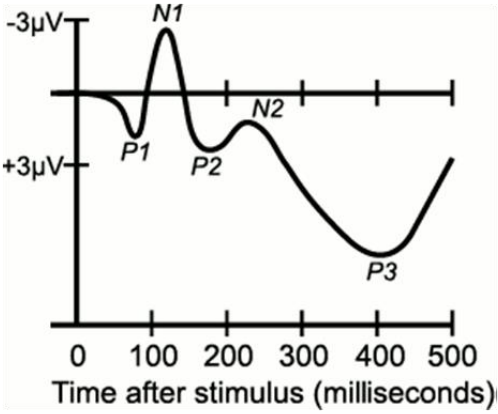


Figure 1. Components of a typical ERP waveform (adapted from wikipedia)

As it can be seen in Figure 1, the largest component of an ERP is called P3, or P300, and it is considered to be associated with stimulus evaluation or categorization (ibid.). A description about different components of ERP waveforms can be found in Sur & Sinha (2009). This empirical study evaluates the Emotiv EPOC headset on the basis of its capability to reflect the P300 component in an experimental study called the oddball paradigm.

Deriving P300 using the oddball paradigm

According to literature (Fabiani et al., 2007; Makeig, Debener, Onton, & Delorme, 2004; Sur & Sinha, 2009), P300 occurs as a positive deflection in the voltage (2-5µV) with a latency range of 250-400 milliseconds from the stimulus onset and it is typically measured by placing electrodes covering the regions of Fz, Cz, and Pz in the standard 10-20 system (Tatum, Husain, Benbadis, & Kaplan, 2008; Teplan, 2002) as represented in Figure 2. Since, the strength of an ERP is very low compared to EEG (which is about 50 µV), ERPs are usually hidden within noise and not visible in a typical EEG waveform. Therefore, to obtain a visible ERP, several segments of EEG signals (containing single-trial ERPs called epochs) have to be averaged by repeating the same experimental stimuli for several times. However, before averaging, it is necessary to filter the EEG signals using a bandpass filter having a pass band range of about 1-20 Hz and to remove artifacts resulting from sources such as eye movements. Fortunately, there are computational tools, such as the EEGLAB toolbox (Delorme & Makeig, 2004), to analyze EEG data by obtaining ERPs.

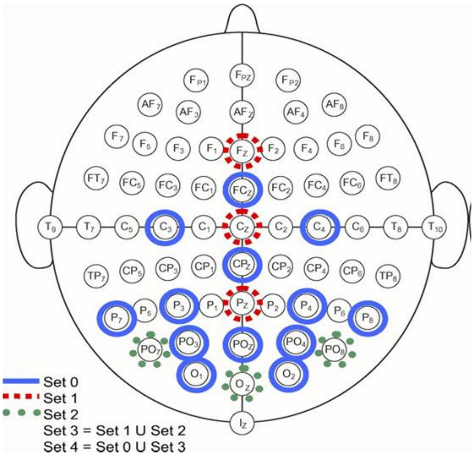


Figure 2. The 64-channel electrode montage and the channels which are used in obtaining ERPs (adapted from Krusienski, Sellers, McFarland, Vaughan, & Wolpaw, 2008)

One of the popular experiments for obtaining P300 is by using the P300-speller which is based on the oddball paradigm (Farwell & Donchin, 1988). The P300-speller consists of a 6x6 matrix of alphanumeric characters of which one of its rows or columns gets flashed one at a time, in a random order, resulting in a sequence of flashes (Figure 3). In this experiment, a subject responds by initially targeting a character and then counting (just as a mental activity without making any muscle movement of the face) the flashes happening in the cell that containing the character. Then, during the analysis, the averaged EEG epoch waveform for targets (i.e., flashes in the focused character) is compared against the averaged EEG epoch waveform for non-targets (i.e., other background flashes). If the experiment has been successful, the examiner will see ERPs as in Figure 1. OpenViBE (http://openvibe.inria.fr/) is an open source software for modeling the above experiment as well as various other BCI experiments/applications.

Figure 3. P300-speller visualization component in OpenViBE

The Emotiv EPOC headset

Earlier the Emotiv (http://emotiv.com/) has published the following information regarding its EPOC headset (Table 1).

