35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Performance of a tactile P300 speller for healthy people and severely disabled patients*

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Abstract— **P300 based Brain-Computer Interfaces (BCIs) for communication are well known since many years. Most of them use visual stimuli to elicit evoked potentials because it is easy to integrate a high number of different classes into the paradigm. Nevertheless, a BCI that depends on visual stimuli is sometimes not feasible due to the presence of visual impairment in patients with severe brain injuries. In this case, it could be possible to use auditory or somatosensory stimulation. In this publication a vibrotactile P300 based BCI is introduced. Two different approaches were tested: a first approach using two stimulators and a second one that utilizes three stimulators for emitting the stimuli. The two paradigms were tested on 16 users: A group of ten healthy users and a second group comprising of 6 patients suffering Locked-In Syndrome. The control accuracy was calculated for both groups and both approaches, proving the feasibility of the device, not only for healthy people but also in severely disabled patients. In a second step we evaluated the influence of the number of stimuli on the accuracy. It was shown that in many cases the maximum accuracy was already reached with a small number of stimuli, this could be used in future tests to speed up the Information transfer rate.**

I. Introduction

A Brain-Computer Interface (BCI) offers a communication channel between the brain and an external device without the intervention of any of the brain's normal output pathways of peripheral nerves and muscle [1]. BCIs have been developed since more than twenty years ago (see e.g. [2], [3], [4]). Until now, many different applications for BCIs were introduced, actually, there are three major noninvasive BCI approaches used; the choice which approach should run the BCI depends on the device that should be controlled. For example, the steady-state visually evoked potentials (SSVEP) paradigm can be used to control robotic- [5], orthotic- [6] or prosthetic devices [7]; it fits well for asynchronous control of several classes. Until now, up to 48 different classes have been reported to be used [8].

A Motor Imagery (MI) based BCI has less degrees of freedom and requires more training time than SSVEP, but it works without any external stimulation device. Furthermore, the MI based BCI is chosen for special tasks like e.g. motor rehabilitation [9], [10].

For a BCI as communication tool, or if a large number of different selections should be provided, a P300 based BCI could be used [1]. The P300, a component of the evoked potential, is elicited when an unlikely stimulus (deviant stimulus) occurs in a train of standard stimuli. It could be elicited visually, auditorily or tactilely, the most popular paradigms use the visual stimulation. The user has to attend the stream of stimuli and wait for the deviant stimulus to appear.

Guger et al. [11] investigated how many healthy people are able to control a visual P300 based BCI. After five minutes of training 89% of 81 persons were able to spell with an accuracy rate between 80% and 100%, when using a row-column flasher (chance level 1/50). Ortner et al. [12] investigated the control accuracy of a visual P300 speller for people with motor impairments, showing that one user suffering from locked-in syndrome (LIS), a condition characterized by quadriplegia and anarthria associated with ventral pons infarction [13], reached an accuracy of 40%. As LIS patients frequently show visual impairments due to the location of the main lesion (brainstem at the level of the pons [14]) other stimulation paradigms must be used such as for example auditory or tactile. In this publication, a tactile P300-based BCI is presented and the control accuracy which users can achieve was evaluated. The feasibility of this paradigm to detect consciousness in non responsive patients is also discussed.

II. Methods

The measurements were performed at g.tec Guger Technologies on a group of ten healthy subjects (nine male, one female, age 25 ± 4,5 years) and at Paris, on 6 patients suffering from LIS (4 female, 2 male, age 37,2 ± 9,6 years) belonging to the French Association of Locked-in Syndrome (ALIS). Four patients were tested at the Institutions where they live and two were tested at their domiciles. The study was approved by the Ethics Committee of the University of Liège and by the Scientific Committee of ALIS. Informed consent was obtained from all the patients or their legal representatives and from all the healthy controls.

Two different setups, with two (2-stim) and three stimulators (3-stim) were tested on both groups. For the 2-stim paradigm, two vibrotactile stimulators were placed on the user's wrists. One stimulator delivered a train of standard stimuli consisting of short vibration events. The stimulator on the other wrist was setup to generate the deviant stimulus with a probability of 12,5%. Participants were asked to

*Research supported by the EU Projects Decoder and Brainable.

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Figure 1. Placement of the two tactors on the user's wrists.

concentrate and if possible to count the deviant stimuli in order to get a P300 response. Fig. 1 shows the placement of two stimulators. The blue belts are for connecting the user to the ground, hence preventing electrical noise to cover the EEG signal.

The second paradigm used three stimulators. Again, one of the stimulators, placed on the user's back, generated the standard stimulus. The two deviant stimuli were now delivered on the left and right wrist; by focusing his attention on one of the two stimulators the subject was able to answer simple yes and no questions.

