Evaluation in a locked-in patient of the OpenViBE P300-speller

E. Maby[1,2], M. Perrin[1,2], D. Morlet[1,2], P. Ruby[1,2], O. Bertrand[1,2], S. Ciancia[3], N. Gallifet[3], J. Luauté[1,2,3], J. Mattout[1,2]

[1] INSERM U1028, CNRS UMR5292, Lyon Neuroscience Research Center, Lyon, France
[2]University Lyon 1, Lyon, France
[3]Hospices Civils de Lyon, Henry Gabrielle Hospital, Lyon, France
manu.maby@inserm.fr

Abstract

This study evaluates the efficacy of a P300-based brain–computer interface (BCI) implemented with the OpenViBE software, in a patient suffering from the locked-in syndrome (LIS). The highest accuracy achieved online reached 24.4% and was obtained for the only session, out of four, for which both training and testing data were recorded on the same day. By contrast, other testing sessions, based on the same training, yielded accuracies no greater than chance level. Subsequent offline analysis and complementary data from an auditory oddball paradigm confirmed that the patient understood and performed the task correctly. Nevertheless and although we increased the offline training set with test data from each session, the overall accuracy reached 20.6% only, which remains substantially lower than healthy subject's performance with the same protocol [1]. Altogether, our results suggest that poor performance coincide with low signal-to-noise ratio and high trial-wise variability. This might be explained by the difficulty for this patient to focus attention and to avoid disturbances caused by stimuli adjacent to the target.

1 Introduction

Locked-in patients are characterized by complete motor paralysis, except for eye movements, with intact cognition and sensation. A communication tool independent of muscle control would enable them to regain autonomy and be less dependent on others for communication. It has been shown that some severely disabled patients can communicate through the P300-based BCI [2]. In this paradigm, symbols are displayed on screen, in a matrix form, whose rows and columns are flashed alternatively. A P300 response is elicited whenever the row or column that contains the target is being flashed. The present study evaluates the efficacy of our recent implementation of the P300-speller in a LIS patient, using OpenViBE (http://openvibe.inria.fr)[3].

2 Methods

The patient is a 38 years old woman who sustained a locked-in-syndrome following a basilar artery thrombosis on March 1^{st} 2009. She was diagnosed with a complete tetraplegia with anarthria. Cerebral MRI revealed a pontine infarction with a complete interruption of the cortico-spinal tract as well as lesions of the cerebellar pedoncules and tegmentum nuclei. Speech and language therapy rehabilitation progressively established a yes/no communication code and developed a words spelling setting using eyes closure in response to letter enumeration. The patient underwent cognitive function evaluation through auditory paradigms. First, a passive novelty oddball paradigm [4] highlighted normal sensory N1 responses to all stimuli and a large novelty P3, suggesting the absence of abnormality in automatic attention orienting to rare salient stimuli. Second, a classical auditory oddball paradigm showed a large P300 response, followed by a long lasting parietal positivity around 500ms in response to deviant tones. Importantly, this was only observed when the patient was instructed to mentally count the deviants, compare to a condition where attention was diverted. This suggests that voluntary cognitive processes were triggered by target tones.

In the P300-speller experiment, EEG referenced to the nose was recorded from a 32-electrode Acticap system (Brain Products, Germany), following a standard extended 10-10 system placement. Impedances were kept below 10kΩ and amplified analog signals were digitized at 100Hz. To make a selection from the 6×6 item matrix, the patient attends to the target symbol and counts how many times it is flashed. While visual stimulations are sent to a CRT screen in random order, a trigger (labeled according to the flashed row or column) is sent to the EEG amplifier via parallel port (jitter < 0.1ms). In addition to enlightment, symbol size is enhanced, which we proved yields larger P300 responses and higher classification rates [5]. The flash duration was set to 100ms and the time between two flash onsets to 250ms. We used eight repetitions per epoch or symbol, meaning that we averaged the responses for each row and column over eight flashes. A 4s interval seperated each symbol, enabling the patient to process the online feedback and then focus attention on the next symbol to spell.
The patient completed one training (Train01) and four online testing sessions (named Sess01, Sess02, Sess03 and Sess04, respectively) within a period of two weeks, each seperated by three or four days. The training and first test were performed on the same day. During the former, the patient was given a sequence of 30 characters to spell. Test sessions consisted in spelling 4-character (french) words. Sess01, Sess02, Sess03 and Sess04 were made of nine, eighteen, twelve and eighteen words, respectively.
All parameters learned from Train01 were subsequently applied during the four online test sessions. These parameters pertain to the feature selection and subsequent classification steps. The former consisted in spatial filters derived from the xDAWN Algorithm [6]. Then a two-class Naïve Bayes classifier was trained, based on the spatially filtered training data. The main processing steps of our OpenViBE P300-speller scenario include[1]:

- Bandpass filtering between 1 and 20Hz
- Spatial Filtering using xDAWN algorithm
- 600ms wide epoching, starting from flash onset
- Averaging over 8 single-sweep epochs for each stimulation type
- Selecting the row and column with the highest posterior probability for class target.

3 Results

To evaluate performance, we considered two types of accuracy: the item selection accuracy and the P300 classification accuracy. While the first one reflects the percentage of items spelled correctly, the second one deals with rows and columns independently and indicates the percentage of target stimuli correctly identified. Consequently, chance level performance for item detection and P300 classification are 2.8% and 16.7%, respectively.