Table 1 Specification of Emotiv EPOC headset

Number of channels	14 (plus CMS/DRL references)
Channel names (Int. 10-20 locations)	AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2
Sampling method	Sequential sampling, Single ADC
Sampling rate	~128Hz (2048Hz internal)
Resolution	16 bits (14 bits effective) 1 LSB = 1.95μV
Bandwidth	0.2 - 45Hz, digital notch filters at 40Hz and 60Hz
Dynamic range (input referred)	256mVpp
Coupling mode	AC coupled
Connectivity	Proprietary wireless, 2.4GHz band
Battery type	Li-poly
Battery life (typical)	12 hrs
Impedence measurement	Contact quality using patented system

However, the new specification contains slightly different values for certain fields (see http://emotiv.com/product-specs/Emotiv%20EPOC%20Specifications%202014.pdf)

Figure 4 shows the scalp locations covered by the headset in the standard 10-20 system.

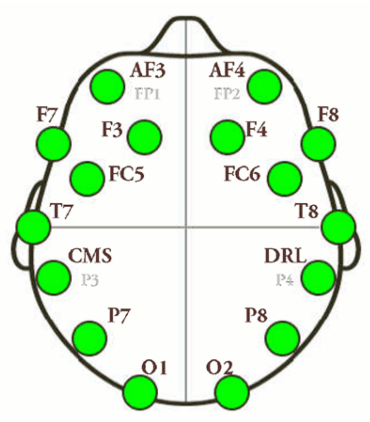


Figure 4. Scalp locations covered by Emotiv EPOC

Experiment & procedure

This section presents the procedure for setting up the experiment and data analysis for previous Windows versions (e.g. Windows Vista) and new Windows versions (e.g. Windows 8). The reasons for proposing two models are that some software in the previous setup is not compatible with Windows 8 (e.g., com0com software) and the availability of new features in the OpenViBE (e.g., VRPN to inform events to data logging software).

Setup 1: Previous model

This model is compatible with previous versions of Windows such as Windows Vista. Figure 5 shows the setup of experiment and the OpenViBE scenario for P300-speller.

