Results of the BCI Competition III

[Berlin]
Benjamin Blankertz, Guido Dornhege, Klaus-Robert Müller

[Albany]
Gerwin Schalk, Dean Krusienski, Jonathan R. Wolpaw

[Graz]
Alois Schlögl, Bernhard Graimann, Gert Pfurtscheller

[Martigny]
Silvia Chiappa, José del R. Millán

[Tübingen]
Michael Schröder, Thilo Hinterberger, Thomas Navin Lal, Guido Widman, Niels Birbaumer

BCI Competition – Introduction

Goal: validate signal processing and classification methods for Brain-Computer Interfaces.

	date	**#datasets**	**#submissions**	**#labs**
BCI Competition I	2001/2002	3	10	8
BCI Competition II	2002/2003	6	57	20
BCI Competition III	2004/2005	8	92	49

Actual Problems in BCI Research

Problems in BCI system design:

- session-to-session transfer
- subject-to-subject transfer (resp. cope with small training sets)
- non-stationary signals: need for adaptivity
- have an idle signal when subject is in idle state
- classify continuous data rather than single-trials
- make BCI work for *all* subjects, not only selected good ones

Problems in evaluation:

- offline evaluations of methods may be biased (overestimate generalization ability)
- results may be reported from selected subjects (data set selection)

Problems not addressed by this competition:

- transfer of methods and paradigms from offline analyses to feedback applications
- human and machine as two mutually adapting systems

Data Sets – Overview

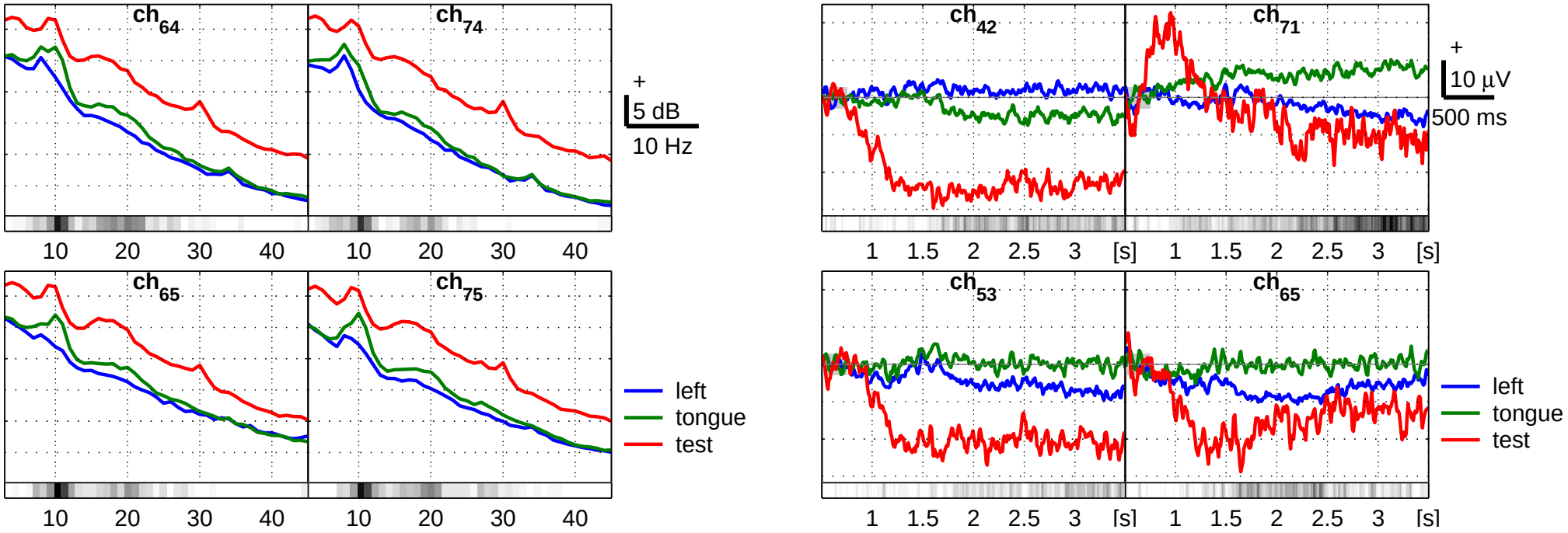
- Data set I (Tübingen): motor imagery in ECoG recordings, session-to-session transfer
- Data set II (Albany): P300 speller paradigm
- Data sets IIIa (Graz): motor imagery, multi-class, good vs. fair subject performance
- Data sets IIIb (Graz): motor imagery with non-stationarity problem
- Data set IVa (Berlin): motor imagery, small training sets
- Data set IVb (Berlin): motor imagery, uncued classifier application
- Data set IVc (Berlin): motor imagery, test data contains 'rest' trials
- Data set V (Martigny): mental imagery, multi-class, uncued classifier application

Data Set I – Tübingen

»motor imagery in ECoG recordings, session-to-session transfer«

The Thrill:

- Train a classifier on data of one day, apply it to data of a different day.
- Watch out for non-stationarities!



