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

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Brainwaves Research Lab.

Colorado State University
Brain-Computer Interfaces Lab.

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

Evaluating EEG Systems in The Real-World

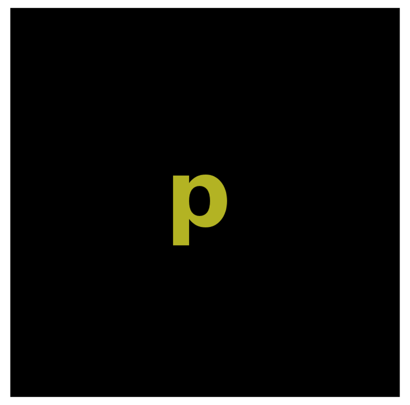
Non-Invasive Brain-Computer Interfaces (BCI) that use Electroencephalography (EEG) may have tremendous potential as assistive technology for those afflicted with motor impairments.

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 user performed 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.

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

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

	Neuropulse Mindset-24R	G.Tec MOBIlab+	Biosemi ActiveTwo
EEG Channels	19	8	32
AUX Channels	5	none	8
Trigger Port	no	yes	yes
Max Sampling Rate	512Hz	256Hz	16384Hz
Max Bandwidth (-3dB)	1.5-34Hz	0.5-100Hz	DC-3276.8Hz
Active Electrodes	no	yes	yes
Reference	linked earlobes	single earlobe	internal
Common-mode	ground	ground	CMS/DRL
Electrode Material	Sn	Ag/AgCl	Ag/AgCl
Conductive Gel	ECI Electrogel	Parker signa gel	Parker signa gel
Communication	SCSI	bluetooth	USB/fiber-optic
Power Source	120V AC	1.5V DC (AA)	DC Rechargeable
Cost (USD)	6,500	11,000	40,000

The g.tec g.MOBILab+ with g.GAMMASys active electrodes is more expensive and has fewer channels and lower sampling rate. It has active electrodes, is very portable and easy to apply.

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 vetted lab environment.

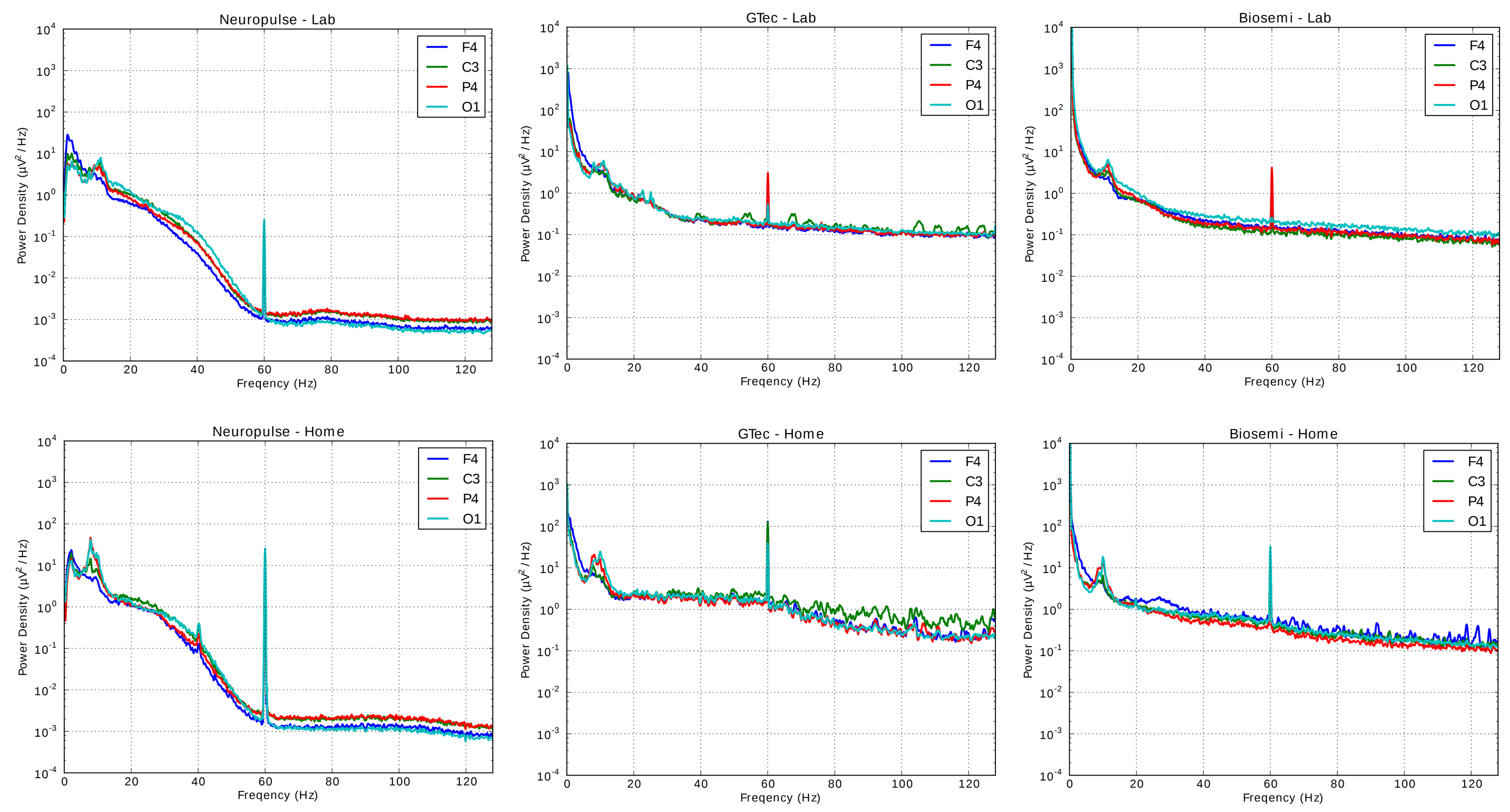
7 participants had severe motor impairments and recording took place in their homes.