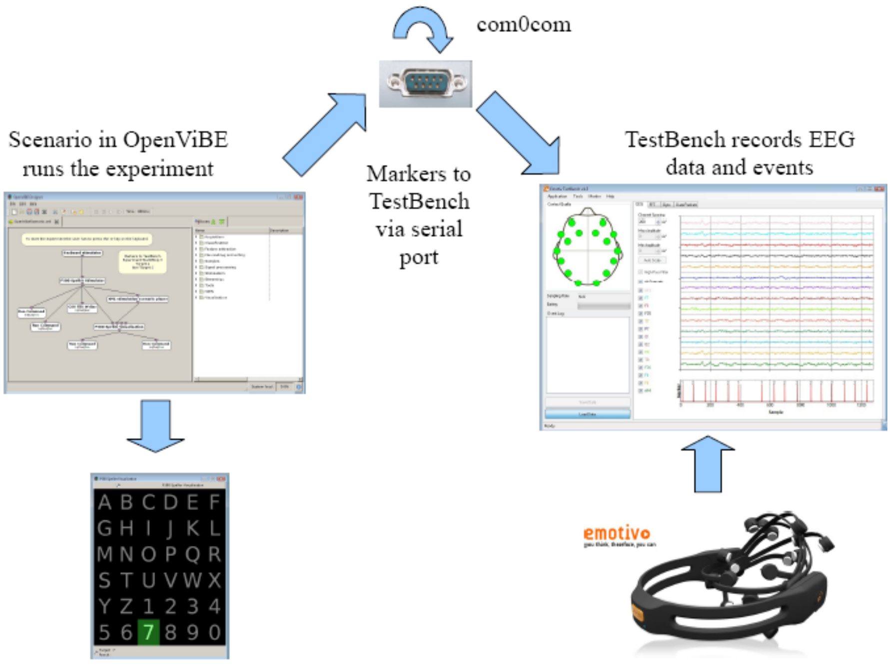


Figure 5(a). Experiment setup

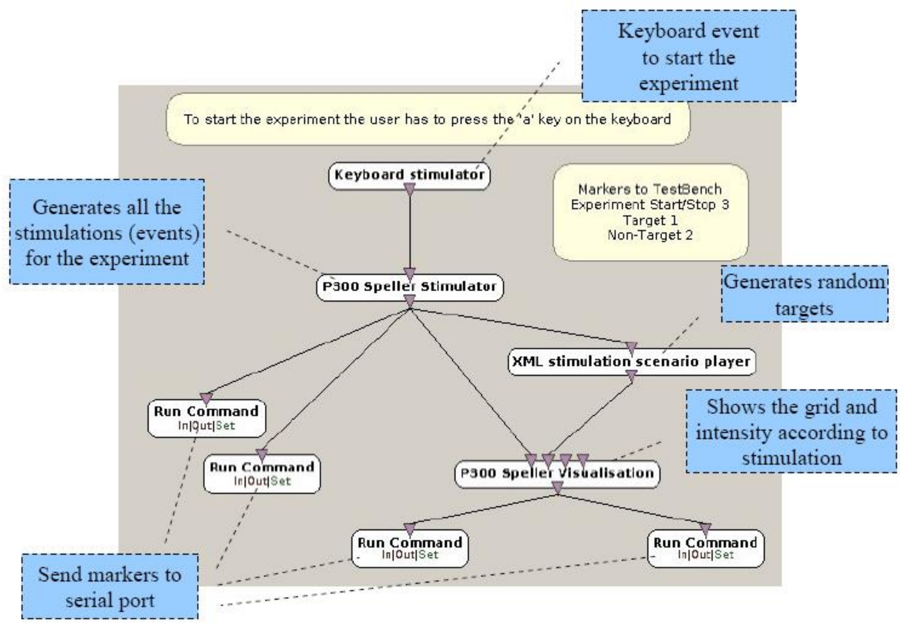


Figure 5(b). The OpenViBE scenario for P300-speller

Procedure for setting up the experiment

- Download a previous version of OpenViBE (e.g., version 0.11.0, Aug. 2011) from http://openvibe.inria.fr/ and install
- Download http://neurofeedback.visaduma.info/P300New.zip and unpack the files
- Open the file p300speller2.xml (file is in P300New) using the OpenViBE menu
- Double click on the box with the label "Target Letter Generation" and setup the path of the Lua Script to p300-speller-target.lua which is in P300New
- Download and install the com0com null modem emulator from http://sourceforge.net/projects/com0com/
- Read the instructions and create a COM port pair in com0com, e.g. COM1-COM2
- Modify the windows environment variables' path variable by including the folder where the PortWrite.exe can be found (file is in P300New)
- In the Emotiv TestBench (you received with the research edition) select one of the ports in the created pair, e.g. COM1 (follow Marker > Configure Serial Port)
- Open the command prompt and type "PortWrite COM2 2". If you have successfully set up the path variable and COM port pair, you will see the marker value 2 in the TestBench
- Restart the OpenViBE and run the model p300speller2.xml (to run use the start button in the OpenViBE designer; also you have to click on the window with the title "keyboard stimulator" and press on the 'a' key on the keyboard). Now, if you can see flashing rows and columns in the OpenViBE visualization window and markers in the TestBench, your first task is complete. Note that marker value 3 indicates the start of the experiment; marker values 1s and 2s indicate targets and non-targets, respectively.

Procedure for data analysis

The following procedure describes the steps of analyzing the EEG data using MATLAB (tested with version 7.6.0, R2008a) and EEGLAB (downloaded from http://sccn.ucsd.edu/eeglab/; tested with version 10.2.3.4b).

- TestBench (e.g. version 1.5) records the data in an EDF file which is not human readable. Therefore, the data needs to be converted into to CSV format using the TestBench's EDF to CSV converter tool in order to import the data in EEGLAB for processing (Note: new versions of EEGLAB can import data from EDF files; however, the process is not described here).
- Next, it is required to extract the only the relevant fields (i.e., the 14 channels of EEG and markers) from the CSV file. This can be performed in MATLAB by importing the data file into the workspace (as a matrix)

and removing the column numbers other than the columns 3:16 (EEG data) and 36 (markers).

