A comparison of a Brain-Computer Interface and an Eye tracker: is there a more appropriate technology for controlling a virtual keyboard in an ALS patient?

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Abstract. The ability of people affected by amyotrophic lateral sclerosis (ALS), muscular dystrophy or spinal cord injuries to physically interact with the environment, is usually reduced. In some cases, these patients suffer from a syndrome known as locked-in syndrome (LIS), defined by the patient's inability to make any movement but blinks and eye movements. Tech communication systems available for people in LIS are very limited, being those based on eye-tracking and brain-computer interface (BCI) the most useful for these patients. A comparative study between both technologies in an ALS patient is carried out: an eye tracker and a visual P300-based BCI. The purpose of the study presented in this paper is to show that the choice of the technology could depend on user´s preference. The evaluation of performance, workload and other subjective measures will allow us to determine the usability of the systems. The obtained results suggest that, even if for this patient the BCI technology is more appropriate, the technology should be always tested and adapted for each user.

Keywords: Brain-Computer Interface (BCI), Eye tracker, ALS, usability, Speller.

1 Introduction

Several of the neurological diseases that human can suffer result in severe disabilities. For instance, the ability of people affected by amyotrophic lateral sclerosis (ALS), muscular dystrophy or spinal cord injuries to physically interact with the environment, is usually reduced, and they may even lose it completely.

ALS patients suffer from a syndrome known as locked-in syndrome (LIS). In its classical modality, this syndrome is defined by the patient's inability to make any movement but blinks and eye movements, despite being still conscious. This renders them completely dependent not only on their close family, but also on ventilatory machines to remain alive. If the disease draws on, the patient is bound to be unable to make even those residual movements, thus remaining completely isolated.

If there are several tech communication systems available for people who has residual muscular control, for people in LIS, these technologies are very limited. Probably, the technologies based on eye-tracking, electrooculography (EOG) and brain-computer interface (BCI) are the only useful for these patients [1].

As much the eye tracker as the electrooculography are based on the measurement of eye activity, and both rely on the users´ abilities to control their eye-muscles.

The eye trackers, generally, include two components: a light source and a camera. The camera tracks the reflection of the light source along with visible ocular features such as the pupil. Electrooculography is a technique for measuring, though electrodes placed around the eyes of the user, the corneo-retinal standing potential that exists between the front and the back of the human eye. The resulting signal is called the electrooculogram.

A brain-computer interface (BCI) is based on the analysis of the brain activity recorded during certain mental activities, in order to control an external device. Currently, the most commonly used BCI systems are those based on electroencephalographic (EEG) signals, mainly because they can be recorded in a non-invasive manner and show adequate temporal resolution. Among them, those based on the P300 event-related potential (ERP) are very common due to easiness with which this ERP can be elicited. Specifically, the P300 is a positive deflection in voltage occurring about 300 ms after an infrequent or significant stimulus is perceived [2]. P300 wave amplitude is typically between 2μV and 5μV and is symmetrically distributed around central scalp areas, showing greater amplitude in occipital rather than frontal regions [3].

From those technologies, the eye-tracking is, at present, one the most advanced devices for communication in patients in LIS and, specially, in patients with ALS. A recent study tried to explore the effectiveness of communication and the variable affecting the eye-tracking computer system utilization in patients ALS [4]. The study was carried out on 30 patients with advanced ALS and 19 showed a high acceptance and average daily eye-tracking system utilization of 300 min. However, the remaining 11 subjects reported limited and irregular daily use of the device, being the reported causes, gaze fatigue (8 subjects), oculomotor impairment, i.e., inability to properly move the eyes (2 subjects) and difficulty to keep the head still (1 subject). Finally, authors concluded that limitation of the eye-tracking is given by the fact that it actually relies on eye movements. For patients with oculomotor dysfunction, the use of an eye-tracking is uncomfortable or even impossible, being necessary to provide other technologies, such are those based on brain-computer interface (BCI).