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.

Spectral Analysis



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.

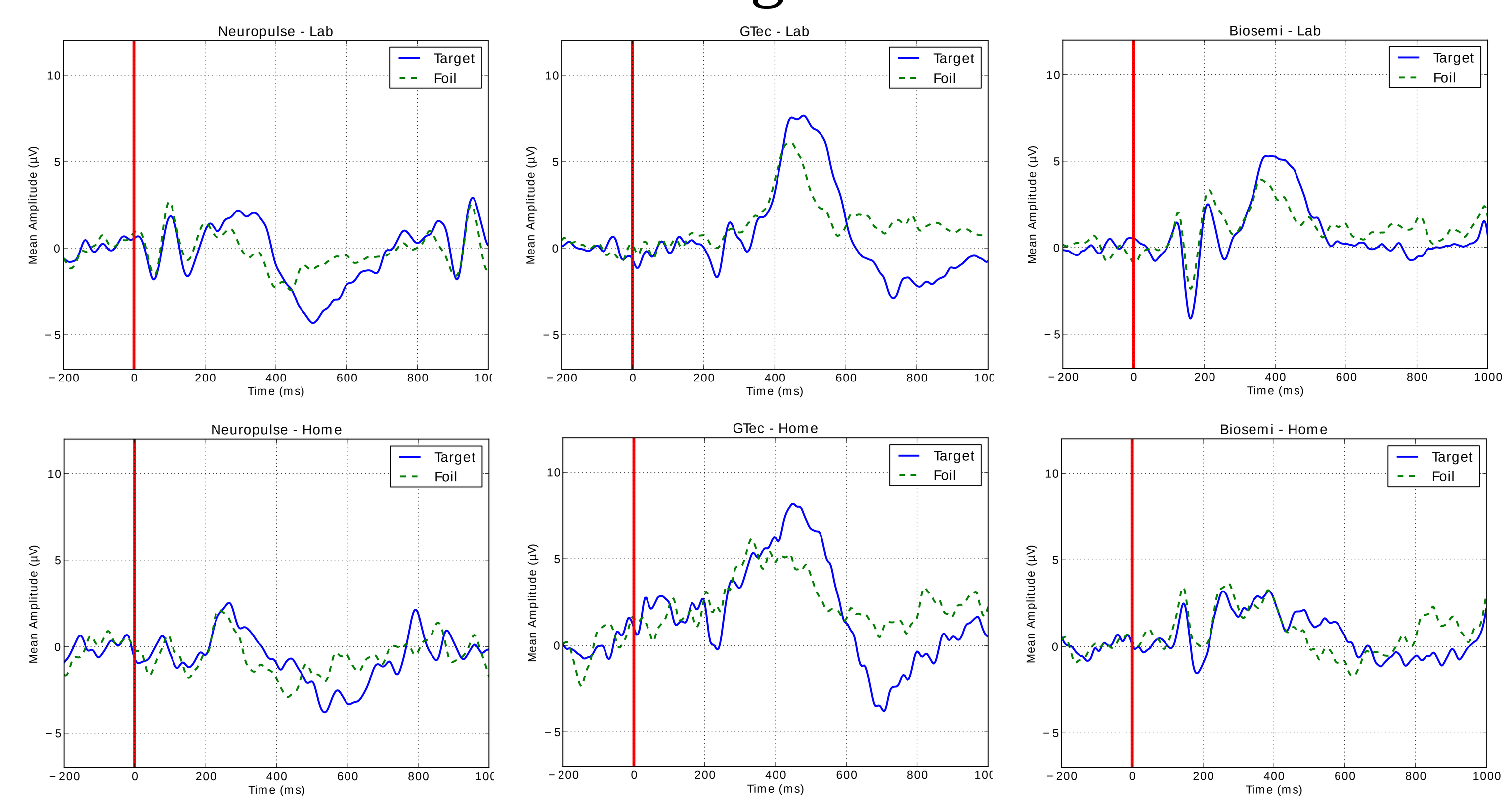
PSD were computed using Welch's method over 3-minutes of resting state data.