- Next, import the data matrix in EEGLAB (File > Import data > From ASCII/float file or Matlab array) by specifying the sample rate as 128. Then, specify the event channel as channel 15 (File > Import event info > From data channel); and channel location file as emotiv.ced (Edit > Channel locations – Read locations & autodetect; file is in P300New).
- The rest of the steps for preprocessing the EEG data is as follows:
    - High pass filter at 1Hz (Tools > Filter the data > Basic FIR filter – Lower edge)
    - Low pass filter at 20Hz
    - Remove artefacts such as eye blinks
    - Extract epochs (Tools > Extract epochs) for event types 1 (targets) and 2 (non-targets)
- Once the epoch data are available for both targets and non-targets, relevant can be obtained such as "Channel ERP image", "Channel ERPs > With scalp maps", "Channel ERPs > With scalp/rect. array", etc.

Note: Apart from carrying out the data processing manually as described above, the following MATLAB script can be used as an automated processing of EEG data except for removing artefacts.

Code listing 1 can be used to extract relevant data from a CSV file, import data in EEGLAB, and to preprocess data.

Code listing 1. Preparing data in EEGLAB

```
% import data from testbench csv file
tbdata = importdata('filename.csv');
eegdata = tbdata.data;

% remove unwanted fields
eegdata(:,17:35) = [];
eegdata(:,1:2) = [];
eegdata = eegdata';

% Prepare data in EEGLAB
eeglab
EEG = pop_importdata('data',eegdata,'srate',128); % im-
port data from MATLAB array
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
0,'setname','eegdata','gui','off');
EEG = eeg_checkset( EEG );
EEG = pop_chanevent(EEG,
15,'edge','leading','edgelen',0); % event channel
EEG = pop_chanedit(EEG, 'load',{'emotiv.ced' 'filetype'
'autodetect'}); % channel locations
```

```
EEG = pop_eegfilt(EEG, 7, 0, [], [0]); % highpass fil-
tering at 1Hz
EEG = pop_eegfilt(EEG, 0, 13, [], [0]); % low pass fil-
tering at 20Hz
eeglab redraw
```

After executing the above code, EEG data should be checked (Plot > Channel data (scroll)) for any artifacts from sources such as eye blinks. Once artifacts have been removed, the following code (Code listing 2) can be executed to extract epochs for target and non-target stimuli.

Code listing 2. Extracting epochs for target and non-target stimuli

```
% Extract epochs
EEG = pop_epoch(EEG, {'1'}, [-1  2], 'newname',
'epochs_t'); % targets
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
1,'gui','off');
EEG = eeg_checkset( EEG );
EEG = pop_rmbase( EEG, [-1000 0]); % remove baseline
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
2,'overwrite','on','gui','off');

[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
2,'retrieve',1,'study',0);
EEG = eeg_checkset( EEG );
EEG = pop_epoch(EEG, {'2'}, [-1  2], 'newname',
'epochs_nt'); % non-targets
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
1,'gui','off');
EEG = eeg_checkset( EEG );
EEG = pop_rmbase( EEG, [-1000 0]); % remove baseline
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
3,'overwrite','on','gui','off');
eeglab redraw
```

After executing the above code (Code listing 2), relevant plots can be obtained by selecting a dataset (Datasets menu) and selecting the plot type (Plot menu).

Setup 2: New model

This model is compatible with both new and previous versions of Windows (tested in Windows Vista, Windows 7, Windows 8, and Windows 8.1; however, sometimes VRPN does not work on systems with new versions of Visual Studio other than Visual Studio Express 2010, may be as a result of incompatible versions of .Net framework). Figure 6 shows the setup of experiment and the OpenViBE scenario for P300-speller.