Data Set I – Tübingen

Perf: **accuracy** [%], Chance: 50%, submissions: 27

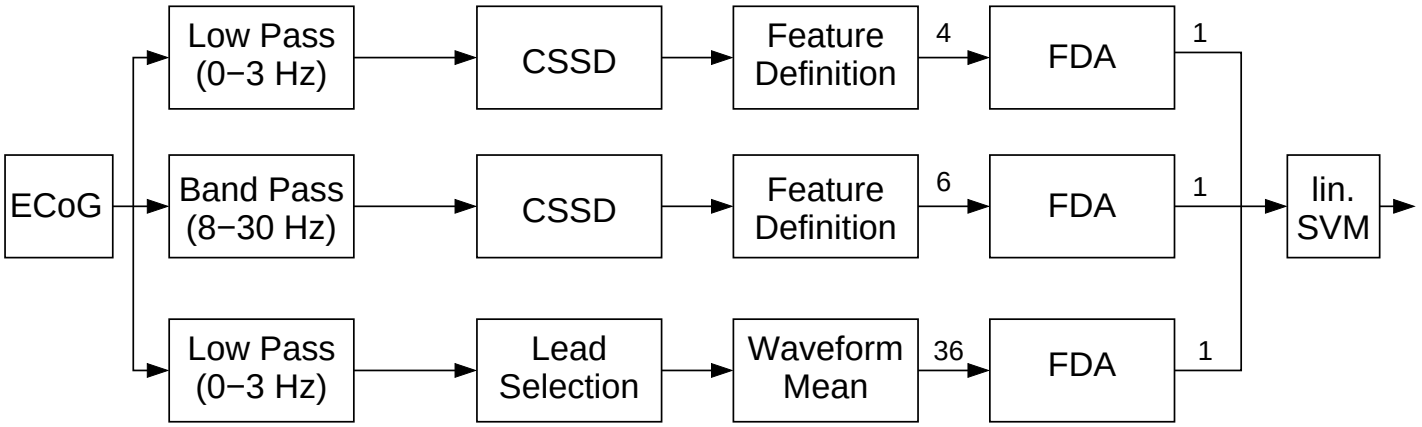
#.	contributor	acc	research lab	co-contributors
1.	Qingguo Wei	**91**	Tsinghua University, Beijing	Fei Meng, Yijun Wang, Shang-kai Gao
2.	Paul Hammon	**87**	University of California, San Diego	
3.	Michal Sapinski	**86**	No affiliation, Poland	
3.	Mao Dawei	**86**	Zhejiang University, P.R.C.	Ke Daguan, Xie Mingqiang, Ding Jichang, Zheng Kening, Zhou Jie, Murat
3.	Alexander D'yakonov	**86**	Moscow State University	
3.	Liu Yang	**86**	National University of Defense Technology Changsha, P.R.C.	Hu Dewen, Zhou Zongtan, Zang Guohua

Data Set I – Tübingen

Winning Method:

[Qingguo Wei, Fei Meng, Yijun Wang, Shangkai Gao]

- Two DC (0–3 Hz) and one broad band (8–30 Hz) features
- CSSD: Common Spatial Subspace Decomposition
- FDA: Fisher Discriminant Analysis
- Fusion by linear Support Vector Machine (SVM)