Another study [1] compares three technologies to provide binary communication: eye-tracking, electrooculography (EOG) and auditory brain-computer interface. The participant of the study was a patient with ALS who had been in the LIS for 6 years. He was able to communicate with slow residual eye movements, restricting the number of choices. With the EOG based system, the user reached an accuracy mean of 71 % with 5 choices. With the eye tracking based system, the user had difficulties looking at a particular direction and only two choices were provided however, the reached accuracy was 100%, being all selections classified correctly. Finally, with the auditory BCI, only two choices were provided and participant reached accuracies above 75%. In this study, the reduced number of choices provided was due to the slow residual eye movements of the participant.

Other BCIs used for communication purpose are those based on visual P300 signal. They are based on the P300 speller first developed by Farwell and Donchin [5], which is still referenced and intensely studied [3, 6, 7, 8]. In this BCI, a 6 x 6 matrix of letters, arranged in rows and columns, is shown to the subject. The user focuses his/her attention on the matrix element he/she wishes to select as each row and column is flashed (i.e., intensified) randomly, one after the other. After a number of flashes, the symbol that the user has supposedly chosen is presented on screen.

Recently, a study compares a visual P300-based brain-computer interface and an eye-tracking for controlling an Internet browser [9]. A total of 12 patients with severe motor impairment (11 affected by ALS, and 1 affected by Duchenne muscular dystrophy, participated in this study. According to the obtained results in this study, the performance measures showed the advantages of using the eye tracker as a communication device. Besides, participants rated the eye tracker as a more satisfying device and considered the BCI as a technology requiring more effort and that was more time-consuming than the eye tracker. The conclusion of this study was that if users can rely on eye movements, they tend to consider the eye tracker as a superior technology.

The purpose of the study presented in this paper is to show that the choice of a technology could depend on user´s preference, and not all the users have the same preference. To this end, the usability of the two technologies [10, 11], the eye tracker and a visual P300-based BCI, will be evaluated.

2 Methods

2.1 Participants

One French man, 57-years-old, diagnosed with amyotrophic lateral sclerosis in 2010 and without any impairment of cognitive functions, participated in this study. The patient, with severe motor impairment, was naïve to both technologies: the eye tracker and the BCI. He was able to move his eyes and had difficulty to communicate through the voice. He gave informed consent through a protocol reviewed by the ENSC-IMS

Cognitive team. The experiment was carried out at the CHU (centre Hospitalier Universitaire) at Bordeaux.

2.2 Procedure

On the same day, the participant tested the visual P300-based BCI (session 1) and the eye tracker (session 2). During the experiment, the participant sat in his wheelchair in a reclining position at a distance about 60 cm from the screen. Before the beginning of each session, instructions regarding the procedure and the device (BCI and eye tracker) management were given in verbal form. The experiment was conducted in accordance with standard ethical guidelines as defined by the Declaration of Helsinki and the study was approved by the Ethics Committee of the University of Málaga.

Because the objective of the study was to compare the usability of the eye tracker and the visual BCI in a communication task, the speller size was the same for both technologies. The speller used was based on the classical Farwell & Donchin [5] speller, which consists on a 6 x 6 matrix of symbols (36 alphanumeric letters and numbers) arranged within rows and columns (see Fig. 1). The matrix size was 14.69 cm, being the symbols size of 1.17 cm and the distance between symbols of 1.53 cm.

Fig. 1. Schematic representation of a classical P300 speller BCI

Each session consisted of a calibration phase and an evaluation phase. The purpose of the calibration phase was to adapt the technology to the user. Once the calibration was done, the subject participated in the evaluation phase to copy-spell the sentence “il fait beau” (i.e., “the weather is nice”). The participant was allowed to correct each error only once. After the copy-spelling tasks, he was asked to complete a visual analogue scale (VAS) of: fatigue, difficulty, stress and difficulty to perceive the characters, and the NASA-TLX test [12] to evaluate the subjective cognitive workload.

At the end of the last session, the participant was asked to express his preference between the two technologies. A comparative questionnaire adapted from the SUS (System Usability Scale) allowed to evaluate six dimensions: favourite, complex, comfortable, stressful, controllable, tiring.

