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VIBRO-TACTILE EVOKED POTENTIALS FOR BCI COMMUNICATION OF PEOPLE WITH DISORDERS OF CONSCIOUSNESS AND LOCKED-IN SYNDROME

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ABSTRACT: In this publication, data of a vibro-tactile P300 BCI are shown. The tool serves for two tasks: for assessment of consciousness in people with disorders of consciousness (DOC) and locked-in syndrome (LIS), and for communication to provide YES/NO answers. Results from one patient, classified in unresponsive wakefulness state and two LIS patients are compared to three healthy controls. The shape of the event related potentials and differences between healthy controls and patients are investigated. We discuss which evoked potentials result in successful communication and provide online results of communication tests for all participants.

INTRODUCTION

Brain-computer interfaces (BCIs) have provided communication for severely disabled users for many years [1]. The P300 speller is the preferred BCI control strategy for these users, since it provides a high information transfer rate and requires very limited training [2]. Most of these systems use a visual P300 speller, providing the whole alphabet plus numbers and/or additional control commands with only one classifier output. However, visual P300 spellers require sight and gaze control [3], although there are attempts to reduce the need for gaze control [4]. P300 BCIs could also be designed with auditory [5] or tactile stimuli [6].

Consciousness has two clinical dimensions: wakefulness and awareness [7,8]. A disorder of consciousness (DOC) results from interference with either or both of these systems [7]. In the unresponsive wakefulness state (UWS), people show complete unawareness of themselves and the environment, but show sleep-wake cycles with some preservation of autonomic brain-stem functions [9]. Patients in the minimally conscious state (MCS) show limited but clearly discernible evidence of consciousness of self or environment [10], but are unable to communicate. The correct classification of UWS and MCS is a challenge. Schnakers and colleagues compared the accuracy of diagnosis between the clinical consensus versus a neurobehavioral assessment [11]. Out of 44 patients diagnosed VS based on the clinical consensus of the medical team, 18 (41 %) were found to be in MCS following standardized assessment with the Coma Recovery Scale-Revised (CRS-R). BCI-based assessment could help overcome the limitations of tests based on observable behavior.

Locked-In Syndrome (LIS) patients have full consciousness but limited or no voluntary muscle control. This can include losing the ability to control gaze. A tactile BCI could also provide communication for these users.

In 2014, we introduced our tactile P300 BCI and tested it with healthy controls and LIS patients [12,13]. Now, we compare data from one patient classified UWS and two LIS patients to data from three healthy controls. The aim of this publication is: to compare the event related potentials (ERPs) of patients vs. healthy controls to explore signals that could be used for assessment of consciousness and for communication. Assessment tests with two and three vibro-tactile stimulators are presented. Accuracy plots are calculated, which show how well a linear discriminant analysis (LDA) classifier can separate the EEG patterns after different kinds of stimulation. The ERPs are averaged and discussed. Furthermore, each participant performed an online test to simulate real-time communication ability.

MATERIALS AND METHODS

Participants: Three patients and three healthy users were recorded for this publication (see Tables 1 and 2). P1 was diagnosed before the test as UWS, and P2 and P3 as LIS patients. The patients' tests were done at the University of Palermo, the healthy controls were assessed in Schiedlberg, Austria. All sessions were approved by the local ethical committee. Informed consent was obtained either from the participants or their legal representatives if patients were not capable. All healthy participants performed two sessions. P1 performed three sessions, while P2 and P3 one session each.

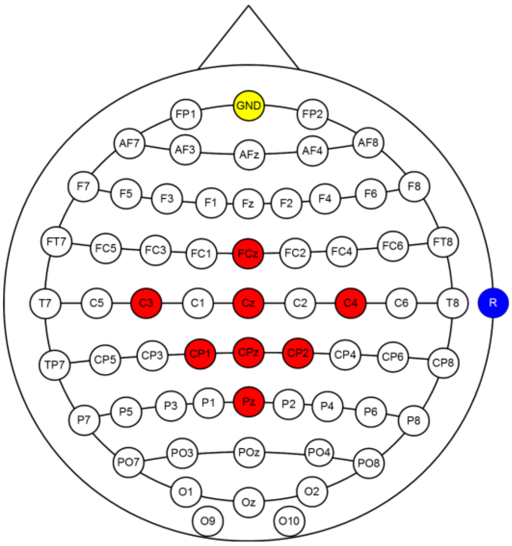

Figure 1: Acquired EEG positions. The red spots mark the positons of eight active EEG electrodes. The reference was placed on the right earlobe (blue), the ground electrode at FPz (yellow).