The EEG was recorded at eight positions according to the international 10/20 system (Fz, FC1, FC2, C3, Cz, C4, CP1, CP2; ground: FPz; reference: right earlobe), using active electrodes (g.LADYbird, g.tec medical engineering GmbH, Graz, Austria). A g.USBamp biosignal amplifier (g.tec medical engineering GmbH, Austria) sampled the data at 256 Hz. Fig. 2 shows the Simulink model for the 3-stim paradigm. At first the signal is bandpass filtered between 0.1Hz – 30Hz using a butterworth filter of 5th order. After downsampling by factor four, the signal was processed and classified using a multiclass LDA classifier. The Interface unit allows defining various paradigm settings, e.g. the number of classes, the probability of the deviant stimulus to appear, or the stimulus on/off time. This generic approach ensures that the Simulink model can be used for tactile P300 paradigms as well as for visual ones. The settings are defined in an XML file which is loaded before the runs starts. The execution of the paradigm is performed by the Paradigm block, which also creates control signals for the classification of the P300 and the stimulators which are turned on/off by the g.STIMbox

Each user performed two runs: one for setting up a LDA classifier, another one to test the classification accuracy. Each run consisted of 5 sequences with 30 target events per sequence. In each sequence the user was told to concentrate to a target stimulator and count the number of stimuli sent.

TABLE I. ACCURACY AND NUMBER OF NEEDED STIMULI FOR THE GROUP OF HEALTHY USERS.

Healthy users		**2-stim paradigm**		**3-stim paradigm**	
	age	***Accuracy (%)***	***#Stimuli***	***Accuracy (%)***	***#Stimuli***
H1	27	100	3	100	19
H2	25	100	1	100	11
H3	26	100	3	100	5
H4	31	100	4	60	12
H5	19	100	3	40	2
H6	25	100	4	60	3
H7	24	100	6	100	11
H8	32	100	5	60	4
H9	23	100	6	80	3
H10	18	100	5	100	18
Average	25	100	4	80	12.8
STD	4.5	0	1.6	23.1	6.3

TABLE II. ACCURACY AND NUMBER OF NEEDED STIMULI FOR THE GROUP OF LIS PATIENTS.

LIS patients		**2-stim paradigm**		**3-stim paradigm**	
	age	***Accuracy (%)***	***#Stimuli***	***Accuracy (%)***	***#Stimuli***
L1	47	100	12	60	4
L2	21	20	2	20	4
L3	46	100	20	40	3
L4	33	100	20	60	7
L5	40	60	2	40	4
L6	36	100	7	100	7
Average	37.2	80	10.5	53.3	4.8
STD	9.6	33.5	8.2	27.3	1.7

Hence in the 2-stim paradigm the user was told to concentrate always onto the same stimulator that delivered the deviant stimuli. In the 3-stim paradigm, where on both, the left wrist and right wrist deviant stimuli were presented, the target command was chosen in random order. For calculating the accuracy, the selected class was compared to the given target command.

In a second step, the classification was re-evaluated offline for ERPs based on averages of 1-30 stimuli, hence providing the accuracy across different numbers of target stimuli. Two examples could be seen in Fig. 3.

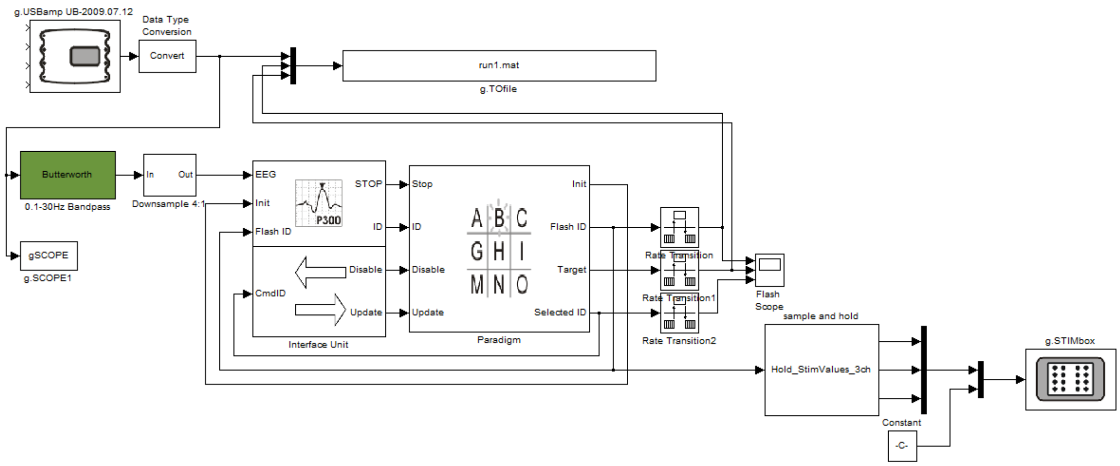

Figure 2: The used Simulink model. The filtered data is classified in the P300 block. The Paradigm and the interface Unit block control the paradigm and present the selected class on a computer screen. The g.STIMbox controls the tactors that are placed on the user's body.

III. Results

Fig. 3 shows the accuracies achieved by subjects H2 and H5 dependent on the number of target stimuli. For subject H2 (Fig 3.A), the accuracy level increases with the number of stimuli whereas it remains constant for subject H5 (Fig. 3.B).

