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Verbal Communication through Brain Computer Interfaces

Maureen Clerc¹, Jérémie Mattout², Emmanuel Maby², Dieter Devlaminck¹,
Théodore Papadopoulo¹, Violaine Guy³, Claude Desnuelle^{3,4}

¹ Athena project-team, Inria Sophia Antipolis Méditerranée, France

² INSERM U1028, Lyon Neuroscience Research Center, France

³ Centre de Référence Maladies Neuromusculaires et SLA,
Centre Hospitalier Universitaire de Nice, France

⁴ UMR CNRS 7277, INSERM 1081, Faculté de Médecine de Nice - IBV, France

Maureen.Clerc@inria.fr

Abstract

Brain Computer Interfaces (BCI) provide a way of communicating directly from brain activity, bypassing muscular control. We report some recent advances in a BCI communication system called the P300 speller, which is a virtual brain-operated keyboard. This system relies on electroencephalographic activity time-locked to the flashing of the desired letters. It requires calibration of the system, but very little training from the user. Clinical tests are being conducted on a target population of patients suffering from Amyotrophic Lateral Sclerosis, in order to confirm the usability of the P300 speller for reliable communication.

Index Terms : brain computer interfaces, assistive technology, virtual keyboard, P300 speller.

1. Introduction

Brain Computer Interfaces (BCI) provide a way of communicating directly from brain activity, bypassing muscular control. BCIs dedicated to speech address the challenge of producing not only *silent* but *motionless* speech. This offers a novel communication perspective for patients with extreme motor impairment.

Different types of brain activity can be considered, leading to different communication possibilities. Ideally, it would be desirable to record language-related brain activity, and BCIs are indeed being proposed that rely on speech motor cortex [1], or on speech networks [2, 3] covering both motor and Wernicke regions. Such BCIs appear promising because these regions are directly responsible for speech. However, in order to obtain features that can directly be decoded as formants, invasive measurements with implanted electrodes are necessary, i.e. multi-unit microelectrodes [1], or electrodes placed on the cortical surface [2, 3].

On the other hand, non-invasive recordings, mainly electroencephalography (EEG), allow the use of brain-controlled virtual keyboards, thus procuring indirect speech production via typing. Brain-controlled typing can be achieved in two ways : by displacement of a cursor on the virtual keyboard, or by paying attention to the desired symbol (character, number, hyphen, etc) which, like all the others, is flashing at short interval.

The P300 speller is a technique of the latter category [4]. It relies on an automatic deflection of the central component of the electric potential, occurring approximately 300 ms after the apparition of an intermittent and rare event, on which the

user's attention is focussing. Its advantage is not to require any training on the part of the user. Only the BCI system has to be trained to detect the P300 component from the background EEG. This paper reports recent advances on the P300 speller, and its experimental validation through translational research with disabled patients.

2. P300 speller methodology

The idea behind the P300 speller is very simple : the system displays series of stimuli (flashes), and detects whether or not the EEG recorded after each flash contains a P300. Its implementation is not so simple, because of the low amplitude of the P300 compared to the background EEG, and of the inter-subject variability of this signal.

2.1. Dynamic keyboard display

The P300 speller can predict the symbol on which the user's attention is focussing, because flashing this symbol elicits a P300 evoked response in the EEG. To accelerate the total flashing time, the keyboard symbols are organized in groups that are flashed simultaneously. The original P300 had a row-column flashing strategy [4], but groups can be arranged into other patterns, e.g. to minimize the probability of a given symbol flashing twice in a row [5]. Indeed, double flashes are both uncomfortable for the user, and produce a reduced P300 evoked response for the second flash.

The signal-to-noise ratio of a P300 evoked response is unfortunately quite low, making it necessary to repeat the sequences of flashing symbols to make its detection possible. Each group of symbols must thus be flashed several times. Besides, to engage the users' attention on the desired symbol, they are asked to count the number of times it flashes.

Most P300 systems either set in advance the number of flashes per group, or adjust it just after the calibration phase (see section 2.2). Perrin et al. propose to adapt the number of flashes online, until a reliable decision can be made [6]. Not only does this procedure increase the speed of the system, but it has the benefit of improving users' motivation, whose focussed attention is rewarded by a faster decision on their target symbol.

The way a symbol is flashed generally consists of increasing its visual contrast with the background, and also increasing its size [7]. Recent findings by Jin et al. show that the P300 signal-to-noise can be increased by replacing the symbols with pictures such as famous faces during the flashing interval [8].

2.2. Calibration and classification

The P300 speller engine is a classifier that analyzes EEG features to decide for which of the flashed groups a P300 has occurred, and *in fine* which symbol the user is attending to. Because of the inter-subject and inter-session variability of the P300 signal, the features and the classifier weights must be learned at each new session. A typical P300 session starts with a copy-spelling task, which is processed offline to perform this calibration. Research is currently being conducted to make this calibration step as short as possible. Some studies completely get rid of the copy spelling, tolerating that the initial predictions are faulty, and gradually become correct when the classifier has been learned [9].

