A Comparison of EEG Systems for use in P300 Spellers by Users with Motor Impairments in Real-World Environments

Elliott Forney, Charles Anderson, Patricia Davies, William Gavin, Brittany Taylor, Marla Roll

Evaluating EEG Systems in The Real-World

Non-Invasive Brain-Computer Interfaces (BCI) that use Electroencephalography (EEG) may have tremendous potential as assistive technology for those afflicted with motor impairations. Yet, most BCI experiments are currently performed in well-controlled laboratory environments. Relatively little is known about how BCI perform in real-world environments and the types of EEG systems that should be used to construct practical, cost-effective and robust BCI. We seek to compare EEG systems in real-world environments and by users with severe motor impairments to determine which systems are most suitable for use in assistive technologies.

Serial P300 Speller

We have explored the performance of various EEG systems when using a Serial P300 Speller. We have chosen to use a Serial P300 Speller, where single characters are presented sequentially, in order to achieve a simple configuration and eliminate the possible influences of eye-gaze. Each participant completed 3 trials with 20 target and 60 non-target stimuli per trial. The target letter was b, d or p to represent a challenging scenario. A stimulus interval of 100ms and an inter-stimulus interval of 750ms was used.

Three Representative EEG Systems

We compare three EEG systems.

- The Neuropulse Mindset-24R
- The g.tec MOBIlab
- The Biosemi ActiveTwo

Each system varies considerably with respect to cost, portability, signal resolution and other features.

The Neuropulse Mindset-24R is relatively expensive with a mid-range number of channels and sampling rate. It has passive electrodes and is not very portable.

The g.tec MOBIlab is relatively inexpensive with a variety of channels and a high sampling rate. It has active electrodes and is very portable.

The Biosemi ActiveTwo is a relatively expensive system with many channels and a high sampling rate. It has active electrodes and medium portability.

Participants and Data Collection

EEG data was collected from a total of 16 participants.

- 9 participants had no impairments and recording took place in a quiet lab environment.
- 7 participants had severe motor impairments and recording took place in their homes.

Impairments were caused by spinal cord injury, multiple sclerosis and cerebral palsy. Several participants had quadriplegia and one required the use of a ventilator. One participant had only limited communication using eyeblinks with caregivers.

Participants were asked to perform 3 sessions on different days with a different EEG system on each day. 3 participants with motor impairments were unable to attend one session.

Each participant completed a questionnaire after the final session regarding their experience.

Participants and Data Collection

We compare three EEG systems.

Each system varies considerably with respect to cost, portability, signal resolution and other features.

The Neuropulse Mindset-24R

- EEG Channels: 24
- AUS Channels: 8
- Trigger Port: no
- Max Sampling Rate: 512Hz
- Max Bandwidth (MHz): 5-50Hz
- Active Electrodes: no
- Reference: foot electrodes
- Common-mode: ground
- Electrode Material: Ag/AgCl
- Conductive Gel: EET Electrode Gel
- Communication: ETTI
- Power Source: 120V AC
- Cost (USD): 40,000

The g.tec MOBIlab

- EEG Channels: 19
- AUS Channels: 8
- Trigger Port: yes
- Max Sampling Rate: 2948Hz
- Max Bandwidth (MHz): 5-50Hz
- Active Electrodes: yes
- Reference: single carbon electrodes
- Common-mode: ground
- Electrode Material: Ag/AgCl
- Conductive Gel: EET Electrode Gel
- Communication: ETTI
- Power Source: 120V AC
- Cost (USD): 6,000

The Biosemi ActiveTwo

- EEG Channels: 32
- AUS Channels: 8
- Trigger Port: yes
- Max Sampling Rate: 15,000Hz
- Max Bandwidth (MHz): 5-50Hz
- Active Electrodes: yes
- Reference: single carbon electrodes
- Common-mode: ground
- Electrode Material: Ag/AgCl
- Conductive Gel: EET Electrode Gel
- Communication: ETTI
- Power Source: 120V AC
- Cost (USD): 8,000

In order to explore noise and signal characteristics, Power Spectral Densities (PSD) were computed and averaged across participants for each system for both the home and lab groups. PSD were computed using Welch's method over 3-minutes of resting state data. In each EEG system, 60Hz interference was higher in the homes than in the lab.

The 1.5-34Hz hardware filter in the Neuropulse may attenuate slow components of the P300. It also does not eliminate all 60Hz interference.

Classification using LDA with Shrinkage

Next, we evaluate the classification accuracy for each user and system in both real-world and lab environments.

The data is filtered from 0.25-12Hz and downsampled to 22Hz and segmented between 0-800ms after stimulus onset.

Classification is performed using LDA with shrinkage toward the average eigenvalue of the covariance matrix. Class labels are assigned by summing the discriminant values of six segments and choosing the largest.

Only 8 channels, common to all systems, are used: F1, F2, C3, C4, P3, P4, O1, O2.

In Table 2, we present the classification accuracies for each system in home environments.

In this case, the g.tec outperforms the other systems. However, an F-test shows no statistically significant difference between the systems (p = 0.05).

Discussion

It appears that P300 Spellers may be effective in home environments and for users with various forms of severe motor impairments.

However, high-end EEG systems do not appear to be necessary for this type of BCI.

Although the g.tec and Biosemi often produce better ERP when averaging, differences in classification performance are not significant and vary depending a number of factors.

A number of factors should be considered when selecting an EEG system for use in P300 Speller type BCI.

- Portability: EEG systems should be portable so that they can be carried with a user. This means that the system must be small, light and have internal power.
- Comfort: Users have indicated that the EEG cap and gel are not very comfortable and that applying them can be unpleasant. EEG systems should have few active electrodes and comfortable caps that function well for long periods of time.
- Ease-of-Use: EEG systems should be easy to use and easy to apply. Again, active electrodes make the system easier to apply.
- Cost: Should be low enough for users to be able to afford BCI and for insurance companies to begin funding their use.
- Signal Quality: Of course, EEG systems for BCI should maintain a level of signal quality. Especially, robustness to noise and artifacts in everyday environments.