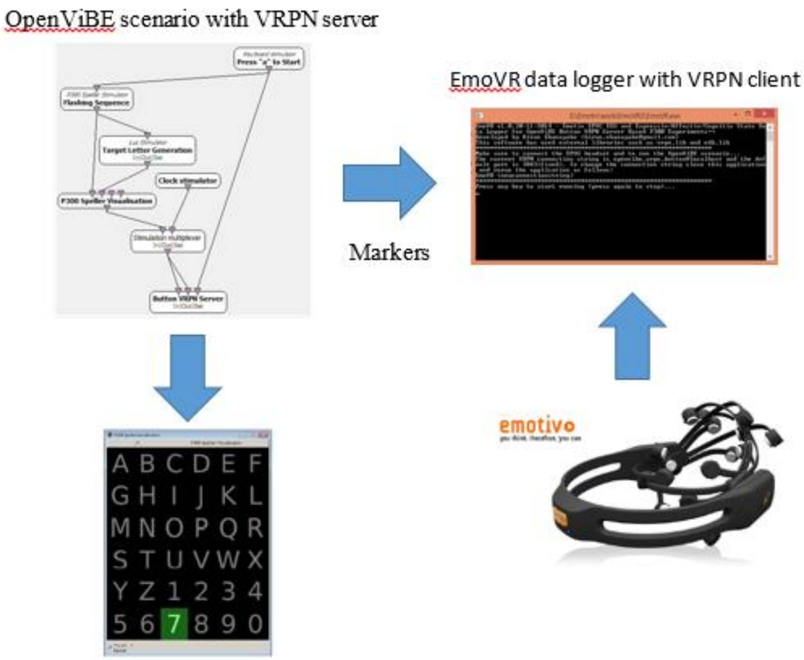


Figure 6(a). Experiment setup

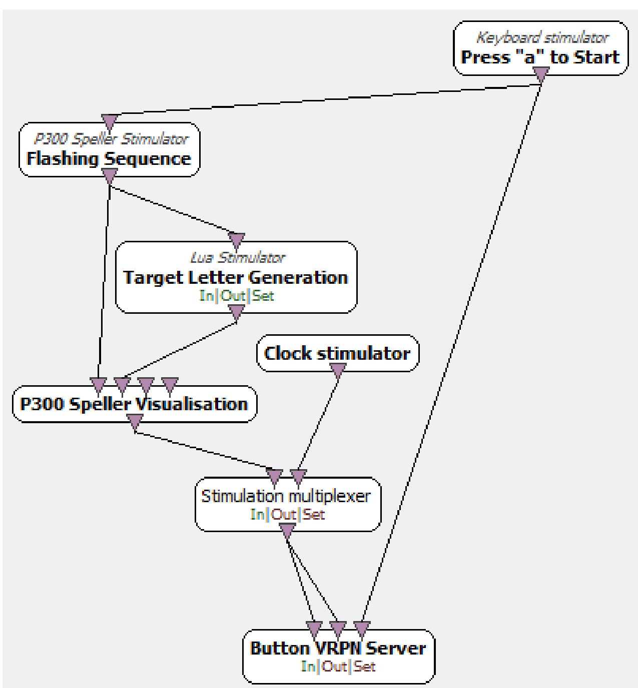


Figure 6(b). The OpenViBE scenario for P300-speller

Procedure for setting up the experiment

Download a new version of OpenViBE (should be version 0.18.0 or higher) from http://openvibe.inria.fr/ and install. Then, download the recording software (alternative to TestBench) from http://neurofeedback.visaduma.info/EmoVR_Release.zip and unpack the files. Copy the two files, edk.dll and edk_utils.dll, which comes as part of Emotiv EPOC research edition SDK, to the EmoVR_Release folder. Now connect the EPOC headset and open the openvibe-to-vrpn scenario in the EmoVR_Release folder within OpenViBE. Then run the EmoVR.exe. It will create two files in the folder for logging EEG data and state data while inserting event markers from the OpenViBE scenario in the last column (marker 1 for targets and marker 2 for non-targets).

Procedure for data analysis

The procedure for analyzing EEG data using MATLAB and EEGLAB is very similar to that of the previous model. However, in this model, the data file is already recorded in a CSV file. Moreover, the MATLAB script for automating the processing of EEG data is same as Code listings 1&2 except the following segment in Code listing 1.

```
% remove unwanted fields
eegdata(:,16:22) = [];
eegdata(:,1) = [];
```

Results

Figure 7 shows the results of the experiment by comparing the plots between target and non-target stimuli.