2.3 Equipment and tasks

Brain-Computer Interface. EEG was recorded using gold electrodes placed at positions Fz, Cz, Pz, Oz, P3, P4, PO7 and PO8, according to the 10/20 international system. All channels were referenced to the left earlobe, using FPz as ground. The EEG was amplified through a 16 channel biosignal amplifier (g.BSamp, Guger Technologies). The amplifier settings were 0.5 and 100 Hz for the band-pass filter, the notch (50 Hz) was on, and the sensitivity was 500 µV. The EEG was then digitized at a rate of 256 Hz by a 12-bit resolution NI-USB-6210 data acquisition card (National Instruments). All aspects of EEG data collection and processing were controlled by the BCI2000 system.

During the calibration phase, each row and column was randomly flashed 10 times. Therefore, each character was randomly intensified 20 times. The duration of each flash was 125 ms and the inter-stimulus interval (ISI) between flashes was also 125 ms. There was a pause of 6 s after each sequence of flashes (i.e., after a character had been selected). The calibration consisted in spelling the words “lune”, “feux” and “kilo” and the number “2015”. It is important to mention that the time required for the calibration phase for the BCI system depends on the number of words to spell (4 in this experiment).

After these runs, we performed a stepwise linear discriminant analysis (SWLDA) of the data from the last three runs to obtain the weights for the on-line P300 classifier.

After calibration and training of the classifier, the evaluation phase started (see Fig. 2). We set the number of intensification sequences to the minimum number need to reach 100% accuracy off-line.

Fig. 2. Participant during the evaluation phase of the BCI system

Eye Tracker. The experiment was carried out using the Tobii C15 (Tobii Technology, Sweden) [13]. The eye tracker interface speller was configured to be identical to the one used for the BCI. The calibration phase consisted in fixating 9 targets located on different positions of the screen. The time required for this calibration phase should be, usually, very short. The evaluation phase started only once the operator considered an acceptable calibration. For the evaluation phase (see Fig. 3), participant could select a symbol by gazing at the intended target for 1.6 s.

Fig. 3. Participant during the evaluation phase of the Tobii communicator system

2.4 Objective and subjective measures

To compare the performance of the BCI and the eye tracker, different objective measured were considered: the time required for the calibration phase, the time required for the evaluation phase, the final written sentence and the number of errors.

Regarding the subjective measures, we analyze the NASA-TLX for each experiment in order to evaluate the subjective workload. The different Visual Analog Scales (VAS), added to the comparative questionnaire adapted from the SUS (System Usability Scale), allow us to obtain a global subjective assessment of usability.

3 Results

3.1 Objective measures

The different objective measures obtained for each technology are shown in Table 1.

Table 1. Objective measures (times, final sentence, errors) obtained for BCI and Tobii system.

	BCI	Tobii
Time for calibration phase	8 min	5 min
Time for evaluation phase	7 min 34 s	7 min 47 s
Final written sentence	IL FAIT BEA7L	IL LFAI7_BEAP65
Number of error	3	7

The user had high difficulty to fix the targets and the calibration failed several times. Finally, the calibration was done considering only the right eye.

Regarding the BCI, the participant required 7 flashes (one flash is the intensification of one row and one column) to obtain 100% of accuracy. Finally, we configured 8 flashes to select a letter during the evaluation phase.

3.2 Subjective measures

The total subjective workload (NASA-TLX- Global score; ranged from 0 to 100) and dimensions contributions to the subjective workload (mental, physical and temporal demand, performance, effort and frustration; ranged from 0 to 33.3) for each technology is sowed in Fig. 4.