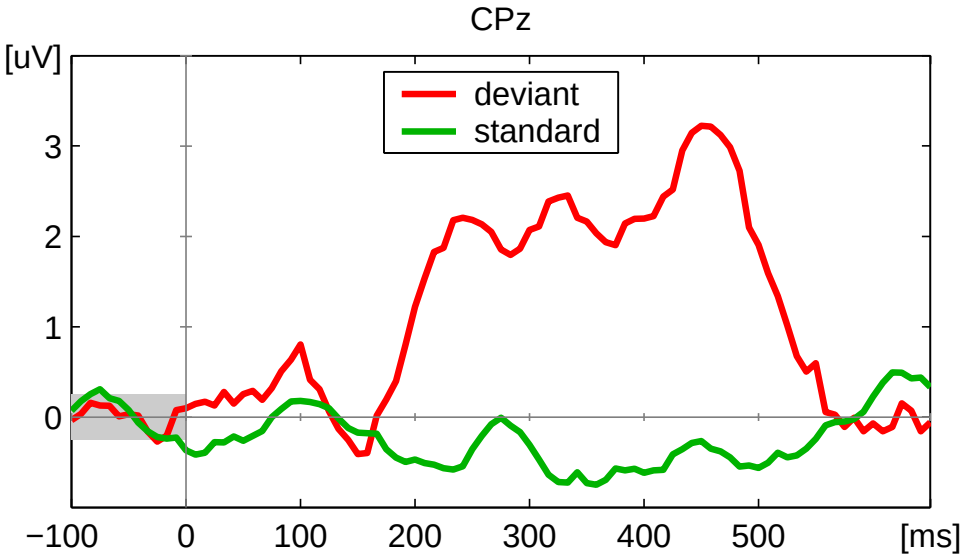


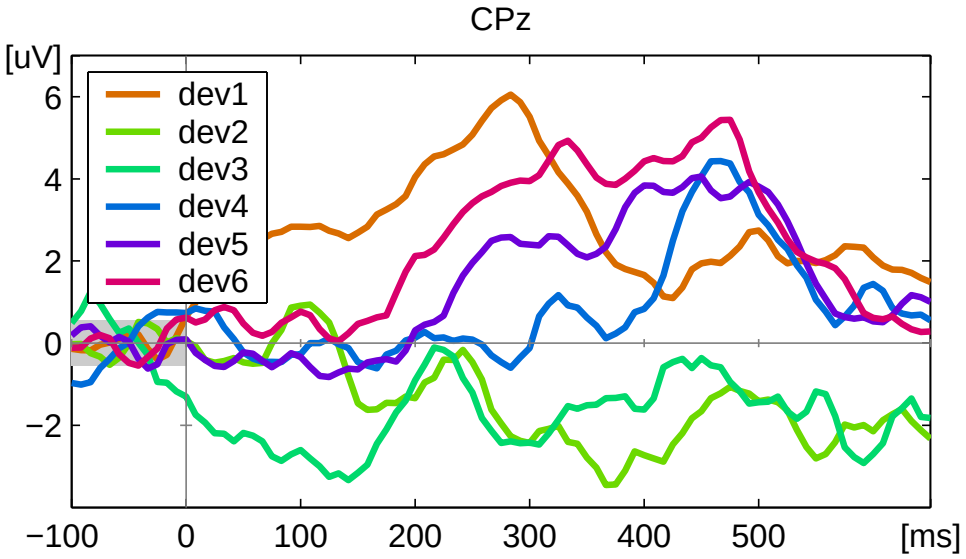
Data Set II – Albany

»P300 speller paradigm«

The Thrill:

- Combine multiple binary classifiers to one 36-class classifier
- Multi-modal target class (ERP depends on previous trials)





Data Set II – Albany

Perf: **accuracy** [%] using all 15 repetitions, chance: 2.8%, 10 submissions

#.	contributor	acc	acc5	research lab	co-contributors
1.	Alain Rokotomamonj	**96.5**	73.5	PSI CNRS FRE-2645, INSA de Rouen, France	V. Guigue
2.	Li Yandong	**90.5**	55.0	Department of Automation Department of Biomedical Engineering, Tsinghua University, China	Gao Xiaorong, Ma Zhongwei, Lin Zhonglin, Lu Wenkai, Hong Bo
3.	Zhou Zongtan	**90.0**	59.5	Department of Automatic Control, National University of Defense Technology, China	Liu Yang, Hu Dewen, Zang Guohu
4.	Ulrich Hoffmann	**89.5**	53.0	Signal Processing Institute, Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland	
5.	Lin Zhonglin	**87.5**	57.5	Department of Automation, Tsinghua University, China	Zhang Changshui, Gao Xiaorong, Zhou Jieyun

Data Set II – Albany

Winning Method:

[Alain Rokotomamonj, V. Guigue]

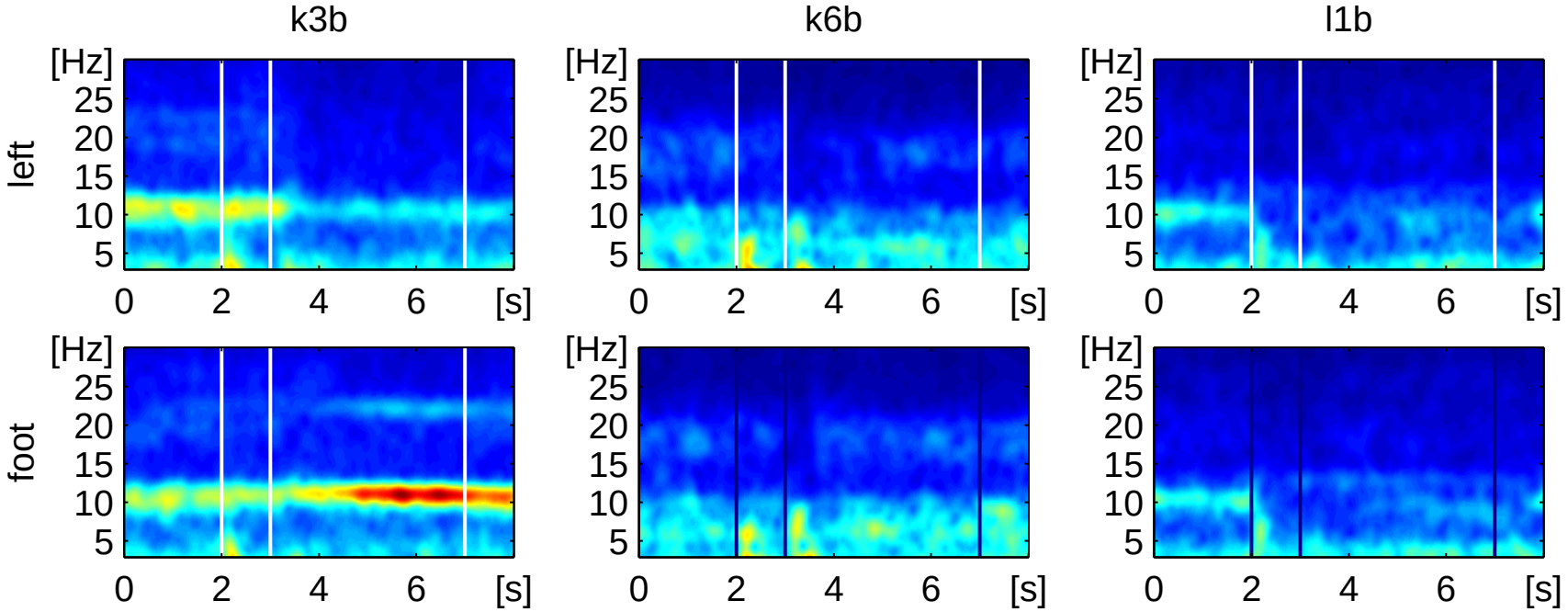
- band-pass filter 0.1–20 Hz, decimation
- cluster BCI signals by 900 signals (?)
- Mixture of 17 SVMs:
- Channel selection for each SVM by criterion TP/(TP+FP+FN).
- Summing SVM scores of all SVMs for all coloumns resp. rows and picking the max.

