Improved Classification of Auditory Evoked Event-Related Potentials

Günther Bauernfeind[1,6], Christoph Pokorny[1,6], David Steyrl[1,6], Selina C. Wriessnegger[1,6], Gerald Pichler[2,6], Walter Schippinger[2,6], Quentin Noirhomme[3], Ruben G. Real[4], Andrea Kübler[4], Donatella Mattia[5], and Gernot R. Müller-Putz[1,6]

[1]*Institute for Knowledge Discovery, BCI Lab, Graz University of Technology, Austria*
[2]*Albert Schweitzer Clinic, 8020 Graz, Austria*
[3]Cyclotron Research Center, University of Liège, 4000 Liège, Belgium
[4]Department of Psychology, University of Würzburg, 97070 Würzburg, Germany
[5]Fondazione Santa Lucia IRCCS, 00179 Rome, Italy
[6]BioTechMed-Graz, Austria

Introduction

Recently we proposed the concept of a novel auditory single-switch BCI and investigated the transition of a paradigm from healthy subjects (HS) to patients (PA) in minimally conscious state (MCS) [1]. The paradigm was evaluated in 10 HS and applied to 12 PA. In 8 of the 10 HS significant single-trial classification accuracies up to 77.2 % could be reached. However, for MCS patients only a small number of classification results were above chance level.
In this study we report on the improvement of classification accuracy by using SWLDA with an increased number of channels and analytic shrinkage-regularized LDA (sLDA) as classifier.

Methods

Subjects, Experimental Paradigm and Data Recording:

- *Subjects* - Data of 10 HS (27.6 ± 3.0 years), 12 PA (45.8 ± 18.2 years) from [1]
- *Experimental Paradigm* - Auditory based P300 BCI: 2 intermixed tone streams (LTS, 396 Hz; HTS, 1900 Hz); deviant tones (LTS, 297 Hz; HTS, 2640 Hz); details see Figure 1a
  - HS instructed visually (Figure 1b), PA auditory (Figure 1c) to focus attention on one stream per run
  - HS: 80 runs (40 runs for each stream; with 4000/400 (standard/deviant) tones in the LTS and 1800/400 in the HTS)
  - PA: 1-2 sessions, with 20 runs (10 for each stream)

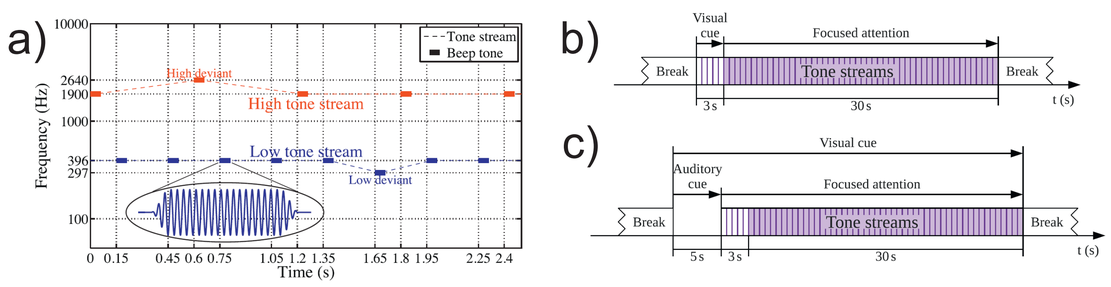

Figure 1: a) Schematic representation of the two intermixed tone streams. b) Paradigm used with healthy participants. c) Paradigm used with MCS patients. Modified from [1].

- *Data Collection* - HS: 15 positions, sampling rate 512 Hz (filter setup: 0.5–100 Hz). PA: reduced channel set (9 positions) to facilitate measurements in a clinical environment. For electrode setup see [1].

Classification and Analysis

- *Classification* - Features: Time points between 200 and 800 ms after tone onset
  - In [1]: Three EEG channels (Fz, Cz, Pz) used for classification (stepwise linear discriminant analysis (SWLDA), with 10x10 cross-validation)
  - In the present work: 1) All channels for SWLDA classification and 2) sLDA [2] instead of the SWLDA
- *Analysis* - P300: Target deviant tones against standard tones (for each target stream)
  - Attentional modulation: Target deviant tones against non-target deviant tones (for each stream separately)

Results

Results are shown for P300 and attentional modulation detection. Figure 2 depicts classification accuracies for both groups (HS, PA). Table 1 summarizes the results of HS, Table 2 for the PA.