In each EEG system, 60Hz interference was higher in the homes than in the lab.

There also appears to be more broad-band power in the homes than in the lab in all of the EEG systems. Possibly due to interference from muscle movements or external electrical sources.

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

Averaged ERP



Averaged, time-locked windows following the stimuli were computed in order to visualize the P300 and other Event-Related Potentials (ERP). Here, we see the grand-average, across all subjects for each system in both the real-world and controlled lab conditions.

EEG was bandpass filtered from 0.2 - 30Hz using a 2nd order butterworth filter. A baseline correct was performed using 200ms before stimulus onset. 20 random non-targets were chosen to balance targets and foils. Here, we see data from electrode site P4 since it was common to all systems.

The P300 does appear in the real-world group, although less pronounced and more variable.

The P300 often appears late, between 400-600ms in g.tec and Biosemi systems, but timing varies between systems. This may be partially due to differences in timing mechanisms in each system.

Peaks near N100 and P200 are more prominent in Biosemi and Neuropulse in lab groups and less visible in real-world groups. These peaks are very small in g.tec system. Possibly related to timing, variability and higher-frequency noise.

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 32Hz 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.

20% is withheld for testing and the procedure is averaged over 10 repetitions.

In Table 1, we present the classification accuracies for each system in the controlled lab environment.

Table 1. 6-Segment Test Classification Accuracies for subjects with no impairments in lab.

Subject	Neuropulse	g.tec	Biosemi
01	97.50%	90.00%	87.50%
02	95.00%	97.50%	82.50%
03	95.00%	77.50%	90.00%
04	95.00%	77.50%	85.00%
05	81.25%	95.00%	87.50%
06	87.50%	65.00%	72.50%
07	81.25%	75.00%	80.00%
08	85.00%	80.00%	60.00%
09	91.25%	90.00%	60.00%
Mean	89.86%	83.06%	78.33%

Table 2. 6-Segment Test Classification Accuracies for subjects with impairments in homes.

Subject	Neuropulse	g.tec	Biosemi
11	73.75%	NA	83.33%
12	NA	87.50%	85.00%
13	100.00%	97.50%	82.50%
14	71.25%	NA	50.00%
15	75.00%	55.00%	77.50%
16	72.50%	92.50%	65.00%
17	77.50%	87.50%	85.00%
Mean	78.33%	84.00%	75.48%

Surprisingly, the inexpensive Neuropulse system yields the highest mean classification accuracy. However, an ANOVA F-test shows no statistically significant difference between the systems ($p = 0.06$). Pairwise t-tests with Bonferroni correction show borderline difference only between Biosemi and Neuropulse ($p = 0.05$).

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 ($p = 0.57$).

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.