Data Set IIIa – Graz

»motor imagery, multi-class, good vs. fair subject performance«

The Thrill:

- multi-channel EEG
- multi-class problem
- subjects with good and with fair performance



Data Set IIIa – Graz

Perf: **kappa** (scaled accuracy with *#classes*), chance: 0, submissions: 3

#.	contributor	kappa	K3	K6	L1	research lab	co-contributors
1.	Cuntai Guan	**0.79**	0.82	0.76	0.80	Neural Signal Processing Lab Institute for Infocomm Research, Singapore	Haihong Zhang, Yuanqin Li
2.	Gao Xiaorong	**0.69**	0.90	0.43	0.71	Tsinghua University, Beijing, China	Wu Wei, Wang Ruiping, Yang Fusheng
3.	Jeremy Hill	**0.63**	0.95	0.41	0.52	Max Planck Institute for Biological Cybernetics, Tuebingen and Tuebingen University	Michael Schroeder

Data Set IIIa – Graz

Winning Method:

[Cuntai Guan, Haihong Zhang, Yuanqin Li]

- Preprocessing. (?)
- Calculating Fisher ratios over discreted channel-frequency-time bins, using the training data.
- $\Rightarrow$ select optimal time sections and channels, and design Mu and Beta passband filters in each section.
- Doing multi-class CSP (with one-against-rest method) on each Mu or Beta band in each time section.
- Combining all CSP features by an SVM

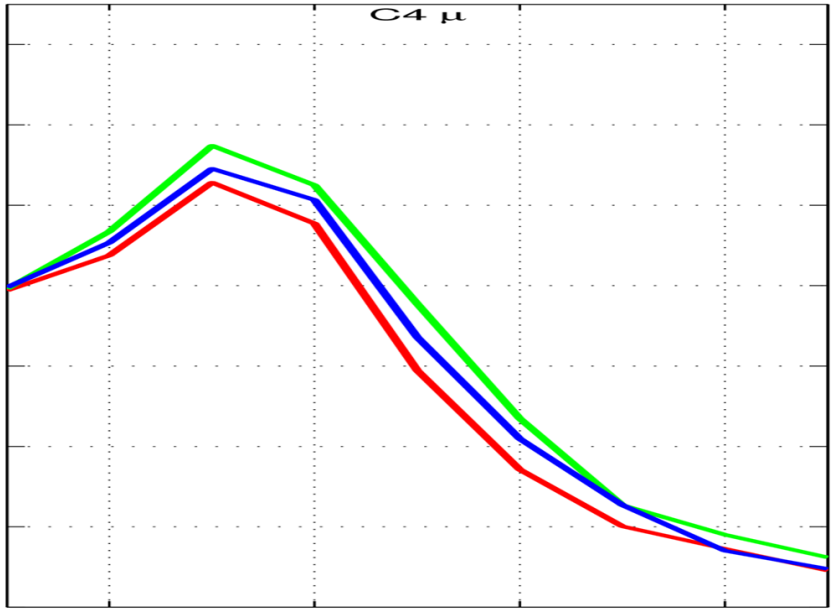
Data Set IIIb – Graz

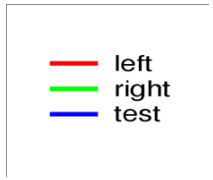
»motor imagery with non-stationarity problem«

The Thrill:

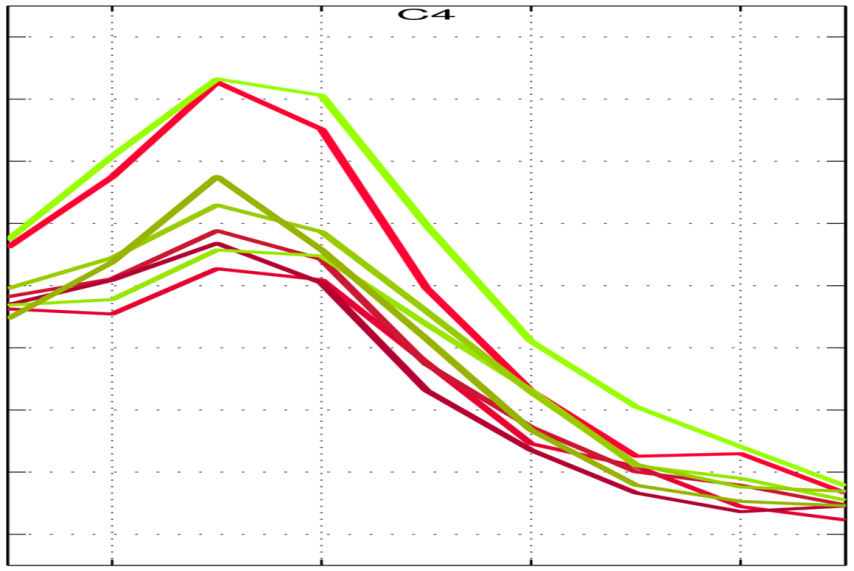
- only 2 channels available
- non-stationary signals (depends on selected features)

C4: Averaged Spectra (μ-band)





C4: Chronological Subaverages



Data Set IIIb – Graz

Perf: **MI/t** (max. steepness of mutual information), chance: 0, submissions: 7

#.	contributor	MI/t	O3	S4	X11	research lab	co-contributors
1.	S. Lemm	**0.32**	0.17	0.44	0.35	Fraunhofer (FIRST) IDA, Berlin Germany	
2.	O. Burmeister	**0.25**	0.16	0.42	0.17	Forschungszentrum Karlsruhe, Germany	M. Reischl, R. Mikut
3.	Xiaomei Pei	**0.14**	0.20	0.09	0.12	Institute of Biomedical Engineering of Xian Jiaotong University, Xian, China	Guangyu Bin

Data Set IIIb – Graz

Winning Method:

[Steven Lemm]

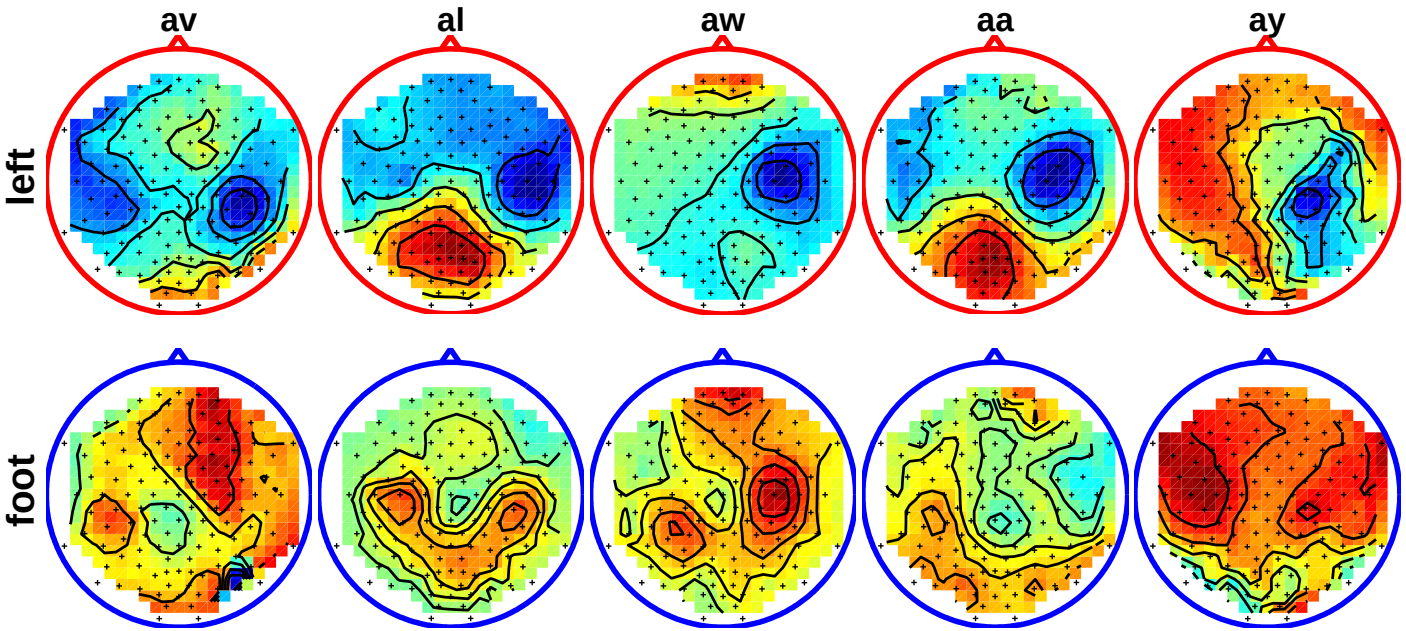
- combined ERP and (alpha, beta) ERD features.
- Training of weak classifiers:
  - (posterior of two multivariate Gaussian distribution) at each time instance.
- Classifier combination over time:
  - using the Bayes error to estimate the discriminative power of each classifier.