Paradigms: Three kinds of paradigms were tested: vibro-tactile assessment with 2 tactors (VT2), vibro-tactile assessment with 3 tactors (VT3) and a communication test. During the VT2 paradigm, the left and right wrists are randomly stimulated with a vibro-tactile stimulator for 100 ms each. One stimulator delivers 87.5 % of the stimuli, and the other stimulator presents only 12.5 % of the stimuli. The subject is verbally instructed to silently count 15 stimuli on the hand that receives the less probable target stimuli, which is called the target hand. The number of presented non-target stimuli is 7*15=105. During each run, the subject performs this task four times, with the target hand selected randomly each time, which results in a recording time of 2.5 min. The resulting data are analyzed to provide two figures: the averaged ERPs of target and nontarget trials; and an accuracy plot, showing how well the ERPs can be separated.

During the VT3 paradigm, in addition to tactors on the left and right hands, one tactor is placed to the back or shoulder of the subject as a distracter. The distracter receives 75 % of the stimuli, while the left and right wrist each receives 12.5 % of the stimuli. Then, the subject is instructed through earplugs to count stimuli to the target hand (15 targets, 7*15 non-targets), which is either the left or right hand. During each run, the subject performs this task four times, with the target hand selected randomly each time, resulting in a recording time of 2.5 min. This run results in the same kind of accuracy plot and averaged ERPs. Furthermore, an LDA classifier is created that will be used in the communication test.

The communication test is an online evaluation to see if the tool could be used for answering simple YES-NO questions. The positions of the vibro-tactile stimulators are the same as in the VT3 paradigm. Five questions are asked to the participant, in which the correct answer is known beforehand. For example: “Were you born in Austria?” The experimenter instructs the participant to answer YES by counting the stimuli on the left hand, or answer NO by counting the stimuli on the right hand. After asking a question, the system presents 30 stimuli to the left hand, 30 stimuli to the right hand and 180 stimuli to the distracter, in randomized order. The classifier generated in the VT3 run is used to analyze all those presented stimuli. The system can convey YES if the left hand was classified as target hand, or NO if the right hand was classified as target, and it provides no output if the distracter was classified as target. After the five questions were answered, the number of correctly answered questions is counted. A communication test is considered successful only if 4 or 5 out of 5 total questions were answered correctly.

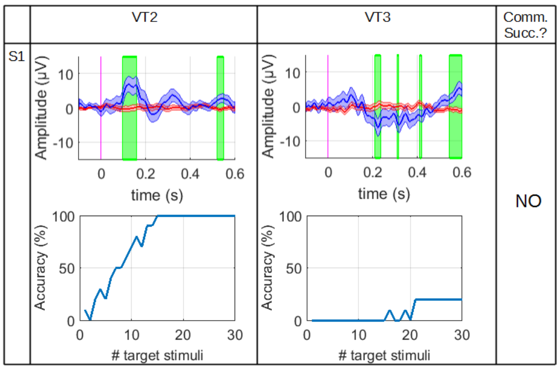

Figure 2: Results of P1, Session 1. Left and middle column top show the averaged EPs of VT2 and VT3. The bottom rows show the accompanying accuracy plot. In the right column one sees that the communication test was not successful.

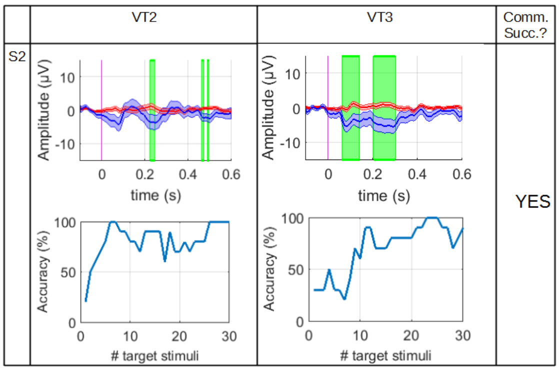

Figure 3: Results of P1, Session 2.

Signal processing: EEG data were acquired from eight sites (Fig. 1) using a g.USBamp and g.LADYbird active electrodes with a sample rate of 256 Hz. Data segments of -100 ms to 600 ms around each stimulus are extracted. To calculate the accuracy plot (see the bottom rows of Figures 2-8), the following procedure is repeated ten times, and the results are averaged into one single plot.