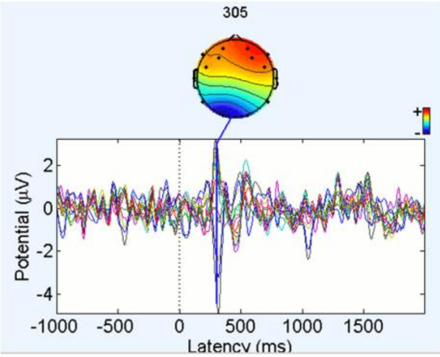


Figure 7(a). ERPs of all channels for target stimuli (using "With scalp maps")

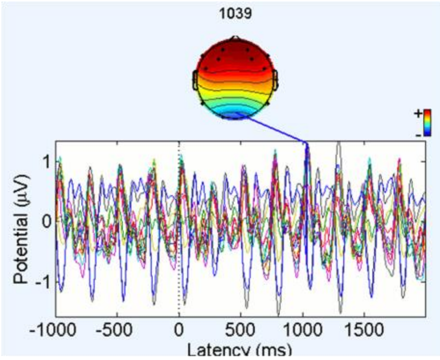
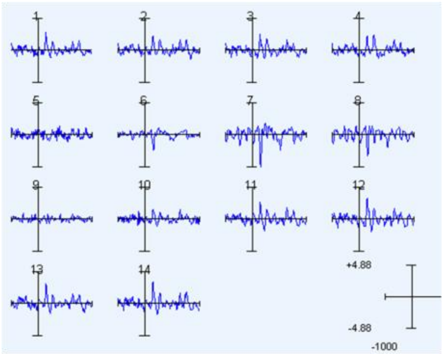


Figure 7(b). ERPs of all channels for non-target stimuli (using "With scalp maps")



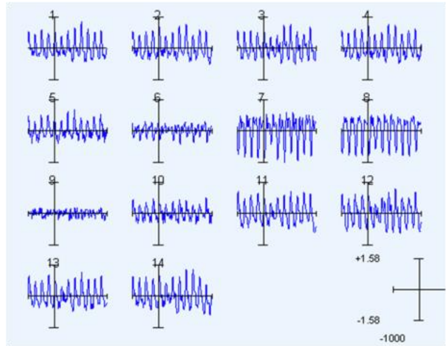
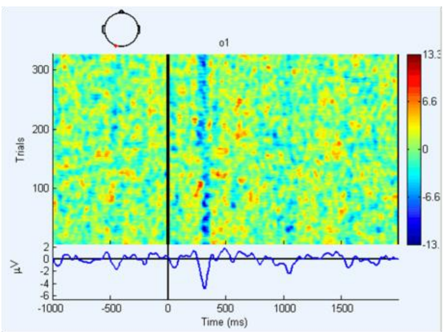


Figure 7(c). ERPs of all channels for target stimuli (using "In scalp/rect. array")

Figure 7(d). ERPs of all channels for non-target stimuli (using "In scalp/rect. array")



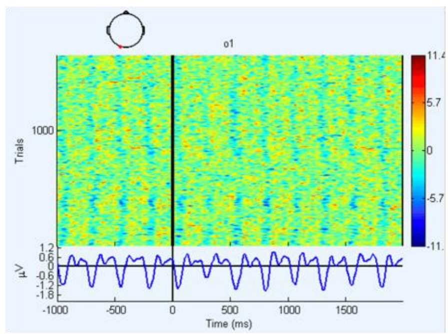


Figure 7(e). ERP of channel 7 for target stimuli (using "Channel ERP image")

Figure 7(f). ERP of channel 7 for non-target stimuli (using "Channel ERP image")