Data Set IVa – Berlin

»motor imagery, small training sets«

The Thrill:

- data from five subjects
- for some subjects only small training set available
- subject-to-subject transfer despite inter-subject variability?



Data Set IVa – Berlin

Perf: overall **accuracy** [%], chance: 50%, submissions: 14

#.	contributor	acc	aa	al	av	aw	ay	research lab	co-contributors
1.	Yijun Wang	**94.2**	96	100	81	100	98	Tsinghua University, Beijing	Han Yuan, Dan Zhang, Xiaorong Gao, Zhiguang Zhang, Shangkai Gao
2.	Yuanqing Li	**85.1**	89	98	76	92	81	Institute for Infocomm Research, Singapore	Xiaoyuan Zhu, Cuntai Guan
3.	Liu Yang	**83.5**	82	95	70	88	88	National University of Defense Technology, Changsha, Hunan	Zhou Zongtan, Zang Guohua, Hu Dewen

Data Set IVa – Berlin

Winning Method:

[Yijun Wang, Han Yuan, Dan Zhang, Xiaorong Gao, Zhiguang Zhang, Shangkai Gao]

- 3 features have been used:
  - ERD-feature extracted by Common Spatial Pattern (CSP)
  - ERD-feature extracted with AR model
  - LRP-feature extracted by LDA on temporal waves
- for subjects *aa* and *av*: combine 3 features
- for other subjects: CSP-feature only
- bootstrap aggregation (bagging) for ultimate decision
- for smallest training sets (*aw*, *ay*): add formerly classified test samples to training samples

Data Set IVb – Berlin

»motor imagery, uncued classifier application«

The Thrill:

- test data is continuous EEG without cues
- test data contains periods of relaxing
- length of motor imagery periods varies

There was only one submission to this data set.

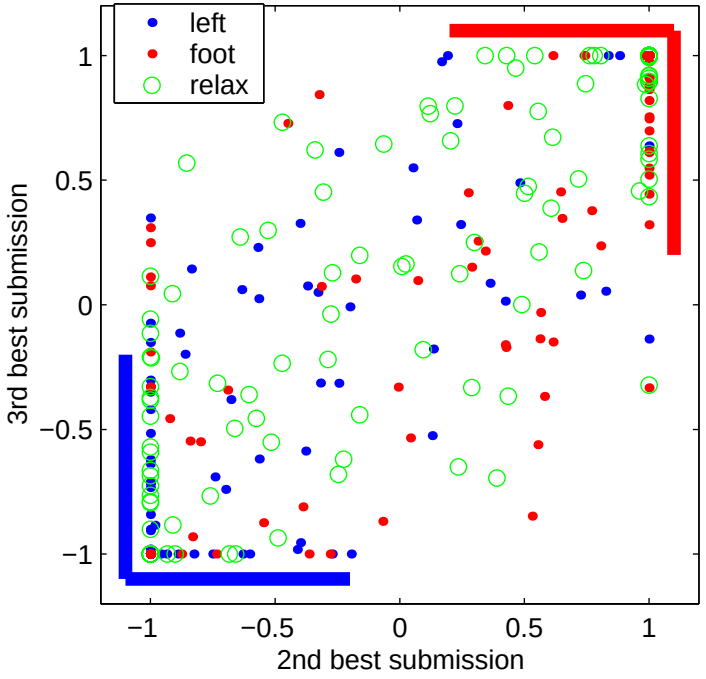
For that reason the competition is not evaluated for this data set.

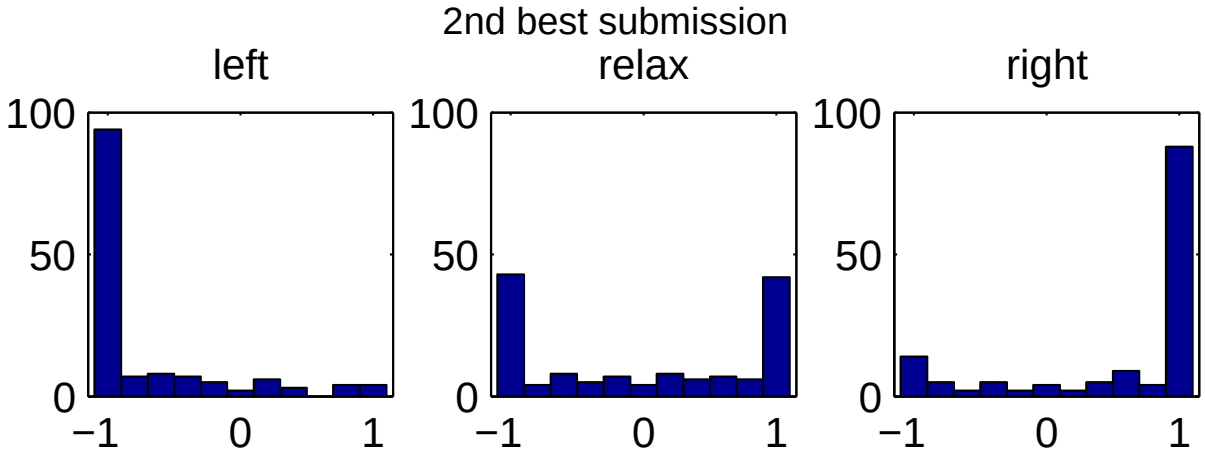
Data Set IVc – Berlin

»motor imagery, rest class in test, but not in training data«

The Thrill:

- test data contains class '*relax*'
- no training data for *relax* available





Data Set IVc – Berlin

Perf: **mean square error (mse)**, constant 0 output: $0.\bar{6}$, submissions: 7

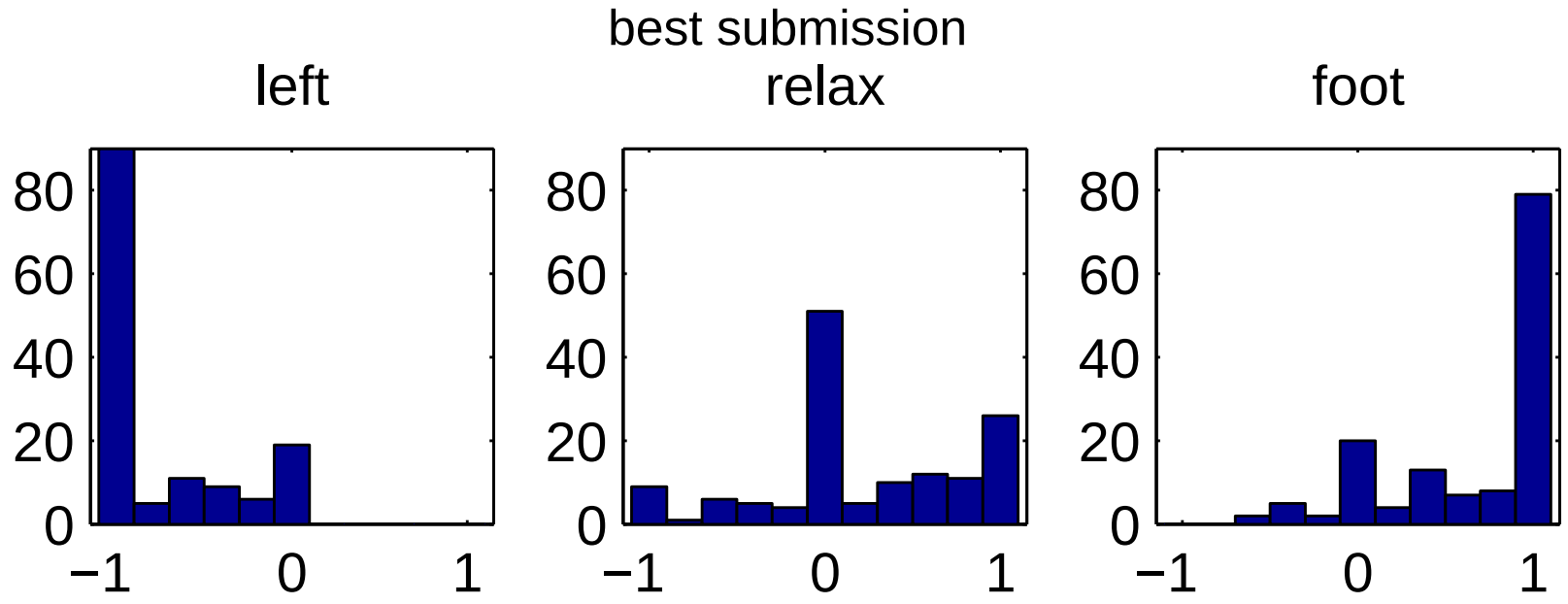
#.	contributor	mse	research lab	co-contributors
1.	Dan Zhang	**0.30**	Department of Biomedical Engineering, Tsinghua University, Beijing	Yijun Wang
2.	Liu Yang	**0.59**	National University of Defense Technology, Changsha, Hunan	Hu Dewen, Zhou Zongtan, Zang Guohua
3.	Zhou Zongtan	**0.60**	National University of Defense Technology, Changsha, Hunan	Hu Dewen, Liu Yang

Data Set IVc – Berlin

Winning Method:

[Dan Zhang, Yijun Wang]

- ERD-features
- extracted by Common Spatial Subspace Decomposition (CSSD)
- classification: Fisher Discriminant Analysis (FDA)
- first-pass: detect *relax* trials on prolonged windows
- second-pass: classify remaining trials into *left* vs. *right*