2.3. Displaying the detected symbol

When the outcome of the P300 speller, i.e. the selected symbol, appears on the screen, this visual stimulation elicits a brain response from the user, which is modulated by the quality of the detection. If the symbol displayed is not the one that the user was attending to, an Error Potential occurs. Much research has been conducted recently to take advantage of this Error Potential, either to correct the prediction if it is wrong, or to adapt the classifier [10]. Detecting the Error Potential is unfortunately even more difficult than detecting the P300 itself : the signal to noise ratio of the Error Potential is as poor as that of the P300, and it must be detected in single-trial, unlike the P300, for which the flashing groups can be repeated. The Error Potential has so far not brought to the P300 speller the progress anticipated. But even if its detection does not appear to be reliable enough to enable the correction of a misspelt letter, it could still be very useful to adapt the classifier in the background during P300 speller operation.

One of the main drawbacks of the P300 speller is its slow throughput. Current P300 systems can afford between 4 and 6 characters-per-minute. A straightforward way to improve the speed of the P300 speller is to couple it to a statistical word prediction library, in order to perform automatic word completion, and propose the following words. Care must be taken in not making the overall system more complicated because of this technology : false positive rate should be controlled at a low level in order for the word completion and/or next word selection not to hamper word production.

2.4. Technical platform

A good detection of the P300 component depends on the quality of the recorded EEG signals. To this end, it is important to use high quality biosignal amplifiers. For the clinical study, discussed in Section 3.3, we use ANT's Refa amplifier with 32 electrodes. This is a high sampling (up to 2048Hz) and high resolution (18.4nV per bit) amplifier that has the possibility of active signal shielding to free the signal of artefacts caused by movement or external electrical sources.

Besides high signal quality, synchronisation between the signal and the stimuli (i.e. the flashes presented to the subject) is of utmost importance. This is especially the case for a P300-based BCI system where any jitter between the stimulus and the elicited P300 can severely degrade the BCI's performance. Therefore, a separate trigger channel as additional input to the amplifier is highly recommended. This extra input can then be used to precisely synchronize the stimuli and the recorded signals.

While the stimuli are generated on the screen by one application, another application takes care of the signal processing and classification. In our clinical study we use OpenViBE [11] for signal analysis, an external application (see Figure 1) for displaying the symbols and flashes on the screen. An easy-to-use front-end application launches the other two applications with some specified parameters.

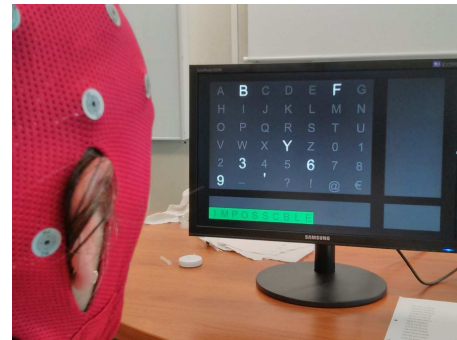


FIG. 1 – P300 display

OpenViBE is responsible for computing the spatial filters [12] and the classifier coefficients (i.e. linear discriminant analysis) based on the calibration data. During the online experiment OpenViBE accumulates evidence for each of the symbols in the P300 speller after applying these spatial filters and classifier to the data. If the evidence for a certain symbol reaches the threshold, the trial is stopped and the result is presented to the user by the stimulation application.

The stimulation application is responsible for how everything is displayed on the screen. We will briefly discuss some of its main features. For example, the flashing strategy defaults to the classic row-column strategy. However, other strategies are available or can be easily implemented. Flashing symbols can be done by either enhancing the contrast and the size of the symbol or by replacing the symbol by another symbol or picture. There is also an interface available to enable the software to use word prediction engines in the future to speed up the bitrate of the P300 speller. Furthermore, the stimulation application compiles on both Linux and Windows platforms as an external application to OpenViBE. The two applications then communicate through shared memory. Many other parameters can be configured as well through an XML specification file, but it would be beyond the scope of this paper to discuss them all.

When performing BCI experiments in a clinical environment, it is not only important to have high quality signals, but the system should also be easy to setup for the caregiver. One possible improvement in this respect concerns the reduction of setup time. This can be achieved by either using dry electrodes [13] which require less time to prepare, or by reducing the number of electrodes that are needed [14]. These optimisations are generally at the expense of the BCI's performance and/or of the subject comfort, although the given references seem to be competitive.

3. Assistive technology

Assistive speech technologies, such as offering silent speech, go beyond the clinical context, and have applications e.g. in highly noisy environments. However, the lack of reactivity of the P300 speller and its non-dependence on muscular input make it ideally targeted to a population of severely disabled patients for which other solutions are scarce.

3.1. Target clinical populations

There are several medical conditions where patients reach a state where they can no longer communicate via speech, writing, nor even gestures.

Locked-in syndrome (LIS) patients are aware of their environment, with intact cognitive and sensory abilities, but are totally incapable of communicating because of a high degree of paralysis. This may occur in case of lesion in the brain stem, which innervates most of the human body. In most cases, some ocular control is still possible (eyelids, and vertical eye movement). Unfortunately, LIS patients are sometimes misdiagnosed as comatose, vegetative or mutic. It is extremely important to find viable means communicating with such patients.