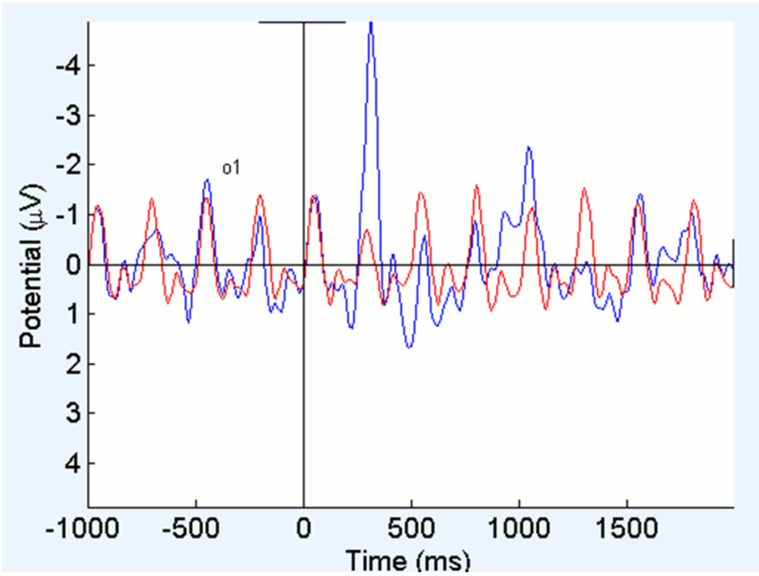


Figure 7(g). Comparison between target and non-target ERPs of channel 7 (using “Sum/Compare ERPs”)

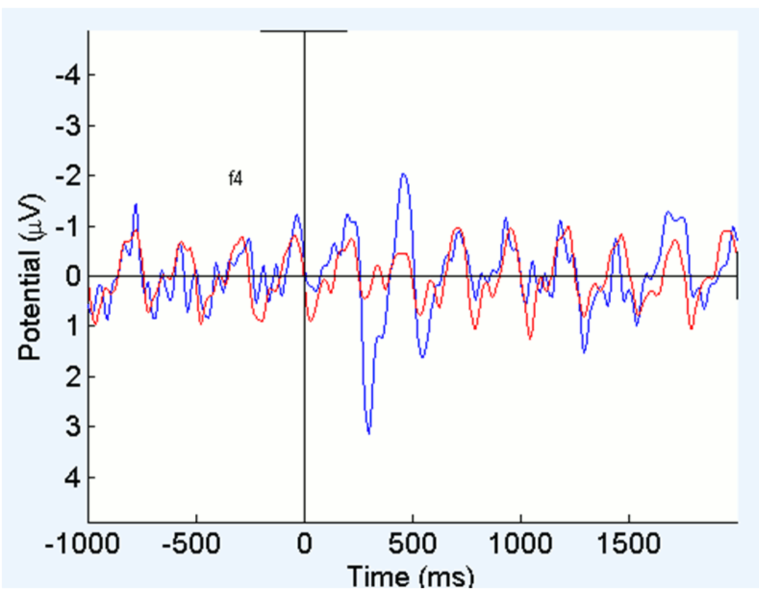


Figure 7(h). Comparison between target and non-target ERPs of channel 12 (using “Sum/Compare ERPs”)

The plots in Figure 7 clearly differentiate the ERPs between target and non-target stimuli. According to those plots, P300 component is visible with a latency of about 305 milliseconds from the stimulus onset, and it is maximum and consistent (as in Figure 7(e)) in the regions of occipital lobe (i.e., o1 and o2).
To ensure that the same results can be obtained across different headsets, another experiment has been conducted using a different headset. The results of that experiment are presented in Figure 8.