Table 1 and Table 2 show the accuracy and the number of stimuli necessary to reach the maximum accuracy level. For the example in Fig.3A the subject H2 reached 100% accuracy after eleven stimuli whereas subject H5 reached the maximum accuracy of 80% with two stimuli and dropped to 40% when using all 30 stimuli. This corresponds to the value reached during the online classification where all stimuli were considered. The average accuracy and average number of stimuli, as well as the standard deviation (STD) thereof are displayed in the last two rows of Table 1 and Table2.

IV. Discussion

For the 2-stim paradigm, all healthy users were able to reach an accuracy of 100% whereas the average performance of the LIS patients was 80% ± 33.5. The number of stimuli needed to reach a high accuracy level was clearly larger for LIS patients compared to healthy controls. Notably, the EEG signal was very noisy for the patients with bad performances on the 2 stimulator paradigm. This noise may result from involuntary movements of the patient, or poor electrical isolation of the stimulators, and had a big impact on the final results.

Nevertheless, 4 out of 6 LIS patients were able to elicit a P300 response with the 2-stim paradigm. Hence, the utilization of these new paradigms could be an interesting possibility in the evaluation of non-communicant patients. The presence of a response to an active paradigm can be a sign of the presence of some residual consciousness. This could allow to differentiate the patients in vegetative state/unresponsive wakefulness syndrome (VS/UWS), who show preserved vegetative nervous functioning (including sleep/awake cycles), but do not show any voluntary response to commands nor verbalization [15], from those in LIS (who are fully conscious but unable to speak or move due to the motor pathways lesions).

In the 3-stim paradigm, healthy controls performed slightly worse compared to the 2-stim paradigm and needed a clearly larger number of stimuli for the classifier to achieve good accuracy. Similarly, LIS patients performed substantially worse in this not-so-easy paradigm. A possible explanation for the bad performance of LIS patients could be related to the presence of a mild cognitive impairment, which has been described in LIS patients [16], affecting the performance of the task. Other factors could be a limited training time with the experimental setup. Finally, a longer communication test could also improve the ratio right/wrong answers and could be more suitable for patients.

The average number of stimuli for the maximum accuracy during the 3-stim paradigm was at 12.8 for the healthy users and only 4.8 for the group of LIS patients. Therefore, the number of necessary stimuli could be lowered for both groups, resulting in a higher information transfer rates.

Of special interest are the accuracy plots of the users that did not reach 100% of accuracy during the 3-stim paradigm. One example is shown in Fig. 3.B. The subject H5 reached his highest accuracy level with two stimuli and did not improve when taking more of them. With the maximum number of stimuli he reached only an accuracy level of 40%. The plots for H6, H8 and H9 and also for all LIS patients were found to be similar. All of them reached their highest accuracy level already at small numbers of stimuli. In a previous study investigating the accuracy of a visual P300 speller on a group of people with motor impairments [12] a similar occurrence was observed for one user suffering LIS, caused by stroke. One can speculate if these users were not always able to concentrate on the correct target and produced unwanted P300 according to the wrong stimulus. But also poor signal quality could have lead to this

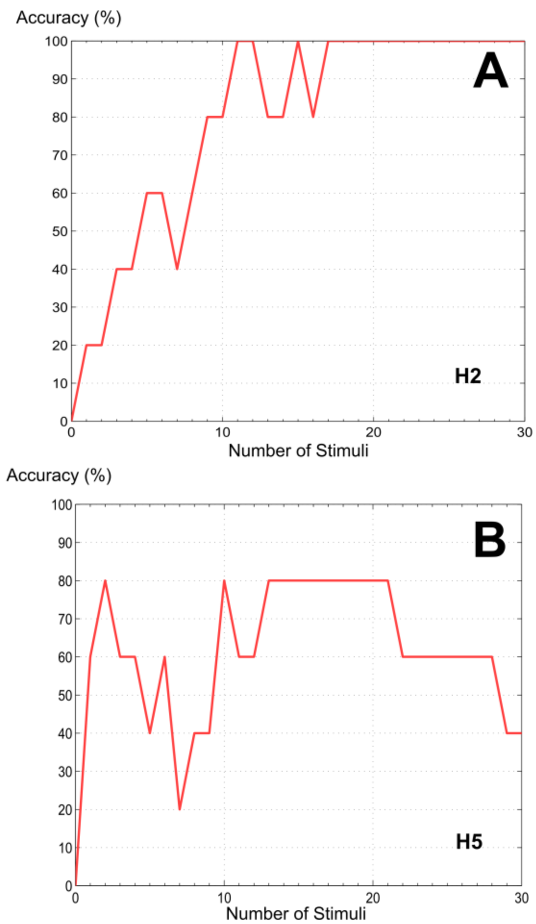

Figure 3. Accuracy versus the number of used flashes for the subjects H2 and H5.

phenomenon.

In conclusion, we have shown the feasibility of using vibrotactile stimulation in healthy subjects and in patients with brain injuries to elicit a P300 evoked response which can be used for a BCI system allowing communication with severely disabled patients.

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