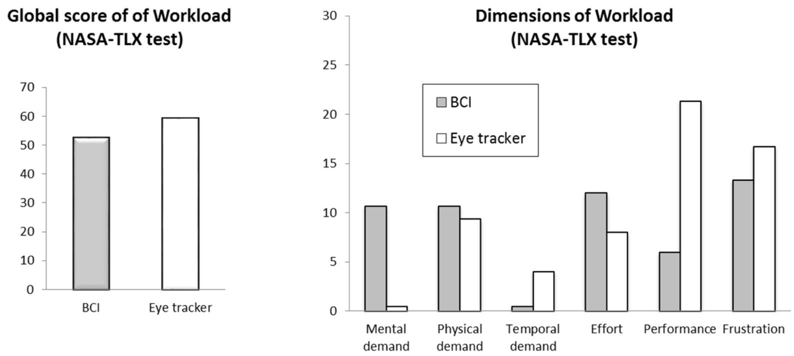

Fig. 4. NASA-TLX scores obtained for BCI and Tobii

The obtained values of the different Visual Analog Scales (VAS) for each technology is shown in Fig. 5.

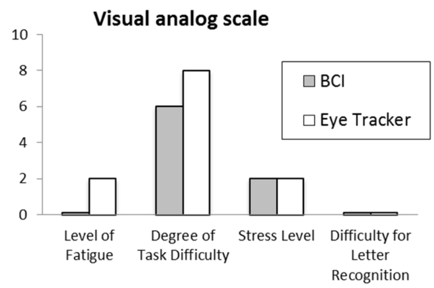

Fig. 5. VAS obtained for BCI and Tobii

Finally, the obtained results of the comparative questionnaire are shown in Table 2.

Table 2. Comparatives results between BCI and Tobii.

	BCI	Tobii
Positive view	The most controllable The most comfortable The favourite	
Negative view	The most stressful	The most complex The most tired

4 Discussion and conclusion

In this study, two different technologies for communication purpose designed for people with severe motor impairment have been compared through objective and subjective measures. The experiment has been carried out in a participant with ALS. The obtained results show that, for this participant, the visual BCI has been considered more advantageous that the eye tracker as a communication device.

During the calibration phase, the participant had, not only a high difficulty to gaze the different targets presented by the eye tracker, but also high difficulty to keep this eyes open, being this an obstacle to calibrate the system. Finally, after several runs, the calibration was carried out with the right eye and, even in this condition, the calibration was not really satisfactory for the operator. This longer time required for the calibration of the Tobi could affect the perceived fatigue and affected the usability of the system. However, for the BCI, the participant did not have any problem during the calibration phase, getting 100% of performance with only 7 flashes. Besides, even if the time required for the evaluation phase was similar for both technologies, the number of error was higher with the Tobii system. These results show a better performance with the BCI system.

Regarding the subjective measures, the global score of workload of the visual BCI was lower than of the Tobii system. This result seems to be contrary to that other study [1, 9] which suggest that the workload of the eye tracker was lower that the workload of the BCI. The mental demand and the effort subscale were considered higher in the BCI system compare to the Tobii System. The higher time needed to select a letter during the evaluation phase with the BCI system (24 s) was, probably, contributed to this increase in both dimensions (mental demand and effort). However, the BCI system requires less temporal demand, makes easier the development of the task and produces less frustration. Probably, the fact that the demand temporal contribution was so low, could have a positive effect on performance and frustration.

The obtained results in the different VAS show no level of fatigue for the BCI. Although the degree of task difficulty was lower for the BCI, the obtained values were important for both technologies (6 for the BCI and 8 for the Tobii). None of the technology were considered stressful and the subject did not present any difficulty to recognize the characters.

The obtained results in the comparative questionnaire allow to summarize which technology has been considered as most advantageous for the participant. Undoubtedly, the visual BCI has been select as the favourite, being the stressful the only dimension with a negative point of view for the BCI however, as it was mentioned before, the level of stress was very low for both technologies.

The preference to BCI system can be due to ability to achieve control of BCI over Eye-tracing. By the way, the participant verbally reported feeling satisfaction particularly related with the BCI experience, possibly because it could represent a greater challenge that needed to be raised.

Although a recent study concluded that an eye tracker system is more advantageous than a P300-based BCI for communication purpose, from these results we conclude that a BCI system may be a not negligible alternative solution for some patients with special difficulties, not only for controlling their eye movements, but who present difficulties to manage an eye tracker. Even if the results have been obtained with only one patient, these show that the technology should be always tested and adapted for each user, not being able to stablish a specific technology as the most appropriate without, previously, testing it.

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