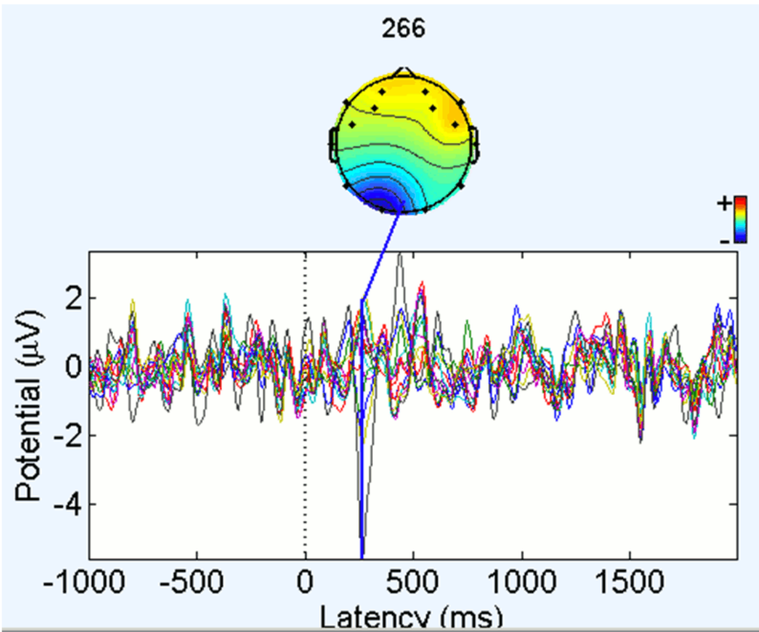


Figure 8(a). ERPs of all channels for target stimuli (using "With scalp maps")

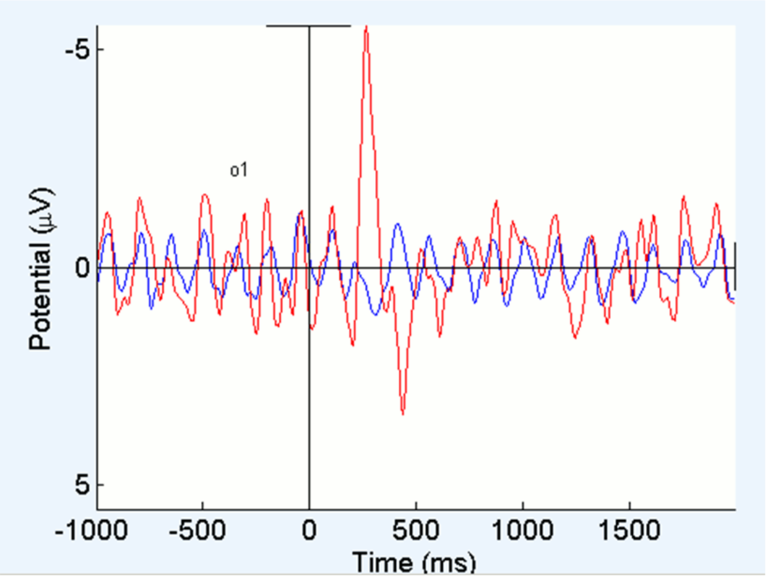


Figure 8(b). Comparison between target and non-target ERPs of channel 7 (using “Sum/Compare ERPs”)

According to Figure 8, the P300 component is visible with a latency of about 266 milliseconds from the stimulus onset.

Conclusion

The plots in both Figures 7 and 8 confirmed the capability of the Emotiv EPOC headset for picking up ‘true’ or ‘real’ EEG. However, there are certain differences between headsets which can be resulting from communication delays and responsiveness of recording software.

References

Delorme, A., & Makeig, S. (2004). EEGLAB : an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9–21.

Fabiani, M., Gratton, G., & Federmeier, K. D. (2007). Event-Related Brain Potentials: Methods, Theory, and Applications. In J. T. Cacioppo, L. G. Tassinary, & G. G. (Eds.), *Handbook of Psychophysiology* (3rd ed.). Cambridge University Press.

Farwell, L. A., & Donchin, E. (1988). Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. *Electroencephalography and Clinical Neurophysiology*, *70*(6), 510–23.

Krusienski, D. J., Sellers, E. W., McFarland, D. J., Vaughan, T. M., & Wolpaw, J. R. (2008). Toward enhanced P300 speller performance. *Journal of Neuroscience Methods*, *167*(1), 15–21. doi:10.1016/j.jneumeth.2007.07.017

Makeig, S., Debener, S., Onton, J., & Delorme, A. (2004). Mining event-related brain dynamics. *Trends in Cognitive Sciences*, *8*(5), 204–10. doi:10.1016/j.tics.2004.03.008

Sur, S., & Sinha, V. K. (2009). Event-related potential: An overview. *Industrial Psychiatry Journal*, *18*(1), 70–3. doi:10.4103/0972-6748.57865

Tatum, W. O., Husain, A. M., Benbadis, S. R., & Kaplan, P. W. (2008). *Handbook of EEG interpretation*. Demos Medical Publishing.

Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement Science Review*, *2*, 1–11. Retrieved from http://www.measurement.sk/2002/S2/Teplan.pdf