	Training dataset	Test dataset	Item selec. accuracy	Classif. accuracy
Online	Train01	Sess01	24.4%	53.7%
	Train01	Sess02	4.2%	19.5%
	Train01	Sess03	0.0%	13.5%
	Train01	Sess04	2.8%	18.4%
Offline	Sess02.01	Sess02.02	15.6%	37.8%
	Sess03.01	Sess03.02	15.0%	52.5%
	Sess04.01	Sess04.02	27.3%	48.9%

Table 1: Item selection and classification accuracies for both the online and offline evaluation

Table 1 shows the performance obtained online, in each session and, offline, after having split each session dataset into a training (Sess0x.01 made of the first thirty letters of Session 0x) and a test set (Sess0x.02 made of the remaining symbols of the same session). Note that those results emphasize the need for a session specific training, which suggest a high variability in the signals from one day recording to another.

Figures 1 and 2 represent the topographical distribution of errors with respect to target location, for session Sess02.02 and Sess03.02, respectively. The pixel at the center of those matrices indicates the target location. The darker the pixel, the higher the frequency of selection of the corresponding location. Note that Sess03.02 exhibits a much less dispersed distribution of errors around target location, compare to Sess02.02.

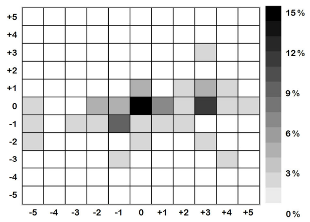

Figure 1: Error distribution for Sess02.02

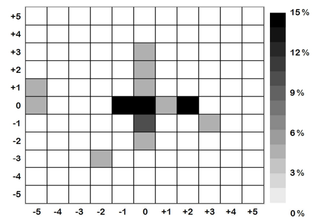

Figure 2: Error distribution for Sess03.02

Finally, figure 3 depicts the learned typical target and non-target responses with associated standard deviation, for the patient (a) and two healthy subjects (a poor (b) and a good (c) performer). Importantly, for comparison between individuals, item selection accuracies obtained in subsequent tests were 27.3% (a), 43.8% (b) and 99.4% (c), respectively.

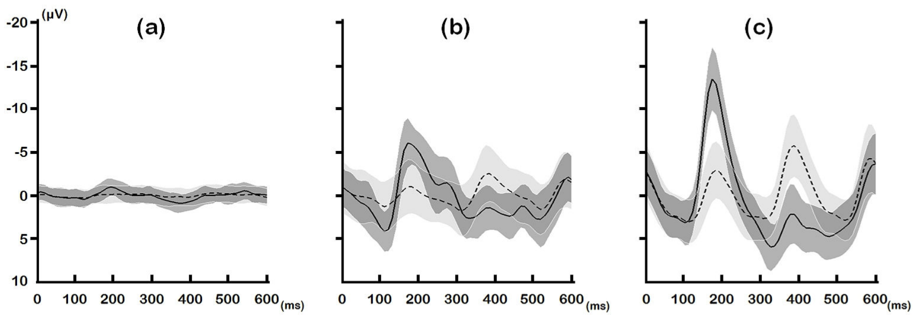

Figure 3: Averaged waveforms for target (solid line) and non-target (dashed line) stimuli, estimated from training datasets, having applied optimal spatial filtering in each individual (a patient (a) and two healthy subjects (b & c)).

4 Discussion

In this short paper, we evaluated for the first time, our OpenViBE implementation of the P300-speller BCI in a Locked-in patient. On average, online performance observed over four sessions were very poor, especially compare to previous evaluation in healthy subjects. Indeed, the LIS patient reached an item selection accuracy of 24.4% at best, while 18 healthy subjects ranged between 73.3 and 100% (mean 97.4%) [1]. Offline analysis of the patient's data clearly revealed that the calibration phase could not be re-used from one day to another. Indeed, generalization from initial training to the last three sessions yielded performance at chance level.
After having ruled out technical explanations and the obvious possibility that the patient would not perform the task correctly, we conclude from this indepth evaluation that this patient's signals suffer from both low signal-to-noise ratio and high variability. This is supported by observed offline performance and associated spatial distribution of errors. Interestingly indeed, although Sess02.02 and Sess03.02 show similar (low) performance in terms of item selection, the former exhibit a significantly lower classification accurcay and a wider spread spatial distribution of errors. This speaks in favour of a difficulty to maintain attentional focus on the target.

Finally, the comparison between typical target and non-target responses, in the patient and two healthy subjects, is also striking. The patient's responses are an order of magnitude weaker. This most probably explains the dramatic difference in performance. Note however that in all three individuals, the same latencies, corresponding to the N170 and the P300, seem to mostly contribute to the discrimination between target and non target patterns.

5 Conclusion

Although limited to a single individual so far, this evaluation is a rare case study in a truly locked-in patient. Performance obtained are significantly poorer than the ones observed in healthy subjects. This is in line with previous observations in BCI, suggesting that performance often decreases as physical impairment increases [7]. However, there is still room for improvement, at least on the computer side. For instance, we believe that adopting a new stimulation procedure to suppress adjacency distractions could boost the online performance [8].

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