Amyotrophic Lateral Sclerosis (ALS) also known as *Charcot's disease* or *Lou Gehrig's disease* is a neurodegenerative disorder combining dysfunction of both upper and lower motoneurons, with a letal outcome in 3 to 5 years due to respiratory deficiency. ALS patients gradually lose their motor abilities, particularly in their arms and legs, as well as in bulbar innervated region with progressive loss of articulatory speech. Ability for oral or written communication is thus gradually lost, and these patients eventually enter a state close to the locked-in syndrome. Oculomotricity is however preserved for quite a long time. With the help of assisted ventilation and parenteral nutrition patients may survive in this disabled state for up to 10 to 20 years. These patients have a high demand for a practical means of communication. Patients who lose all muscular control, including ocular control are said to be in *Completely Locked In State*.

The *Guillain-Barré syndrome* is an auto-immune disease of the peripheral nervous system, which harms the myelin sheath around the spinal nerve roots (acute inflammatory demyelinating polyradiculoneuropathy), causing sensorimotor disorders, possibly involving cranial nerves and then leading to total paralysis. Patients may recover from this syndrome in some cases but with severe sequels when expanded.

Depending on their condition, patients can be taught to communicate with their caregivers with the help of assistive technology. Skilled therapists adapt and hand-tune systems at the bedside so that they can be operated with the limited muscular control available (muscle twitches, eye movements or blinks). Alternative communication method may be considered using light-tech device as alphabet boards, individual picture communication charts or symbols. High-tech devices based on computer communication system are commercially available. In this field, Brain Computer Interfaces provide a new type of communication channel for patients to experiment.

3.2. Clinical BCI studies

In the last decade, several studies have been conducted to test the communication abilities of patients with brain computer interfaces. First attempts to use a P300-based BCI in ALS were made in 2006 on three patients, for a four-symbol selection task, with operational success [15]. More studies conducted by

the groups of Birbaumer [16] and Piccione [17] confirmed the ability of ALS patients to operate P300-based BCI, with 70% correct symbol rates on average. Sellers et al. were the first to put into patients' homes a comprehensive P300 system enabling email production and dispatching, remote control applications, voice synthesis and control of a Windows keyboard. This system was used by a patient, up to eight hours a day for two and a half years [18].

According to Birbaumer's results, there is no observed correlation between the ability to control the BCI and the degree of impairment, apart from the completely locked-in state [16]. BCI communication with completely locked-in patients has so far not been achieved, and the reasons for this are currently under investigation [19]. Current hypotheses include a prolonged loss of operant conditioning, or of goal directed thinking [20]. It must be admitted that devising means of communication for CLIS patients requires tremendous efforts to tailor the right communication channel, which can involve other body sensors than EEG.

ALS patients, who gradually lose the ability to communicate freely, can learn to use a BCI while they still have other (muscular) means to communicate. Loss of operant conditioning could be prevented by encouraging ALS patients to use the BCI before they become completely locked-in. Successful communication through brain activity may have a chance to persist in the completely locked-in state.

3.3. Ongoing ALS clinical study

The P300 speller has now matured to a point where it must be tested on the target audience. With the Centre de Référence Maladies Neuromusculaires et SLA (CRMN/SLA) of Nice University Hospital, we are currently conducting a large-scale feasibility study on 20 ALS patients. The patients, who routinely come to be examined at the hospital, are screened (to eliminate e.g. dyslexy, dementia). They will give their informed consent after watching a presentation on the modus operandi of the P300 and on their role in the study, and will undergo two P300 spelling sessions, two weeks apart.

The P300 speller system exposed in Section 2.4 has been organized in a way to make it relatively easy to deploy in a clinical setting : it involves only one laptop, and requires limited intervention from the caregiver. The most intricate operation is to position the EEG headset and ensure a correct impedance (below 5 k Ω) for all electrodes.

Each session consists of three blocks, after the initial calibration phase : a copy spelling task of two ten-letter words, a free spelling task of approximately twenty characters, and an optional block of free use of the system for writing. Finally, the patient and the caregiver are both asked to answer a questionnaire. This study intends to investigate the feasibility of setting up and using the P300 speller, from an operational point of view at the hospital. Translational studies of this type are extremely important for the adaptation the BCI systems to the target patient populations, and a large-scale usability study for the P300 speller has never been done before in France.

4. Discussion

Future improvements that should certainly improve the usability of the P300 speller include shortening the setup time, and an adapting to patients' disabilities (by using the most appropriate auditory or visual stimuli). Comparisons will have to be made with other existing assistive technologies such as eye-

trackers. Although the speed of the system is still relatively slow, it will improve with the use of word completion. Integration of P300 speller with other technologies, for instance with voice synthesisers, should also be considered.

Many other usages of the P300 BCI can be considered, for instance to interact with the patients' home environment (remote control), or for artistic expression.

5. Conclusions

Patients who encounter quasi-total loss of motor control have an essential demand for communication, which Brain Computer Interfaces may address. In the context of neurodegenerative diseases, BCI open an alternative channel, that can be learned while there is still an other communication means functioning, and be used to occasionally free the muscular channel from the burden of communication.

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