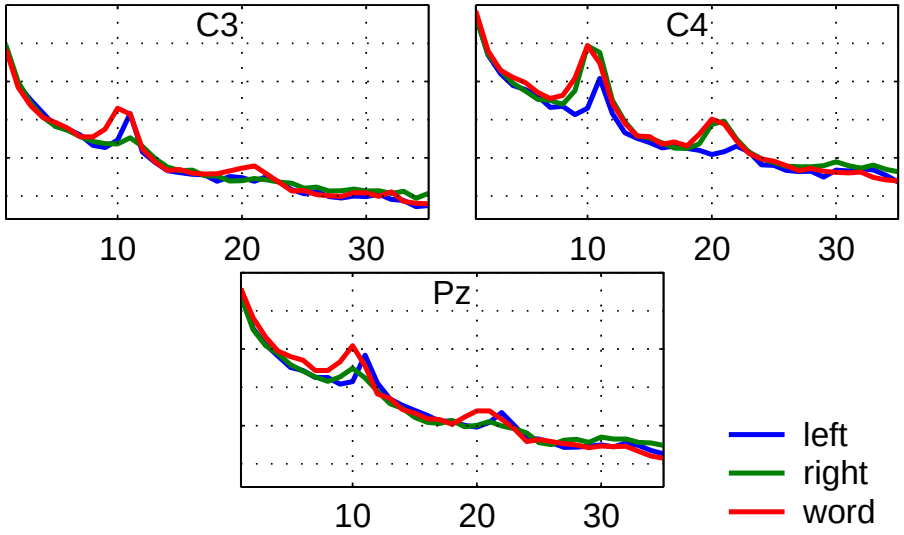


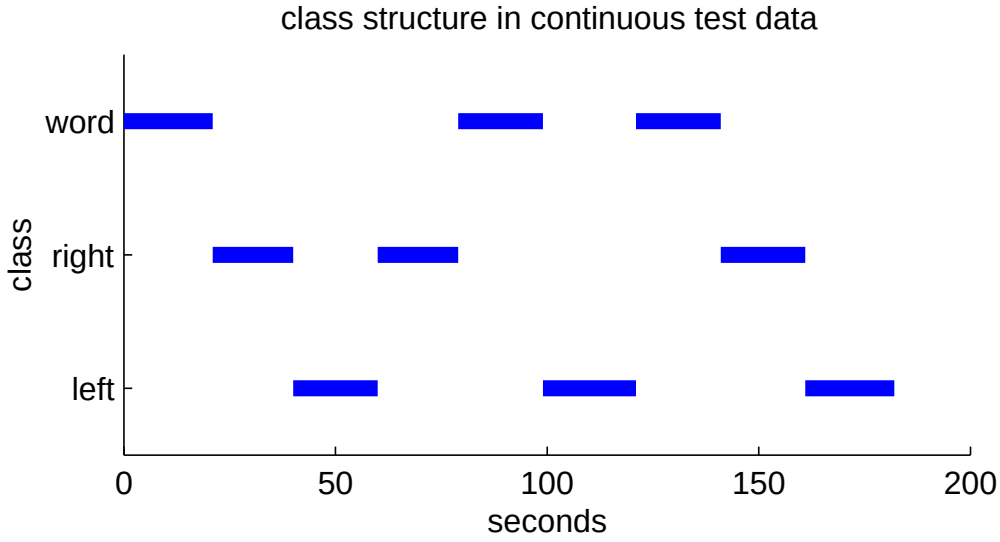
Data Set V – Martigny

»mental imagery, multi-class, uncued classifier application«

The Thrill:

- test data is continuous EEG without cues





Data Set V – Martigny

Perf: **accuracy** [%], chance: $33.\bar{3}$%, submissions: 19

#.	contributor	psd	acc	s1	s2	s3	research lab	co-contributors
1.	Ferran Galan	y	**68.7**	80	70	56	University of Barcelona	Francesc Oliva, Joan Guardia
2.	Xiang Liao	y	**68.5**	78	72	56	University of Electronic Science and Technology of China (UESTC)	Yu Yin, Dezhong Yao
3.	Walter	y	**65.9**	78	66	53	???	

Data Set V (raw data) – Martigny

Winning Method:

[Ferran Gelán, Francesc Oliva, Joan Guàrdia]

- normalization of PSD features
- feature selection by Fisher's Discriminant (multi-class version)
- 'distance based' discriminator
- controller process for post-processing

All Winners

Congratulations!

data set	research lab	contributor(s)
I	Tsinghua University, Beijing, China	**Qingguo Wei**, Fei Meng, Yijun Wang, Shangkai Gao
II	PSI CNRS FRE-2645, INSA de Rouen, France	**Alain Rokotomamonj**, V. Guigue
IIIa	Neural Signal Processing Lab Institute for Infocomm Research, Singapore	**Cuntai Guan**, Haihong Zhang, Yuanqin Li
IIIb	Fraunhofer (FIRST) IDA, Berlin, Germany	**Steven Lemm**
IVa	Tsinghua University, Beijing, China	**Yijun Wang**, Han Yuan, Dan Zhang, Xiaorong Gao, Zhiguang Zhang, Shangkai Gao
IVc	Tsinghua University, Beijing, China	**Dan Zhang**, Yijun Wang
V	University of Barcelona	**Ferran Galan**, Francesc Oliva, Joan Guardia