The target and nontarget trials are randomly assigned into two equal sized pools. One pool is used to train a classifier, and the other pool is used to test the classifier. The classifier is tested on an increasing number of

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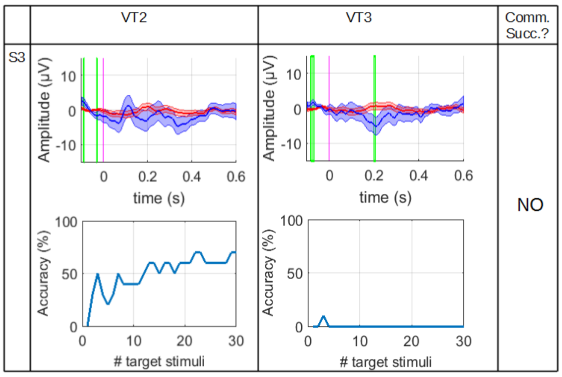

Figure 4: Results of P1, Session 3.

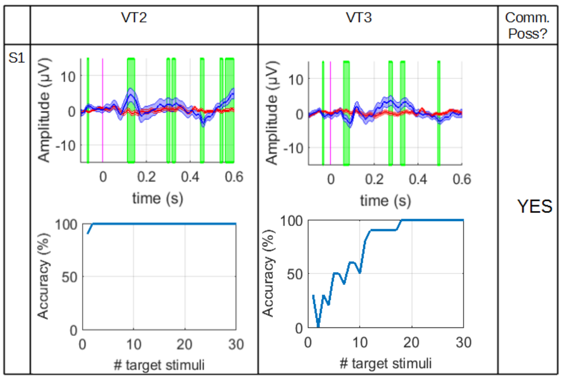

Figure 5: Results of P2, Session 1.

averaged stimuli out of the test pool. At first, it is tested on only one target and seven nontarget stimuli. If the classifier detected the target stimulus correctly, the resulting accuracy is 100 %; otherwise, it is 0 %. This process is repeated for two averaged target stimuli and 14 averaged nontarget stimuli, for three nontarget stimuli and 21 target stimuli, and so on until the full test pool is used. This produces a plot of 30 single values (for 30 target stimuli in the test pool), each one either 100 % or 0 %. The averaging of 10 single plots results in values ranging from 0 % to 100 %. Increasing the number of averaged stimuli will increase the accuracy if the subject follows the task, because this averaging reduces random noise in the data. An accuracy significantly beyond the chance level of 12.5 % shows that the subject can direct attention to the task of counting target stimuli for most or all of a run.

The ERPs from target and nontarget trials are averaged for all channels separately. Each trial is baseline corrected before averaging, using the time segment 100 ms before stimulus onset. For each sample point, a Kruskal Wallis test ($p<0.05$) is done to find statistical differences between target and nontarget trials. The top parts of Figures 2-8 show the averaged ERPs of site Cz. The thick red line presents the averaged nontarget trials. The thin red lines above and below it presents the standard error. The averaged target trials and their standard error are plotted in blue. The magenta vertical line shows the trigger time. Green areas mark areas in which the target vs. nontarget lines differ significantly.

Experimental procedure: Each session consisted of three runs in pseudorandom order: A VT2 assessment run, a VT3 assessment run and communication run.

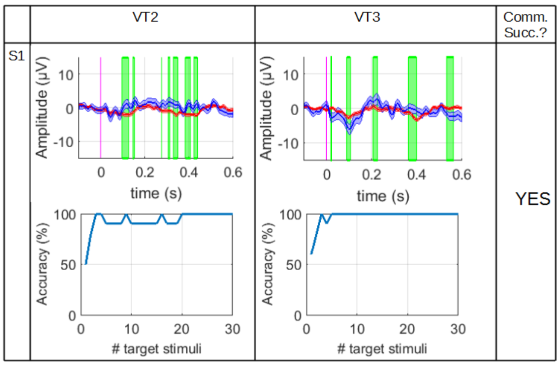

Figure 6: Results of P3, Session 1.

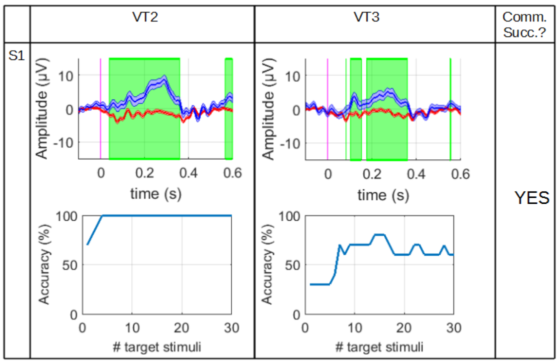

Figure 7: Results of H3, Session 1.