	P300						Attention					
Subj.	SWLDA $_3$		SWLDA $_{all}$		sLDA $_{all}$		SWLDA $_3$		SWLDA $_{all}$		sLDA $_{all}$	
	LTS	HTS	LTS	HTS	LTS	HTS	LTS	HTS	LTS	HTS	LTS	HTS
HS01	*57.3*	*61.2*	*58.0*	*62.5*	***64.0***	***68.2***	55.2	*57.8*	55.8	56.0	***58.6***	***59.3***
HS02	*70.7*	*61.8*	*73.5*	*63.6*	***76.7***	***65.2***	*62.6*	*62.8*	*61.9*	*62.9*	***65.3***	***69.4***
HS03	*77.2*	*72.0*	*78.2*	*73.3*	***85.1***	***77.7***	*69.5*	*70.4*	*70.9*	*69.2*	***75.9***	***74.8***
HS04	*62.2*	*57.2*	*64.3*	*57.9*	***67.2***	***61.4***	*56.9*	53.5	*59.4*	*57.4*	***61.1***	***61.2***
HS05	*63.9*	*60.7*	*65.2*	*61.5*	***69.2***	***65.8***	*63.5*	*61.0*	*65.4*	*65.5*	***67.2***	***71.2***
HS06	*71.5*	*64.4*	*78.7*	*75.0*	***81.3***	***79.7***	*65.5*	*65.5*	*71.6*	*76.7*	***76.5***	***78.8***
HS07	*61.9*	54.4	*62.9*	55.6	***67.2***	***59.8***	53.3	55.6	54.1	54.6	***56.7***	***58.1***
HS08	*67.2*	*59.7*	*74.0*	*65.1*	***80.7***	***72.1***	*58.9*	*60.2*	*61.0*	*62.2*	***65.9***	***69.3***
HS09	*56.8*	55.4	*59.6*	*57.6*	***62.6***	***58.6***	52.8	52.1	53.4	53.0	**54.7**	**55.9**
HS10	56.0	52.6	*60.9*	53.6	***64.4***	***56.7***	51.4	50.6	51.4	53.4	***57.0***	***60.3***
Mean	64.5	59.9	67.5	62.6	71.8	66.5	59.0	59.0	60.8	61.1	63.9	65.8
SD	7.1	5.6	7.8	7.1	8.3	7.9	6.1	6.3	6.7	7.7	7.7	7.9

Table 1: SWLDA and sLDA classification accuracies (in %) for the HS for P300 and attentional modulation detection using either 3 or all channels. All results significantly better than random [3] ($\alpha = 1\%$) are indicated in *italic*. Highest subject specific accuracies are indicated in **bold**.

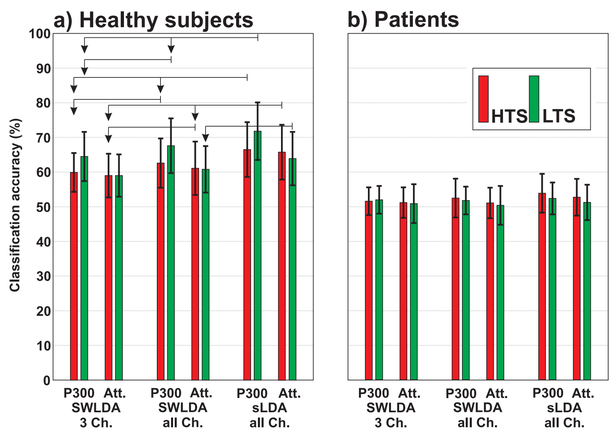

Figure 2: Mean (± SD) classification accuracies (in %) for a) HS and b) PA. Significant differences are indicated.

	P300					
	SWLDA $_3$		SWLDA $_{all}$		sLDA $_{all}$	
	LTS	HTS	LTS	HTS	LTS	HTS
Mean	51.9	51.5	51.7	52.4	52.3	53.8
SD	4.0	3.9	4.1	4.2	4.6	5.6
	Attention					
	SWLDA $_3$		SWLDA $_{all}$		sLDA $_{all}$	
	LTS	HTS	LTS	HTS	LTS	HTS
Mean	50.8	51.1	50.3	51.0	51.2	52.7
SD	5.6	4.4	5.6	4.4	5.1	5.3

Table 2: Mean (± SD) SWLDA and sLDA classification accuracies (in %) for the patient group for P300 and attentional modulation detection using either 3 or all channels.

Discussion

For the HS group the classification accuracies could be significantly improved by using sLDA and the inclusion of all recorded channels. Unlike HS, for PA the results were less encouraging, although in some PA the single-trial classification accuracies could be improved.
For PA recordings further studies should aim on investigating the use of additional electrode positions [2, 4] and improvements on the used paradigm are required [1].

References

1. C. Pokorny, D. S. Klobassa, G. Pichler, H. Erlbeck, R. G. L. Real, A. Kübler, D. Lesenfants, D. Habbal, Q. Noirhomme, M. Risetti, D. Mattia, and G. R. Müller-Putz. The auditory P300-based single-switch BCI: Paradigm transition from healthy subjects to minimally conscious patients. *Artif Intell Med*, 59(2):81–90, 2013.
2. B. Blankertz, S. Lemm, M. Treder, S. Haufe, and K.-R. Müller. Single-trial analysis and classification of erp components - a tutorial. *Neuroimage*, 56:814–825, 2011.
3. G. R. Müller-Putz, R. Scherer, C. Brunner, R. Leeb, and G. Pfurtscheller. Better than random? A closer look on BCI results. *Int. J.Bioelectromag.*, 10:52–55, 2008.
4. M. Schreuder, B. Blankertz, and M. Tangermann. A new auditory multi-class brain-computer interface paradigm: Spatial hearing as an informative cue. *PLoS ONE*, 5(4):e9813, 2010.

Acknowledgments

This work is supported by the ICT Programme Project FP7-247919 and "Land Steiermark" Project (ABT08-22-T-7/2013-17). This paper only reflects the authors' views and funding agencies are not liable for any use that may be made of the information contained herein.