RESULTS

Results from patients: Table 2 and Figures 2-6 present results from patients. In each figure, the first column represents the results of the VT2 run, the second column the result of the VT3 run and the third column shows the result of the communication run (successful or not). In session 1, P1 attained 100% accuracy during the VT2 assessment but poor accuracy in VT3, and did not successfully communicate (Figure 2). P1 was able to successfully communicate in session 2, with accuracy of 80% or more in both the VT2 and VT3 runs (Figure 3). In session 3, his VT2 assessment yielded only modest accuracy, and the VT3 assessment attained 0% accuracy (Figure 4).

The two locked-in patients were both able to communicate, with high accuracy in both VT2 and VT3 (see Figures 5 and 6).

Results from healthy controls: Table 1 summarizes results from healthy controls. Figures 7 and 8 focus on a notable result, which is that H3's second communication attempt was not successful. Also, the accuracy from the preceding VT3 is worse than in other results from the healthy controls. Otherwise, the healthy subjects performed very well.

DISCUSSION

All six participants were able to communicate via vibro-tactile stimulation in at least in one session. All ERPs of the healthy subjects showed a P300 peak.

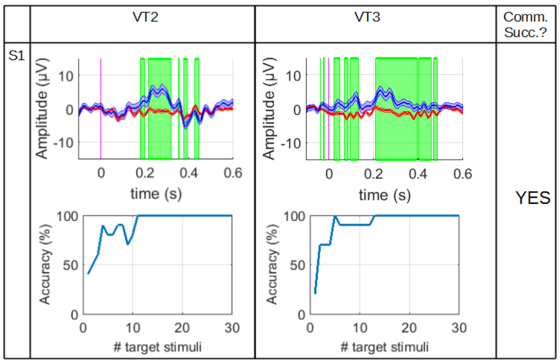

Figure 8: Results of H3, Session 2.

Only one of the patients, P2, exhibited a small P300 in the VT2 condition only. Nonetheless, classification was often accurate, indicating that other ERP components contributed heavily to classification for most patients.

P1 showed a negative deflection in all three sessions. In session 2 only, this deflection produced a stable long-lasting significant difference between target and nontarget stimuli. In sessions 1 and 3, the significant areas are much shorter, and communication was not successful. The absence of activity that reflects voluntary stimulus processing in sessions one and three may be consistent with the previous classification of UWS. Thus several tests on different days should be conducted before reaching a final decision about a patient's status.

Visual inspection of the ERPs shows that the P300 was generally not the main signal that differed between targets vs. nontargets. In most patient data, the normative P300 is not apparent. Thus, it seems that ERPs before and after the P300 probably contribute substantially to effective classification.

The observation that the ERPs of the patients did not show a P300 but still could be used for communication is consistent with earlier publications. In an auditory oddball experiment, Lulé and colleagues [14] show that classification relied largely on a negative deflection. Another study [15] presented LIS patient with a large negative deflection in a vibro-tactile oddball experiment.

Notably, H3 failed in the communication test during the first session. Although his ERPs show a high amplitude P300 during VT3 (Figure 7), the accuracy plot resulting from VT3 showed only 60% of accuracy across 30 target stimuli. Therefore, the accuracy plot provides a useful measure of target vs. nontarget separability when looking at averaged ERPs could be misleading. Nevertheless, in addition to the accuracy plots, we chose an approach of performing online communication involving real questions. This validated the practicability of our device to be used for patients with DOC and LIS.

Table 1: Healthy subjects and their results

ID	Session #	Sex/ Age	VT2 (%)	VT3 (%)	Comm success.?
H1	1	f	100	90	Yes
	2	26	100	100	Yes
H2	1	f	100	100	Yes
	2	36	100	80	Yes
H3	1	m	100	60	No
	2	33	100	100	Yes

The results also support the general approach of assessing users with VT3 prior to communication. In all results from both patients and healthy users, accuracy during the VT3 run effectively predicted the likelihood of successful communication. This is reasonable, as the communication runs are similar to the VT3 assessment runs in many ways.

As with other P300 BCIs, our approach required very little time to train the classifier. Collecting data to train the VT3 paradigm took 2.5 minutes. More training data could improve classifier performance. However, when working with severely disabled patients, longer training times could cause fatigue and ultimately provide worse results. Worse, patients with UWS or related conditions could end wakefulness during a session, meaning that effective communication is no longer possible that session.

The VT2 runs are not used for communication. Those runs are intended as an initial assessment of consciousness as well as a way to familiarize each user with the system.

CONCLUSION

This publication showed that DOC and LIS patients could use a vibro-tactile paradigm for communication. This result further supports the nascent consensus that BCI technology could be helpful for assessment of awareness in these patients and for communication.

Table 2: Patients and their results

ID	Session #	Sex	Age	Diagnosis	Disease (months)	Duration	Clinicial Description	VT2 (%)	VT3 (%)	Communication successful?
P1	1	m	19	TBI	12		UWS	100	0	No
	2							80	80	Yes
	3							60	0	No
P2	1	f	76	ALS	145		LIS	100	90	Yes
P3	1	f	68	ALS	89		LIS	95	100	Yes

Even users who do not have a robust P300 in the paradigms used here could attain good performance based on other ERP differences. The simplicity and low cost of a noninvasive EEG-based BCI makes this technology very promising for these groups of patients, compared to fMRI or invasive electrodes. More data will be needed though to show the reliability for all groups of potential users.

REFERENCES

[1]Wolpaw JR, Birbaumer N, McFarland DJ, Pfurtscheller G, Vaughan TM, Brain–computer interfaces for communication and control. Clinical Neurophysiology 2002:113:767–791

[2]Guger C, Daban S, Sellers E, Holzner C, Krausz G, Carabalona R., et al., How many people are able to control a P300-based brain–computer interface (BCI)? Neuroscience Letters 2009:462:94–98. doi:10.1016/j.neulet.2009.06.045

[3]Brunner P, Joshi S, Briskin S, Wolpaw J, Bischof H, Schalk, G, Does the "P300"speller depend on eye gaze? Journal of neural engineering 2010:7:56013.

[4]Aricò P, Aloise F, Schettini F, Riccio A, Salinari S, Babiloni, F et al., GeoSpell: an alternative P300-based speller interface towards no eye gaze required. International Journal of Bioelectromagnetism 2011:13:152–153.

[5]Halder, S., Rea, M., Andreoni, R., Nijboer, F., Hammer, E. M., Kleih, S. C., et al.. An auditory oddball brain–computer interface for binary choices. Clinical Neurophysiology, 2010:121(4):516–523.

[6]Brouwer A.-M, Van Erp JB, A tactile P300 brain-computer interface. Frontiers in Neuroscience, 2010:4:19.

[7]Bernat JL, Chronic disorders of consciousness. The Lancet, 2006:367(9517):1181–1192.

[8]Posner, J. B., & Plum, F. (2007). *Plum and Posner's diagnosis of stupor and coma* (Vol. 71). OUP USA.

[9]Ashwal S, Cranford R, Bernat J, et al. The multi-society task force on PVS. Medical aspects of the persistent vegetative state (1), N Engl J Med, 1994:330:1499–1508.

[10]Laureys S, Owen AM, Schiff ND. Brain function in coma, vegetative state, and related disorders. The Lancet Neurology, 2004:3(9), 537–546.

[11]Schnakers C, Vanhaudenhuyse, A, Giacino J, Ventura M, Boly M, Majerus S, et al. Diagnostic accuracy of the vegetative and minimally conscious state: Clinical consensus versus standardized neurobehavioral assessment. BMC Neurology, 2009:9(1):35.

[12]Ortner R, Lugo Z, Noirhomme Q, Laureys S, Guger C, A tactile Brain-Computer Interface for severely disabled patients, in: Haptics Symposium (HAPTICS), 2014 IEEE. pp. 235–237.

[13]Lugo ZR, Rodriguez J, Lechner A, Ortner R, Gantner IS, Laureys S, et al.. A vibrotactile P300-based BCI for consciousness detection and communication. Clin EEG and Neurosci. 2014:45(1):14-21.

[14]Lulé D, Noirhomme, Q, Kleih S, Chatelle C, Halder S, Demertzi A, et al. Probing command following in patients with disorders of consciousness using a brain–computer interface Clinical Neurophysiology, 2013:124: 101–106

[15]Lugo ZR, Rodriguez J, Lechner A, Ortner R, Gantner I.S, Laureys S, et al. A vibrotactile P300-based BCI for consciousness detection and communication. Clin EEG and Neurosci. 2014:45:14-21